Soil health across a Kansas precipitation gradient

by

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B.S., University of Maryland, College Park, 2018

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Agronomy
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2021

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Abstract

This project used the precipitation gradient across Kansas from less than 400 mm in the west to over 1000 mm in the east with three land uses. The locations, Tribune (472 mm), Hays (579 mm), and Manhattan (850 mm), KS, were selected for soil characterization. The land uses included native prairie (NP), conventional tillage agriculture (AG), and no-till agriculture (EA). Soil biological, chemical, and physical properties were measured based on USDA-NRCS chosen soil health metrics. The objectives of this research were to 1) assess differences in soil health metrics across the precipitation gradient with three land uses, 2) compare soil metric methods for wet aggregate stability and infiltration, and 3) assess soil health metrics to a one m depth.

Several soil health metrics distinguished differences between land use and precipitation to a one m soil depth. Soil organic carbon and total nitrogen stocks increased with increasing precipitation. Mean weight diameter was higher in NP, than EA and AG at all locations. Soil microbial biomass was generally higher in NP than cropping systems with increasing precipitation. Surprisingly, EA in Hays had greater soil health metrics than EA Manhattan due to the inclusion of cover crops in no-till at Hays. Positive correlations between biological properties, explained 77.3% of the data variance as determined by principal component analysis.

The aggregate methods tested included Mikha and Rice (2004), Kemper and Rosenau (1986), and Soil Survey Staff (2014). All methods were highly correlated to one another with significant p-values. The Bland-Altman plot showed agreement between Mikha and Rice (2004) and Kemper and Rosenau (1986) with relative random error. The choice of aggregate stability method ultimately depends on the level of sensitivity needed, available resources, labor, costs, and data of interest, with the Mikha and Rice (2004) method providing the most robust information.

Cornell sprinkler infiltrometer and single infiltration methods were variable in results by location. The single ring method was more sensitive to land disturbance as the infiltration rate increased with decreased soil disturbance. Variability and method approaches makes both infiltration methods difficult to recommend. The single ring method was more portable and required less material, training, maintenance, and water. The Cornell Sprinkler Infiltrometer can simulate a range of rainfall rates, designed to measure runoff and infiltration, and reduces unnatural macropore flow from ponding (Cornell University, 2019).

Soil health metrics to assess differences in land use detected surface and subsurface changes. Several soil properties were highly correlated, such as alkaline phosphatase and phosphodiesterase; or soil organic carbon and soil respiration. A single sampling time can not be used to compare fields with differing management. However, a single point in time measurement for the prairie across the precipitation gradient could be used to assesss soil health properties. Thus, the best approach to document soil health is to track changes in a single field rather than compare sites.

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Acknowledgements

I would like to thank my advisor Dr. Charles Rice for his mentorship and insight into soil microbiology. The experience in his Soil Microbial Agroecology Lab has allowed me to broaden my outreach, develop a wider acquaintance, and network with a multitude of professionals in science and academia. I thank my committee members Drs. Ganga Hettiarachchi and DeAnn Presley for their guidance in soil chemistry and soil science.

I thank the faculty, staff, and colleagues at in the Department of Agronomy and associated facilities with Kansas State University for their support. In particular, the people of the K-State Soil Testing Lab (Jacob Thomas and Kathleen Lowe), Agronomy Graduate Student Association, Agronomy North Farm and Shop, K-State Agricultural Research Center-Hays, KS, Southwest Research and Extension-Tribune, KS (Amanda), Konza Prairie Biological Station, and any unmentioned mentors. I thank the various technicians for operating Giddings probes and characterizing soil profiles for me, especially David Kohake (NRCS-Manhattan), Joseph Kimzey (Hays). I thank private farmers for allowing me to sample their farms, especially David Mengel (Manhattan) and Rick Werth (Hays).

I thank the friendship and support from the members of the Soil Microbial Agroecology Lab, especially Dr. Johanie Rivera-Zayas, Dr. Che-Jen Hsiao, Dr. Tiffany Carter, Dr. Marcos Sarto, Dr. Edwin Akley, Dr. Andrew McGowan, Carlos Pires, Irosha Wanithunga, Will Davis, Noortje Notenbaert, and newly inducted members. I thank the many undergraduate lab assistants and lab technicians who helped me collect and analyze data, especially Fabio De Barros, Jessica Demarco, Victoria Dutra, and Priscila Marchioro. I thank graduates outside of my lab for the friendship and support, especially Manjot Kaur Rekhi and Sevendeep Kaur Chahal.

I thank the funding source provided by USDA-NRCS NR183A750025C015.

Dedication

This thesis is dedicated to my family, friends, and everyone who wants to understand soil health.

Chapter 1 - Introduction and Literature Review

Importance of soil quality and soil health

Soil quality and soil health are often used interchangeably and will be used interchangeably in this review. However, the history of defining and institutionalizing the terms for state, federal, and private organizations proved challenging and controversial among soil scientists (Sojka and Upchuch, 1999). Before the 1990s, soil quality assessments stemmed from a narrow perspective and emphasis on crop production and maximizing yields that allowed for soil and environmental degradation (Bünemann et al., 2018; Sojka and Upchuch, 1999) (Fig. 1.1). The earliest reference in literature defines soil quality as "the ability of soils to yield corn, soybeans, and wheat under conditions of high-level management" (Mausel, 1971). The soil quality paradigm acknowledged additional soil functions, but those functions were not recognized and integrated into testing soil quality management. Thus, to guide soil research and conservation policy, comprehensive critical examinations of soil quality and soil health were held by soil scientists following the 1990s (Sojka and Upchuch, 1999) (Fig. 1.1).

The term soil quality came into fashion in the 1990s after a 1993 National Research Council Committee (NRCC) reported on the long-range soil and water conservation for agriculture (National Research Council, 1993; Letey et al., 2003). The report focused on sustaining agricultural profitability by preventing soil degradation, promoting soil quality, enhancing input use efficiencies, and reducing farm erosion and runoff (National Research Council, 1993). Soil quality was perceived as one of the three key environmental components along with water and air quality (National Research Council, 1993; Nortcliff, 2002). However, soil quality was much harder to define since the physical, chemical, and biological components of soil varied widely. Compared to soils, water and air had known standard states and did not

involve a complex integration of static and dynamic factors, so water and air quality are easier to define and regulate (Sojka and Upchuch, 1999; Nortcliff, 2002). A general agreement among soil scientists evaluating soil quality maintained that a soil quality index must balance a combination of measurements and responses to management practices that will be unique to each type of soil assessed (Stott, 2019; Sojka and Upchuch, 1999; Letey et al., 2003).

Currently, the United States Department of Agriculture, Natural Resource Conservation Service (NRCS) defines soil health or soil quality as the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Pankhurst and Doube, 1997). Soil health can be accessed to understand the sustainability of different types of land management, specifically ecosystem services for environmental health and agricultural productivity (Doran et al., 2002; Doran, 2002; Karlen et al., 1997).

Interest from agricultural producers and researchers has led to a focus on land management practices on soil health. In response, the NRCS made soil health a priority in 2012 and instituted a soil health division in 2014. Through this organization, the NRCS collaborates with academic institutions, private stakeholders, and public partners to develop a comprehensive standard set of soil health indicators to measure soil health and promote soil health management systems. Soil health includes soil organic matter (OM) depletion, compaction, concentrations of salts or chemicals, aggregate instability, and degradation of habitat for soil organisms. To study soil health and degradation, the NRCS developed a set of quantitative analyses for biological, chemical, and physical soil properties approved for laboratory and field use. Currently, the approved methods require evaluation of differing procedures, identification of their limitations, and improvements of accepted techniques before widespread adoption. It is important to note

that soil health indicators should use region and land-use specific methods while at a reasonable cost and capable of high throughput. Long-term agricultural experiments offer a unique foundation where such breakthroughs can be used for management practices to agroecological solutions (Geisseler and Scow, 2014). Overall, coordinated regional research on agricultural soil health can promote economic development while achieving sustainability goals (Labarthe and Laurent, 2013).

In general, soil formation is influenced by climate, organisms, relief, parent material, and time. The biota of concern is humankind and our management of agricultural soils that impact soil community structure and species assemblages (Brussaard et al., 2007). As of 2016, more than 37% or 48 million square kilometers of land worldwide is under agricultural production (FAO, 2020). Management of agricultural soils includes crop selection, rotation, tillage, and inputs. The soil quality is dynamic and responds differently to management inputs evident in differing biological, chemical, and physical properties that are measurable as soil health indicators (Andrews et al., 2004). Useful indicators must be easy to measure, scientifically robust, time conscious, low cost, assess changes in soil function. These indicators include the biological, chemical, and physical properties and be sensitive to variations in climate and management (Wander and Drinkwater; 2000; Allen et al., 2011; Linyangi 2007). Historically, an overemphasis on chemical soil properties resulted in the deterioration of the biological and physical processes in soils (Idowu et al., 2008). Thus, a holistic soil health paradigm that uses a triad of soil health indicators to represent soil processes relevant to soil function will better assess variations between land management systems.

In terms of ecosystem services, soil processes are classified in terms of transformations of inputs into outputs (Dominati et al., 2010). However, ecosystem functions and ecosystem

processes have been used interchangeably and are seen as complex interactions among abiotic and biotic ecosystem components that can be described as rates (Wallace, 2008). Primary soil processes include water retention and infiltration, mineral weathering, OM decomposition, and nutrient release and retention (Fig. 1.2) (Dominati et al., 2010; Wallace, 2007; Oudenhoven et al., 2012). While secondary soil processes or soil functions supported by the primary soil processes include solar energy capture from plant growth, storage of organic material, and support of soil organisms. The soil functions or processes contribute to soil ecosystem services such as water purification, carbon cycling, nutrient cycling, and habitation for plants and organisms (Fig. 1.2) (Van Oudenhoven et al., 2012).

Soil health indicators

Soil health indicators can have inherent and/or dynamic biological, chemical, or physical properties (Doran and Parkin, 1994). Inherent properties result from soil-forming processes, such as geologic parent material, time, slope, orientation, depth, climate, and organisms (Bünemann et al., 2018; Schwilch et al., 2016). On the contrary, management practices influence dynamic properties, such as nutrient content, moisture, pH, land cover, bulk density, aggregation, and porosity (Bünemann et al., 2018; Schwilch et al., 2016). Some soil properties can be both inherent and dynamic, such as temperature, bulk density, and aggregation (Bünemann et al., 2018; Schwilch et al., 2016). Overall, soil health indicators are measurable properties that allow soil interpretation on a relative scale (Dominati et al., 2010).

The minimum dataset with approved indicators and methods by the NRCS include a field-based soil health assessment, a basic pedon description, single-ring infiltration, Cornell infiltration, soil organic carbon, water-stable aggregates, macroaggregates stability, soil respiration, enzymes, permanganate-oxidizable carbon, available

organic nitrogen (protein), and phospholipid fatty acid (Table 1.1). Additional soil tests include pH, soil carbonates, cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), inorganic nitrogen, extractable phosphorus, sodium, cation exchange capacity, texture, electrical conductivity, and metals (Cu, Mn, Zn, Fe). Combinations of indicators should be selected based on the objectives of the assessment (Cardoso et al., 2013). However, not all indicators have equal importance to all soils and locations. For example, soils with a pH greater than 7.2 should be tested for soil carbonates to aid in proper analysis and correction of other soil indicators, such as texture and soil organic carbon (Weil and Brady, 2019; Sherrod et al., 2002). Overall, the proper use of soil health indicators depends on how well indicators are understood and interpreted for land use and environmental objectives.

The two essential methods to assess soil quality are measurements over time to monitor changes or to compare measured values to a standard reference soil condition (Andrews et al., 2002). Standard reference soil conditions can be soils such as native ecosystems or non-degraded soils (Carter et al., 1997; Doran and Parkin, 1994). However, using reference values from a standard reference soil may not represent the optimal value a managed system can achieve after undergoing management (Bünemann et al., 2018). The effectiveness of a soil health indicator should be management-sensitive, short-term, time-sensitive, interpretable, and useful (Scott, 2019). Short-term time sensitivity refers to indicators that can detect changes within 1 to 3 years in subhumid to humid climates after management changes. Semiarid to arid climates may take longer for management to affect indicators. Soil properties used should not be extremely dynamic and transient, such as soil moisture or inorganic nitrogen (N). Overall, soil health indicators should have conceptual (tied to a function), practical (affordable, reproducible results, timely), sensitive, and interpretable (comparable to a baseline or reference) uses.

Field assessment and site characterization

Basic field assessment and site characterization should consider signs of erosion, management history, slope, topographical features, and climatic data (Kellogg Soil Survey Staff 2014; Bünemann et al., 2018). Different signs of erosion include gullies, rills, pedestals, exposure of subsoils, and damage to plant life (Weil and Brady, 2019). Management history relates to crop growth, tillage type, inputs, and management duration (Kellogg Soil Survey Staff, 2014). Slope and topography are related to hills, ridges, and depressions in the land (Weil and Brady, 2019). Climatic information is based on precipitation and temperature (Weil and Brady, 2019).

Biological soil properties and indicators

Biological indicators of soil health are related to soil organisms that mediate important self-regulating processes, such as nutrient cycling and availability (decomposition), aggregate stability, water movement (infiltration and uptake), and plant growth (production) (Jarrett et al., 2017; Brussaard et al., 2007). The measurable biological indicators include soil organisms and pathogen, microbial biomass C and N, particulate and soil organic matter (SOM), potentially mineralizable N, soil protein, soil enzymes, soil respiration, permanganate-oxidizable carbon, and soil organic carbon (Seifu and Elias, 2019; Cardoso et al., 2013, Bastida et al., 2006; Nannipieri and Kandeler, 2002). Soil microbial biomass relates to fungi, bacteria, protozoa, and algae present in the soil. The phospholipid fatty acids in the membranes of living microbes can be used as biomarkers for profiling the microbial communities in the soil through phospholipid fatty acid assay (PLFA) and ester-linked fatty acid methyl ester (El-FAME) (Zelles, 1999; Schutter and Dick, 2000). Soil microorganisms can also be classified into

functional groups corresponding to biological processes, such as N and C cycling microorganisms (Cardoso et al., 2013).

Changes in soil biological characteristics are more sensitive to environmental changes in management than many chemical and physical properties, so biological indicators can be early projections of disturbance in the environment (Bastida et al., 2006; Masto et al., 2008). Higher microbial diversity in the soil is vital for ecological resilience and biological buffering after a disturbance event (Kennedy, 1999). In healthy, undisturbed soils, there is greater functional redundancy due to greater biodiversity (Wolterz, 2001; Harris, 2003). In disturbed soils, there is a greater suppression of certain microbial functional groups (Harris, 2003; Matsumoto et al., 2005). In general, agricultural systems with less soil disturbance, no-till systems compared with conventional tillage systems have higher microbial activity based on higher microbial biomass C, N, and P (Balota et al., 2003; Babujia et al., 2010).

Phospholipid fatty acid

The microbial-derived phospholipid fatty acids (PLFA) represent living soil microbial biomass based on biomarkers associated with various microbial groups, such as bacteria, fungi (saprophytic and arbuscular mycorrhizae), rhizobia, and actinomycetes (Bossio and Scow, 1998; Buckley and Schmidt, 2003). Fatty acids are found in the cell membrane of a living organism, specifically fungi, and bacteria and degrade relatively quickly after death (Kaur et al., 2005). In this sense, PLFA is a snapshot of the microbial community and abundance at the moment of sampling (Kirk et al., 2004). The ability for microbes to rapidly respond to environmental conditions (pH, temperature, moisture) and management (tillage, crop rotation, chemical inputs) make PLFA a useful indicator for soil health, changes in fertility, and

management conditions (Acosta Martínez et al., 2010; Buckley and Schmidt, 2003; Helgason et al., 2009).

Phospholipid fatty acid profiling as an indicator of diversity and biomass can be used to understand how microorganism's abundance and structure shift at the phenotypic level with environmental changes caused by land use and climate (Kandeler, 2007; Zelles, 1999; Kaur et al., 2005). Several studies have found arbuscular mycorrhizal fungi and saprophytic fungi to be sensitive to tillage and soil disturbance due to reduced filamentous hyphae growth (Wardle et al., 1995; Mcgonigle and Murray, 1996; Kabir et al., 1999; Beare, 1997; Lemanski and Scheu, 2014). No-till management systems increase total, fungal, and bacteria PLFA due to greater organic residue in undisturbed surface soils (Helgason et al., 2009; Cookson et al., 2008; Spedding et al., 2004; Drijber et al., 2000; Zhang et al., 2014; Minoshima et al., 2007). Bossio et al. (1997) ranked the environmental variables affecting microbial structure: soil type > time > specific farming operation (cover crop) > management system > spatial variation. Long-term agricultural systems with higher OM from manure and cover crops have higher microbial biomass vs. conventional farming systems with mineral fertilizer and pesticides (Bossio et al., 1997; Wander et al., 1995; Vukicevich et al., 2016).

Seasonal effects on microbial activity and biomass are due to the temporal nature of temperature, soil water, and management system (Bossio et al., 1997; Hsiao et al., 2018). Hsiao et al. (2018) found greater temporal variability of soil microbial activity in no-till surface soil than conventional tillage. Soil microbial biomass was greatest in the spring and fall and lowest in the summer and winter where temperature extremes were present (Bååth and Söderström, 1982; Sarathchandraw et al., 1989). Gram (+) bacteria typically dominate early in the growing season and following a fallow period (Acosta-Martinez et al., 2007). They survive better under

stressed environmental conditions, such as drought or extreme temperatures due to their ability to form spores and have a thicker peptidoglycan layer that allows greater resistance to water stress (Hoorman, 2011; Gupta, 2011, Kirk et al., 2004; Williams, 2007). Therefore, Gram + bacteria are common after coming out of dormancy. Actinomycetes are a type of Gram (+) bacteria capable of forming spore-bearing mycelium and are metabolically diverse (McCarthy and Williams, 1990). A majority of actinomycetes are saprophytes, able to solubilize lignocellulose and chitin polymers, while some have symbiotic relationships with plants (McCarthy and Williams, 1990). Actinomycetes require aerobic conditions but can adapt to acid or alkaline pH conditions and high temperatures (McCarthy and Williams, 1990).

Gram (-) bacteria are fast-growing, resistant to heavy metals, and genetically stable (Singh et al., 2020). Bacteria alter their membrane activity under various environmental conditions to maintain optimal fluidity for nutrient and waste transport in and out of the cell. Gram (-) bacteria can form polarized groups (phosphate, carboxyl, hydroxyl, and amino groups) for binding metal ions and prevent metal ions from entering the extracellular membrane (Taniguchi et al., 2000; Singh et al., 2020). Bacteria communities under stressed conditions, like high temperature, low substrate, low pH, heavy metal, pesticide, and tillage, have increased production and proportion of trans/cis ratio of unsaturated fatty acids (Kaur et al., 2005).

Soil microbial community composition also changes with depth. Microbial biomass declines strongly with depth due to a decline in resource inputs (Allison et al., 2008; Hsiao et al., 2018). Subsoils tend to decline in fungi relative to bacteria abundance (Zelles and Bai, 1994; Blume et al., 2002; Taylor et al., 2002; Li et al., 2017; Hsiao, 2018), and an increase in actinomycetes and Gram-positive bacteria relative to Gram-negative bacteria (Zelles and Bai, 1994; Feng et al., 2003l Fierer et al., 2003).

Soil organic carbon

Soil organic carbon is a primary component of SOM, synonymous with the term humus, the organic fraction of soil entirely made up of undecaying plant and animal residues (Soil Science Society of America, 1997). Soil organic carbon is a product of OM formation and degradation primarily microbially mediated (Scott, 2019; Hurisso et al., 2016). Soil organic carbon may change slowly, 3 to 5 years in sub-humid temperate climates and slower in drier climates (Scott, 2019). Organic carbon can be determined through wet or dry combustion. For dry combustion, an air-dry sample sieved past 2 mm, is analyzed for total C by an elemental analyzer (Combs and Nathan, 1998). If the soil pH is less than 7.2, total C is equivalent to soil organic carbon. However, if soil pH is above 7.2, inorganic C is either removed by acid treatment or measured and deducted from total C (Sherrod et al., 2002).

Since SOC is a primary constituent of SOM, SOC is used for the indirect determination of SOM (Sherrod et al., 2002). However, total SOM is not an ideal indicator of nutrient cycling and availability because most SOM is in stable forms with slow-turnover rates (Wander, 2004; Hurisso et al., 2016). Of the various OM active, slow, and recalcitrant pools (Fig. 1.3), the active or labile substrates, mineralizable C and permanganate-oxidizable C, are associated with nutrient supply and microbial growth (Wander, 2004).

Permanganate-oxidizable carbon and mineralizable carbon

Permanganate-oxidizable C (POXC) is a test for labile or readily available C within SOC used by soil microbial organisms for microbial processes (Weil et al., 2003).
The reactive and labile soil organic C is altered by microbial activity more than the highly recalcitrant or humified forms of passive C (Weil et al., 2003). Changes in labile SOC indicate soil degradation or improvement based on management (Weil et al., 2003). Easily oxidizable C

deep in the soil profile indicates mobility (Blair et al., 1995). Several studies determined POXC to be a better indicator of long-term soil C sequestration based on long-term OM stabilization and accumulation (Hurisso et al., 2016; Culman et al., 2012). However, recent research indicates POXC is not a good indicator due to increased analytical variability from using different size sieves, greater variability only using 2.5 g soil mass, and high variability due to differences in SOC content in different soil types (Hurisso et al., 2018; Wade et al., 2020; Pulleman et al., 2021). Mineralizable C is an effective indicator of practices that encourage OM mineralization and short-term nutrient availability (Hurisso et al., 2016). Mineralizable C quantifies the flush of CO_2 after rewetting the soil during a short-term aerobic incubation period (Franzluebbers et al., 2000). High values of both POXC and mineralizable C indicate short-term nutrient availability and long-term OM accumulation (Hurisso et al., 2016).

Soil respiration

A majority of CO_2 released from soils results from activity in the soil from microorganisms, living roots, and macro-organisms decomposing organic substrate to acquire energy for survival (Parkin et al., 1997; Wang et al., 2003). The activity of soil organisms is considered a positive attribute for soil quality, fertility, and terrestrial C cycling. Soil respiration is highly variable in both spatial and seasonal changes due to changes in moisture and temperature. Darker colored soils with high respiration rates are generally considered healthy with high SOM levels (Moebius-Clune, 2016). Tillage or cultivation can result in soil C loss and increases CO_2 released due to the greater availability of organic substrate to soil microorganisms (Franzluebbers et al., 2000). A high soil respiration rate, indicative of high biological activity, indicates rapid decomposition of organic residues into nutrients available for plant growth. High respiration measured in the field can indicate recent disturbance

and access to OM for mineralization by microbes, while high respiration in lab incubations can indicate OM present in the soil protected from mineralization until rewetting and access by microbes (Lopez-Sangil et al., 2018; Barnard et al., 2020). The amount of CO_2 pulse associated with rewetting and soil disturbance contributes to the net annual terrestrial CO_2 exchange and determines the rate or magnitude of carbon stored in soils (Lopez-Sangil et al., 2018; Bernard et al., 2020).

Biological activity directly reflects the degradation of OM based on the two processes of soil carbon loss and nutrient turnover (Parkin et al., 1997, Wade et al., 2018). Soil respiration measures the CO_2 released after a rewetting of air-dried soil in a short-term incubation period (Franzluebbers et al., 2000; Moebius-Clune, 2016; Wang et al., 2003). The burst of respired CO_2 following rewetting or air-dried soil is referred to as the "Birch effect" and is a commercially viable soil health test (Birch, 1959; Wade et al., 2018). However, a standardized protocol has not been widely accepted and requires refinement on differences in soil processing, incubation times, rewetting method, and final soil water content to minimize procedural variations (Wade et al., 2018). The general approach of air-dried soil sieved less than 2 mm incubated in 24-h with multiple replications is the most common approach. However, this research method uses a modified form of Schindelbeck et al. (2016) four-day incubation with air-dried soil sieved through 8 mm.

Mineralizable nitrogen

Potentially mineralizable nitrogen is a portion of soil organic nitrogen most easily mineralized with the conversion of organic N to inorganic N by soil microorganisms (Drinkwater et al., 1997). The ability of soil to provide inorganic plant-available N is an indicator of soil health (Drinkwater et al., 1997). Nitrogen mineralization replenishes

inorganic N taken up by plants (Geisseler et al., 2019; Osterholz et al., 2017). Proteinaceous compounds regulate the mineralization of plant-available N due to its abundance, intermediate molecular weight, and diverse microbial degradability (Schindelbeck, 2016; Stevenson, 1982). The major form of plant N is proteins (2-5%), while amino acids, available for direct uptake, is usually 100 times lower (Jones et al., 2005). The depolymerization of proteins by enzymes into free amino acids is considered the start of N mineralization and rate-limiting step before microbial assimilation (Jan et al., 2009; Schimel and Bennett, 2004; Schulten and Schnitzer, 1997). Thus, measurements of protein content may be considered predictors of potential N mineralization and N cycling (Hurisso et al., 2018).

Enzymes

Enzyme assays measure soil metabolic activity based on the type of enzyme. Extracellular enzymes excreted by soil microbes are useful biological indicators because they are responsible for catalyzing critical soil processes such as nutrient cycling (Caldwell, 2005; Das and Varma, 2011; Dick, 1994). Common enzyme assays are classified as hydrolases and can be used to measure biogeochemical cycling, specifically C (β-glucosidase), C and N (N-acetyl-β-glucosaminidase), N (aspartase, asparaginase, urease), P (acid and alkaline phosphomonoesterase, phosphodiesterase), and S (arylsulfatase) cycling (Moebius-Clune, 2016; Tabatabai, 1994). Soil enzymes can distinguish land management practices since they are associated with soil microbial activity (Nannipieri et al., 2002). However, individual enzyme analysis does not adequately reflect the soil health status because individual enzyme activity can only represent the metabolic process for certain C, N, and P cycling (Adetunji et al., 2017; Alkorta et al., 2003). In addition, enzyme assays only measure the cumulative potential of microbial activity and not *in situ* activity of enzymes (Alkorta et al., 2003; Dick, 1994).

β-glucosidase

β-glucosidase (cellobiase) is common in soils. It facilitates the degradation and hydrolysis of plant polysaccharides, like cellulose, maltose, and cellobiose, to generate glucose, a source of energy for microbes (Eivazi and Tabatabia, 1988; Turner et al., 2002; Esen, 1993). The enzyme can monitor changes in land management since β-glucosidase is the most abundant and easily detected cellulose-degrading enzyme in soil and is generally not substrate limited (Eivazi and Tabatabai, 1988; Debosz et al., 1999; Acosta-Martinez and Tabatabai, 2000). β-glucosidase activity decreases with increased soil pH from 4.5 to 8.5 (Eivazi and Tabatabai, 1990). Since the rate of enzyme activity changes with soil pH, it would be a useful biochemical marker for environmental change and not used to represent in-field activity levels for acidic soil (Acosta-Martinez and Tabatabai, 2000). High salinity and heavy metal contamination decrease β-glucosidase activity, while β-glucosidase generally decreases with soil depth (Acosta-Martínez et al., 2003). In agricultural soils, β-glucosidase activity increases with less tillage and crop residue quantity (Pandey et al., 2014). Overall, β-glucosidase activity is related to SOM, biological activity, soil pH, and land use.

N-acetyl-β-glucosaminidase

N-acetyl-β-D-glucosaminidase (chitinases) is an enzyme that hydrolyzes the glycosidic bond in N-acetyl-β-glucosamine residues incorporated in chitin, the second most abundant polysaccharide on earth after cellulose (Stryer, 1988; Karamanos, 1997; Nannipieri et al., 2002). Chitin occurs in a wide distribution of invertebrates, plants, fungi, bacteria, and animals (Muzzarelli, 2013; Trudel and Asselin, 1989). Chitinases degrade chitin into low molecular weight chitooligomers or monomers for C and N cycling (Cohen-Kupiec and Chet, 1998). Plants, bacteria, and fungi produce chitinases for chitin digestion and energy (Cohen-Kupiec and Chet,

1998). The importance of N-acetyl-β-D-glucosaminidase in biological systems is long established for C and N cycling in the soil (Parham and Deng, 2000). In particular, the enzyme activity is correlated with high levels of fungal biomass in the soil since chitin is a major structural component of fungal cell walls and is a major source of temporary soil organic C and N. (Wood et al., 1994).

Alkaline and acid phosphomonoesterase

Phosphomonoesterase (phosphatase) is the primary P-cycling enzyme studied for its involvement in mineralizing organic P (Eivazi and Tabatabai, 1977; Acosta-Martínez at al., 2011). Alkaline Phosphomonoesterase (orthophosphoric monoester phosphohydrolase) predominates in alkaline soils (pH 9-11), while acid phosphomonoesterase (orthophosphoric monoester phosphohydrolase) predominates in acidic soils (pH 4-6) (Eivazi and Tabatabai, 1977; Dodar and Tabatabai, 2003; Dick and Tabatabai, 1984), suggesting soil pH and phosphatase activity are related to enzyme stability (Tabatabai, 1994; Dick and Tabatabai, 1983). Numerous studies suggest both phosphomonoesterases are derived from soil microbial communities (Beever and Burns, 1981), largely fungal populations (Acosta-Martinez et al., 2003; Acosta-Martinez et al., 2008), but acid phosphatase can also be released by plants too (Estermann and McLaren, 1961; Juma and Tabatabai, 1988a,b,c; Lou et al., 2017). Phosphomonoesterase hydrolyzes phosphate monoesters, low molecular monoester P bonded compounds like nucleotides, and polyphosphates, to produce phosphate (PO_4^-) (Adetunji et al., 2017; Eivazi and Tabatabai, 1977). In agricultural soils, alkaline and acid phosphatase can evaluate liming needs since phosphomonoesterases are very sensitive to changes in pH (Dodar and Tabatabai, 2003). In addition, agricultural practices from crop rotation, N fertilization, and crop residue quality impact phosphatase activity (Dodar and Tabatabai, 2003). Kalembasa and Symanowicz (2012)

and Lemanowicz (2011) both found higher acid phosphatase activity in N fertilized wheat and corn crops and a decrease in alkaline phosphatase activity due to changes in P availability and soil pH. Phosphatase activity decreases with inorganic P fertilizers but increases with SOM availability and less tillage (Margalef et al., 2017; Nannipieri et al., 2002). Overall, phosphatase enzymes are important biological soil indicators of land-use change regarding fertilizer, OM, tillage, and soil pH effects.

Phosphodiesterase

Phosphodiesterase is a phosphatase enzyme responsible for mineralizing and cycling of P through the hydrolysis of phosphate diester bonds (phosphodiesters) (Acosta-Martínez et al., 2011; Hou et al., 2015). It is involved in the degradation of nucleic acids (Anderson, 1970), phospholipids (Kowalenko and Mckercher, 1970), glycerol phosphates, phosphatidyl choline, and other diesters in the soil that are majority fresh organic P inputs (Cosgrove, 1967; Sparling et al., 1986; Acosta-Martinez et al., 2011; Hance and Anderson, 1963). The enzyme occurs in plants, animals, and microorganisms (Browman and Tabatabai, 1978).

Arylsulfatase

Arylsulfatase is a sulfatase enzyme that hydrolyzes organic sulfate esters, representing about 30 to 70 % of soil organic S (Schere, 2001; Tabatabai, 2005; Klose et al., 2011). Arylsulfatase occurs in plants, animals, fungi, and bacteria, but arylsulfatase is primarily microbial in origin (Tabatabai and Bremner, 1970; Fitzgerald, 1978; Germida et al., 2021).

Chemical soil properties

The availability and amount of macro- and micronutrients for crop plant production in agricultural soils can determine deficiencies or toxicities that impact crop quality and production. Chemical indicators of soil health are related to measurable soil nutrients dependent on soil pH, cation exchange capacity, percent base saturation, and OM (Kelly et al., 2009; Schoenholtz et al.,

2000). Nutrients measured include organic carbon, short-term C mineralization, total nitrogen, nitrogen mineralization, extractable P, cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), and metals (Fe, Zn, Cu, Mn) (Idowu et al., 2008). Soil organic carbon functions by supporting soil processes like aeration, nutrient and water storage/turnover, aggregate stability, and microbial activity (Kong et al., 2005; Dexter, 2004). The rate of decay and decomposition in soil governs the change in soil organic fractions and, overall, soil fertility (Schmidt et al., 2011).

Inorganic nitrogen

Soil nitrogen (N) occurs in several chemical forms that behave based on different environmental conditions. Inorganic N in soil is mainly in the form of nitrate (NO_3^-) and ammonium (NH_4^+), while nitrite (NO_2^-) is rarely present (Maynard et al., 1993). Nitrate is formed through nitrification from ammonium with nitrite as an intermediate (Bremner, 1997). Nitrate is water-soluble and can leach through soils or become nitrous oxide (N_2O) through denitrification in anaerobic conditions like waterlogged soils (Bremner, 1997). Total N includes inorganic and organic N. Organic N makes up >95% of total N, which is largely unavailable for plant uptake and requires microbial conversion to usable plant forms (Schoonover and Crim, 2015). As a result, inorganic N is one of the most limiting nutrients for plant growth and requires careful management for soil productivity.

Phosphorus

Phosphorus (P) availability in soils is important in assessing soil health because it is needed for biological composition and biochemical reactions such as cell signaling, cell membrane, genomic structure, photosynthesis, respiration, and energy generation (Cardoso, 2013; Hazelton and Murphy, 2016). Soil P is derived from mineral weathering and OM decomposition (Schoonover and Crim, 2015). Thus, P amendments are needed to sustain crop

productivity. However, careful P management is needed since P binds to soil or is transported with eroded soil (Schoonover and Crim, 2015).

Potassium

Potassium (K) is derived from crystalline structures of soil minerals (feldspars and micas) and contribute to K in two forms, exchangeable K or non-exchangeable K (Pratt, 1965; Schoonover and Crim, 2015). Exchangeable K is adsorbed on soil colloids and takes part in cation exchange capacity (Weil and Brady, 2019). Soil solution is in equilibrium with exchangeable K and is released from cation exchange complexes as soil solution is not in equilibrium from plant uptake (Schoonover and Crim, 2015). Plants can take up excess K, leading to deficiencies in subsequent crops, but leaving crop residue can return K taken by plants (Schoonover and Crim, 2015).

Cation exchange capacity

Cation exchange capacity (CEC) is the total exchangeable cationic charges that soil can absorb and is used to assess the fertility and environmental behavior of cations (Bronick and Lal, 2005; Weil and Brady, 2019). Abundant soil cations include Ca^{2+}, Al^{3+}, Mg^{2+}, Na^{+}, and K^{+} (Weil and Brady, 2019). Other cations present in small amounts include Fe^{3+}, Mn^{2+}, Cu^{2+}, and Zn^{2+} (Weil and Brady, 2019). Sandy soils usually have low CEC, while high OM soils have high CEC (Weil and Brady, 2019). Higher CEC soils can retain Ca, which can buffer against soil acidification (Hazelton and Murphy, 2007). Low CEC soils have a low resistance to changes in soil chemistry (Rengasamy and Churchman, 1999). High OM soils also buffer against acidification with greater cation exchange capacity than mineral soils (Parfitt et al., 1995).

Soil pH

Soil pH is affected by climate, soil buffer capacity, N fertilization, and vegetation type (Hong et al., 2019). Generally, soil pH is lower in wetter environments (Slessarev et al., 2016), lower in low latitudes (Binkley and Fisher, 2019), and regulated by overlapping buffering systems (Hong et al., 2019). Ammonium based fertilizers cause soil acidification through nitrification, releasing H^+ ions from plant absorption and slightly through NH_4^+ ions displacing base cations (Ca^{2+}, Mg^{2+}, Na^+, K^+) in soil exchange sites and (Tian and Niu, 2015). Regions with carbonate-dominated soils are less sensitive to acidification due to greater buffering capacity (Yang et al., 2012). Soils become potentially toxic to plants when base cations have leached out from soil exchange sites and non-base cations (Al^{3+}, Mn^{2+}, Fe^{3+}) are mobilized to buffer against acidification (Bowman et al., 2008).

Physical soil properties

Physical indicators of soil health include soil structure, soil texture, infiltration rate, aggregate stability, bulk density, porosity, soil depth, and water holding capacity. The ability of soil to retain and transport water and nutrients while providing a habitat suitable for soil microbes is crucial for plant health. Overall, symptoms of poor physical soil properties include poor infiltration, runoff from the surface, crusting, poor aeration, poor rooting, poor workability, and high bulk density (Kinyangi, 2007; Cardoso et al., 2013).

Soil structure

Soil structure is the composition of sand, silt, and clay particles described by its type (shape) of structural peds present, relative size (fine, medium, coarse), and degree of development or distinctness of the peds (strong, moderate, weak) (Lal, 1991; Weil and Brady, 2019). The physical structure of soil influences aeration, water movement, plant growth, erosion potential, heat conductivity, and plant and root growth (Lal, 1991; Schjønning et al.,

2004). Porosity is the space not occupied by matter. Water-holding capacity is related to the soil texture and OM content (Weil and Brady, 2019). Water retention is due to gravity, capillary, and osmotic pressure (Weil and Brady, 2019).

Aggregate stability

Aggregate stability is based on the formation of secondary particles through a combination of minerals with organic and inorganic substances (Tisdall and Oades, 1982; Bronick and Lal, 2005). The grouping of aggregate size is classified as macroaggregates (>250 µm) made from microaggregates (<250 µm) by organic and inorganic binding agents, roots, and hyphae entanglement (Six et al., 2004; Tisdall and Oades, 1982; Tisdall et al., 1997; Sillanpää and Webber, 1961). The environmental variables with disruptive forces that dominate macroaggregate turnover need to be slow enough to allow for microaggregate formation, which accounts for the medium to long-term C sequestration in soil (Jastrow et al., 1996; Six et al., 2002; Angers and Chenu, 1997). Macroaggregates are influenced by soil management, specifically, cultivation which disrupts macroaggregates and reduces soil organic C and N (Tisdall and Oades, 1982; Cambardella and Elliott, 1993; Elliott, 1986; Mikha and Rice, 2004; Elliot, 1986). Microaggregates develop from the generation of humic substances that stabilize SOM with interactions of mineral surfaces (Blanco-Canqui and Lal, 2004; Oades, 1984). Soil aggregate stability is based on inorganic and organic compounds (Tisdall and Oades, 1982). Soil disturbance disrupts soil structure releasing OM for decomposition as microbial activity mineralizes organic compounds (Lal, 1993; Blanco-Canqui and Lal, 2004). Overall, soil aggregates are important for soil structure, aeration, water permeability, erosion, nutrient cycling, C sequestration, and diverse microbial microsites (Six et al., 2002; Six et al., 2004; Bronick and Lal, 2005; Le Bissonnais, 1996).

Numerous protocols test aggregate distribution and stability. These include raindrop impact, dry sieving, wet sieving, ultrasonic vibration, and clay dispersion (Almajmaie et al., 2017; Nimmo and Perkins, 2002). Water-stable aggregates by wet sieving determine the size distributions of soil aggregate (Le Bissonnais, 1996; Yoder, 1936; Tinulin, 1928). Wet sieving measures the stability of air-dried soil clods into smaller aggregates after slaking, the process of rapidly wetting air-dry soil to rupture air trapped inside aggregates (Yoder, 1936; Kemper and Rosenau, 1986). Air-drying reduces variation from field moist Yoder, 1936). Aggregate stability methods can vary in sample preparation, sieve sizes used, sieving time, emersion time in water, oscillation rate, sand correction, and level of detail returned (Yoder, 1936; Kemper and Rosenau, 1986; Le Bissonnais, 1996; Mikha and Rice, 2004).

Infiltration

Infiltration is the process of water entering the soil and is dependent on the soil type, structure, topography, soil surface cover, and soil water content (Lowery et al., 1997; Lili et al., 2008). Infiltration measurements compare management effects on compaction, soil structure, aggregation, surface crusting, and pore connectivity (Lowery et al., 1997; Grosholz, 1992). Infiltration measurements are highly variable due to varying soil types and initial soil moisture levels. Drier soils have higher infiltration rates than wetter soils. Thus, the soil water content must be similar when comparing different locations and treatments. Infiltration tests can use an unlimited supply of water or a ponded head of water (Lili et al., 2016). Single-ring infiltration uses two consecutively applied 444 mL of water, equivalent to 2.54 cm depth of water in a 15.24 cm dia. ring, to first wet the soil and then measure the infiltration rate at field capacity (Moebius-Clune, 2016; Prieksat et al., 1992). Two ring infiltration uses a constant 5-cm depth of water in both rings, one placed inside the other, to measure the volume of water

supplied to the inner ring divided by the area of the inner ring (Lili et al., 2016). Infiltration rate is based on the time per depth or amount of depth per time, i.e., minutes per cm or cm per hour (Moebius-Clune, 2016). A simulated rainfall method can simulate infiltration, rainfall rate, and runoff simultaneously (Dixon, 1975; Bouwer, 1986; Lili et al., 2016).

At the beginning of an infiltration event, high soil infiltrability declines rapidly with time (Lili et al., 2016). The rate decreases exponentially as the infiltration rate reaches a steady-state, with the infiltration rate equivalent to or very similar to the saturated hydraulic conductivity (Lili et al., 2016; Grosholz, 1992). The steady-state infiltration rate is usually achieved in two to three hours (Lili et al., 2016). Tillage can improve infiltration immediately afterward by loosening the surface and compacted areas. However, soil structure and aggregates are disrupted, which can lead to potential compaction, surface crusting, and loss of soil pores (McVay et al., 2006; Alvarez and Steinbach, 2009). In addition, plant roots, fungal hyphae, earthworm burrows, and OM affect the infiltration rate (Dixon and Peterson, 1971).

Land use

Native grassland prairies

Grasslands are considered highly fertile, high in SOM, drought-tolerant, and diverse in plant and microbe species (William, 2007; Roscher et al., 2005; Cambardella and Elliot, 1993). Native prairies can serve as benchmarks for soil health and agricultural land restoration (Conant et al., 2001; Bauer et al., 1986). The precipitation gradient in Kansas determines the prairie vegetation. Kansas native prairie, centered in the Great Plains, contains various species in the shortgrass prairies, mixed-grass prairies, and tallgrass prairies (Axelrod, 1985). Shortgrass prairies form in areas with precipitation that averages 400 mm (Western Kansas), while tallgrass prairies form in areas with precipitation that averages 1,000 mm (Eastern Kansas) (Axelrod,

1985). The transition between the east and west of Kansas is dominated by mix-grass prairie species (Axelrod, 1985). Each type of prairie ecosystem has varying soil conditions and benefits. For example, shortgrass prairies can sequester C between 0.12 to 0.07 Mg C ha^{-1} yr^{-1} (Derner et al., 1997; Reeder and Schuman, 2002), northern mixed-grass prairie can sequester 0.30 Mg C ha^{-1} yr^{-1} (Schuman et al., 1999; Frank, 2004), and restored tallgrass prairies can average 0.45 Mg C ha^{-1} yr^{-1} (Potter et al., 1999). Thus, different prairies serve as a natural reference to monitor changes in soil quality. However, prairies are perennial plant species, while most agricultural systems are annual plants species. (Glover et al., 2007; Culman et al., 2010). The change from perennial to annual plants affects the soil profile through root depth, C and nutrient allocation between roots and shoots, and seedbed preparation (Glover et al., 2007; Culman et al., 2010). Therefore, a direct comparison with native systems may not be appropriate.

Agriculture

The transition of a native grassland ecosystem to an agricultural ecosystem often depletes soil nutrients, increases decomposition, increases greenhouse gases, and increases erosion (Cole et al., 1997; Vermeulen et al., 2012; Lal, 2003). Based on the Environmental Protection Agency's latest 2017 report on greenhouse gas emissions, the United State's agriculture sector contributes to 9% of emissions, around 581 million metric tons of CO_2 equivalence (U.S. EPA, 2017). This is an increase from the EPA's 2012 report that U.S. agriculture contributed 8% of all U.S. emissions, around 530 million metric tons of CO_2 equivalence (U.S. EPA 2012; Rogers et al., 2019). Current practices that release carbon stocks from the soil to the atmosphere include tillage, monoculture systems, fossil fuel-based chemical inputs, and land conversion from forests or prairies to agriculture (Delgado et al., 2011; Jackson et al. 1996).

Carbon sequestration through no-till and cover crops is a short-term solution to global warming by utilizing the natural process of photosynthesis and soil microbial cycling. Through regenerative soil management, agriculturists can also develop soil biological, chemical, and physical properties to promote soil health (Sherwood and Uphoff, 2000). By promoting soil health, not only would biological productivity increase but soil resilience to environmental stresses would also increase (Sherwood and Uphoff, 2000; Bünemann et al., 2018). Thus, agriculture can play a prominent role in agro-environmental sustainability as society increases its demand for environmental services under growing environmental pressures.

Conventional tillage

Tillage has been used for preparing seedbeds, reducing compaction, incorporating soil amendments, and controlling weeds (Gebhardt et al., 1985; Köller, 2002). However, long-term tillage depletes the SOM, increases atmospheric CO2, reduces biodiversity, destroys soil structure, reduces soil water retention, increases erosion and runoff, decreases infiltration, and increases compaction (Reicosky et al., 1995; McVay et al., 2006; Choudhary et al., 1997; Lal, 1993). Tillage increases the abundance of aerobes, facultative anaerobes, and denitrifiers in the surface soil (<15 cm) where tilling occurred (Mbuthia et al., 2015; Nivelle et al., 2016; Mackelprang et al., 2018).

No-till

No-till operation is defined as having no plows or disk machinery used on the field between the harvest of the previous crop and the current year's crop. No-till farming reduces disturbance to soil and microorganisms, leaves crop residues on the surface, reduces soil surface evaporation, reduces surface sealing, decrease runoff velocity, reduces wind and water erosion, increases soil holding capacity and moisture, and increase soil C storage overtime (Reicosky,

2008; Derpsch et al, 2010; Alvarez and Steinbach, 2009; Franzluebbers, 2005). Significant advantages of surface residue management are increased C near the soil surface and enhanced nutrient cycling and retention. Another benefit of no-till is the reduced cost of time, fuel, and labor. However, disadvantages of just no-till include a greater reliance on herbicides, increased disease pressures, and may increase compaction (Soane et al., 2012; Buchholz et al., 1993; Krupinsky et al., 2002).

No-till, cover crops, and crop rotation

Agricultural practices that promote soil carbon sequestration include cover crops, no-till, crop rotation, and organic C inputs (compost, biochar) (Kassam et al., 2009). These practices known as conservation agriculture, promote three principles of reducing soil disturbance, maintaining a permanent soil cover, and growing diverse plant species (Food and Agriculture Organization 2007; Kassam et al., 2009). Presently, many agricultural soils have lower soil quality due to continuous cultivation, erosion, salinization, compaction, and other factors (Baumhardt et al., 2015). As a result, conservation practices are also regenerative practices that restore health and improve productivity (Delgado et al., 2011).

Cover crops provide soil protection and soil improvement between periods of normal/cash crop production (Fageria et al., 2005; Hartwig and Ammon, 2002). Cover crops can increase SOM, suppress pests/weeds, provide a habitat for beneficial organisms, control erosion, prevent compaction, enhance soil biological activity. Using a diverse mix of cover crops can support a higher diversity of soil microorganisms (Schmidt et al., 2018; Vuvicevich et al., 2016; Snapp et al., 2005). Crop rotation involves growing crops in a rotation that maximizes the benefits for each crop. For instance, growing nonhost crops in a diseased crop residue can reduce pathogens and reduce the need for synthetic control (Krupinsky et al., 2002).

As a system, diverse cover crops and crop rotation in no-till systems can increase soil resilience to climate extremes, support biodiversity, improve infiltration, reduce erosion and runoff, promote pest suppression, increase SOM, increase pore space, reduce herbicide use, and support aggregate formation (Snapp et al., 2005). The challenges with implementing no-till, cover crops, and crop rotation stem from managing logistics, covering cover crop costs, maintaining commitment, and managing a complex ecosystem to retain biomass (Mirsky et al., 2012).

Nutrient management

Nitrogen fertilizer and retention affect the relationship between plants and fungi more than plants and bacteria (Bradley et al., 2006). Non-fertilized grasslands commonly favor fungi communities than bacterial communities (Bardgett et al., 1996; Grayston et al., 2001), while fungi are adversely affected by high mineral N (Bardgett, 1996). Chemical fertilizers may increase nutrient enrichment, but studies have reported soil acidification, decreased microbial enzymes, decreased microbial biomass, and reduced microbial diversity (Wang et al., 2018; Liu and Greaver, 2010; Tian and Niu, 2015; Ullah et al., 2019).

Environment

Soil Depth

Soil depths have biological, chemical, and physical properties that can affect plant production, root morphology, microbial composition, water movement, pH, temperature, and mineral composition (Blume et al., 2002). Subsurface soil microbial communities are specialized for their environment and are distinct from surface microbes (Blume et al., 2002; Van Gestel et al., 1992; Fierer et al., 2003). Thus, research is needed on the soil microbiome of soil profiles as affected by land management. Crop type impacts soil properties through the soil depth. Annual

crops have relatively shallow roots, usually in the top 0.3 m of soil, compared to perennial plants that develop roots to >2 m (Glover et al., 2007). Breeding plants for greater root depth and incorporating greater plant diversity into agricultural systems would facilitate greater C sequestration, soil fertility, crop yields, and soil structure (Glover et al., 2010; Culman et al., 2010).

Precipitation

Two of the soil-forming factors are climate and topography (Jenny, 1994). The precipitation gradient across Kansas is a major driver of crop productivity and soil properties through the soil profile (Blanco-Canqui et al., 2011). Precipitation variability can cause differences in water distribution that governs the rate of soil formation (Jenny, 1994). Higher soil water promotes weathering of parent materials, increases chemical and biological activity (Pidwirny, 2006; Jenny, 1994). Water movement increases eluviation and leaching of weathering byproducts (Jenny, 1994). Precipitation supports crop productivity, SOM, and soil microbial activity, promoting faster soil profile development (Jenny, 1994). However, higher precipitation soils are more susceptible to water erosion that can lead to soil loss and degradation in upper soil layers (Milne, 1936).

Plant-Microbe Interaction

Bacteria and fungi generally comprise more than 90% of the total soil microbial biomass and are responsible for SOM decomposition and soil function (Six et al., 2006). Defining each interaction of soil species with varying spatial and temporal heterogeneity requires understanding in the areas of the detritusphere, drilosphere, porosphere, aggregatusphere, and rhizosphere (Beare et al., 1995). Each sphere operates as a microsite or a habitat with defined structures,

organism cascades, and regulating agents that are all encompassed into the soil ecosystem (Lavelle, 2002).

Arbuscular mycorrhizal fungi (AMF) are root-symbiotic fungi that secrete glomalin protein through their hyphae (Wright and Upadhyaya, 1996). Glomalin promotes stable soil aggregates that protect soil C from mineralization (Wright and Nichols, 2002; Tisdall et al., 1972). Under high CO_2 concentrations, glomalin production increased, further promoting soil aggregation (Rillig et al., 1999). Following hyphae decomposition, glomalin's inherent binding properties remain, providing a lasting soil carbon stabilization mechanism (Rillig et al., 1999; Rillig, 2004). The formation of aggregates by fungal hyphae and mycelium networks may also be direct or indirect for vegetative production, sexual reproduction, protection, and decomposition, fungi help give rise to soil structure that is crucial for soil stability, water movement, diffusion of gases, and biotic activity (Wessels, 1996; Schreiner and Bethlenfalvay, 1995).

Soil organisms are most abundant and diverse at the soil-root interface, known as the soil rhizosphere. While leaves, detritus, and above-ground biomass provide carbon for the soil biota, plant roots are more significant. Living roots continually release an extensive array of organic materials and nutrients. Thus, living root-soil interfaces are more nutrient-rich near roots than in bulk soil mass. In dry ecosystems, dead plant roots can sustain macroaggregates during the dry season. Living microbes can maintain soil structure by decomposing organic residues that become encrusted with clays and exudates (Six et al., 2000; Blankinship et al., 2016). Since cropped soils typically contain more than 2 tons of root biomass per hectare, this unharvested plant material eventually dies and decomposes, allowing roots to be a major source of detritus for microorganisms and supporter of soil aggregation (Stirling et al., 2016; Marschner et al., 1995).

Soil microorganisms are then nutrient sources for the next cycle of plants grown. Soil microbes should be regarded as a key regulator for nutrient dynamics and agricultural productivity.

The rhizosphere is defined as the narrow zone of soil directly adjacent to and affected by plant roots. The rhizosphere contains root exudates, leaked and secreted chemicals, sloughed root cells, and mucilages. Plant root exudates contain sugars, amino and organic acids, fatty acids, and steroids, vitamins, nucleotides, and other compounds (Curl and Truelove, 1986).

A change in agricultural management can cause shifts in microbial community composition and substrate utilization. This can alter the ratio of fungi:bacterial biomass, which is sensitive to soil disturbance, with lower ratios in increased cultivation (Bailey et al., 2002; Beare et al., 1992). To restate, substrate quality alters fungal:bacterial ratios, usually with low-quality substrates (high C/N) favoring fungi and high quality (low C/N) substrates favoring bacteria (Bailey et al., 2002; Beare et al., 1992; Bossuyt et al., 2001). The decomposition rate for organic compounds in order of ease follows the general order of sugars, starches, and simple proteins; crude proteins; hemicellulose; cellulose; fats and waxes; and lignin and phenolic compounds (Weil and Brady, 2019).

Study Objectives

The overall objectives of this research were to 1) assess the differences in soil health status across a Kansas precipitation gradient under three different land management systems (native prairie, enhanced agriculture, and conventional agriculture) using selected indicators, 2) assess the utility and reliability of a standard set of soil health procedures under different soil types down to a 100 cm depth, and 3) compare different soil metrics that measures the same soil property (wet aggregate stability and infiltration). The objectives of the individual chapters are:

Chapter 2: Comparison of wet sieving soil aggregate methods. The objective of this study was to quantify and evaluate differences for three types of laboratory-based wet aggregate stability methods between 3 land management types, native prairie (NP), no-till (NT), and conventional tillage (AG), across 3 locations of a Kansas precipitation gradient (Tribune, Hays, Manhattan, KS) to a 100 cm soil depth.

Chapter 3: Soil health within the topsoil. The objective of this study was to characterize the soil health parameters in the top 15 cm based on land use (LU), location (L), and interaction effects (LU*L).

Chapter 4: Soil health down to a 100 cm depth. The objectives of this study were 1) to assess the differences in soil health status across a Kansas precipitation gradient under three different land management (native prairie, conventional tillage, enhanced agriculture), 2) to assess the utility and reliability of a standard set of soil health procedures under different soil types to a 100 cm depth.

Chapter 5: Comparison of Single Ring and Cornell Sprinkler Infiltrometer Methods. The objectives of this study were to (1) compare two infiltration methods (single ring and Cornell Sprinkler Infiltrometer) and (2) determine the infiltration rates of different land uses across a precipitation gradient.

Chapter 6: Conclusions and Recommendations. The objective of this chapter was to provide recommended metrics for analyzing soil health and future suggestions on soil health measurements.

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Tables

Table 1.1. Methodological description of soil health metrics with references to updated methods.

Methodological Description of Soil Health Metrics		
Metric	Method	Updated Methods
Single Ring Infiltration	Soil Quality Institute (1999)	Soil Survey Staff (2014) pg. 121-123
Cornell Sprinkle Infiltrometer	Schindelbeck et al. (2016)	Schindelbeck et al. (2016)
Soil Organic Carbon	Nelson and Sommers (1996)	Kellogg Soil Survey Staff (2014) pg. 464-471
Total Nitrogen		Kellogg Soil Survey Staff (2014) pg. 464-471
Water Stable Aggregates	Mikha and Rice (2004)	Mikha and Rice, 2004
ARS Wet Macroaggregate Stability	Kemper & Rosenau (1986)	Kemper & Rosenau (1986)
NRCS Wet Aggregation		Kellogg Soil Survey Staff (2014) pg. 213-216
β-Glucosidases	Eivazi and Tabatabai (1988)	Acosta-Martinez et al. (2018)
N-Acetyl-β-glucosaminidase	Parham and Deng (2000)	Acosta-Martinez et al. (2018)
Arylsulfatase	Tabatabai and Bremner (1970)	Acosta-Martinez et al. (2018)
Phosphodiesterase	Browman and Tabatabai (1978)	Acosta-Martinez et al. (2018)
Phosphomonoesterase	Tabatabai and Bremner, 1969; Eivazi and Tabatabai, 1977	Acosta-Martinez et al. (2018)
Autoclaved Citrate Extractable Protein Content	Wright and Upadhyaya (1998)	Schindelbeck (2016) pg. 55-69
Short-Term Carbon Mineralization/ Soil Respiration	Zibilske (1994)	Personally Modified
Permanganate-Oxidizable Carbon	Weil et al. (2003)	Schindelbeck (2016) pg. 31-36
Phospholipid Fatty Acid	Bligh and Dyer (1959)	White and Ringelberg (1998)

Figures

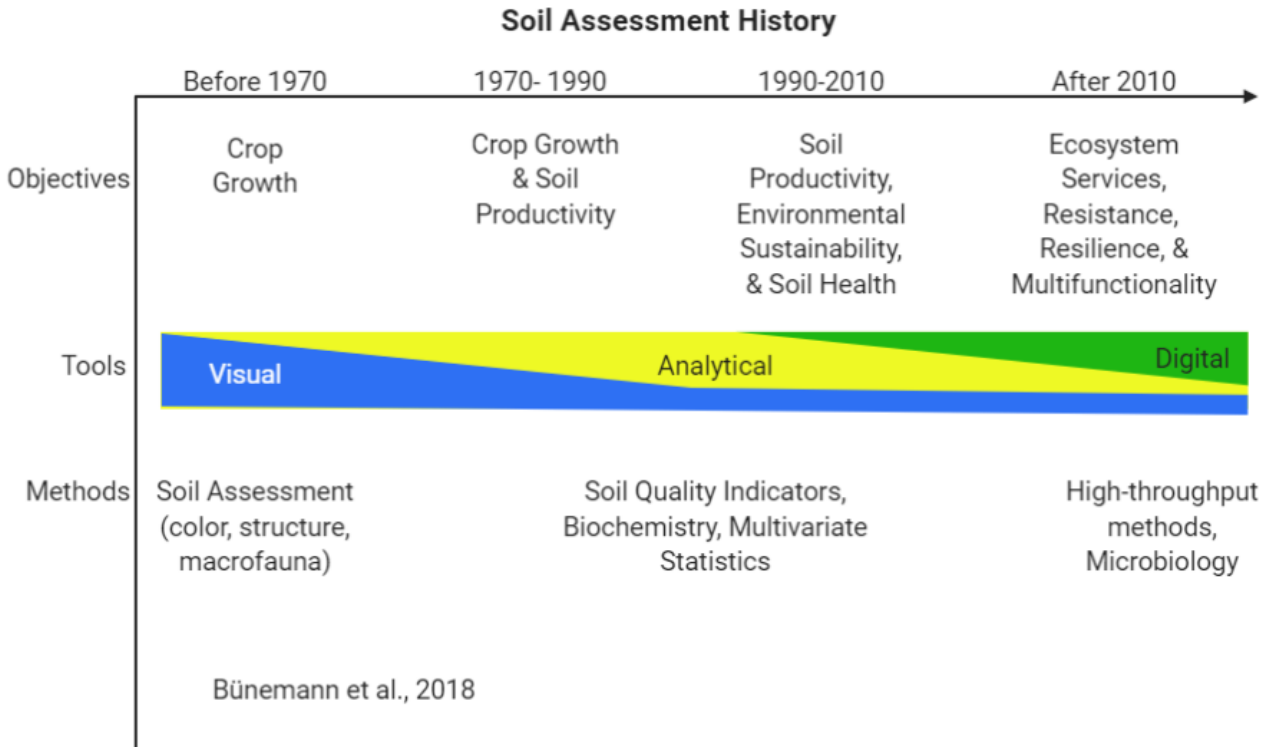

Figure 1.1. General soil assessment history adapted from Bünemann et al., 2018.

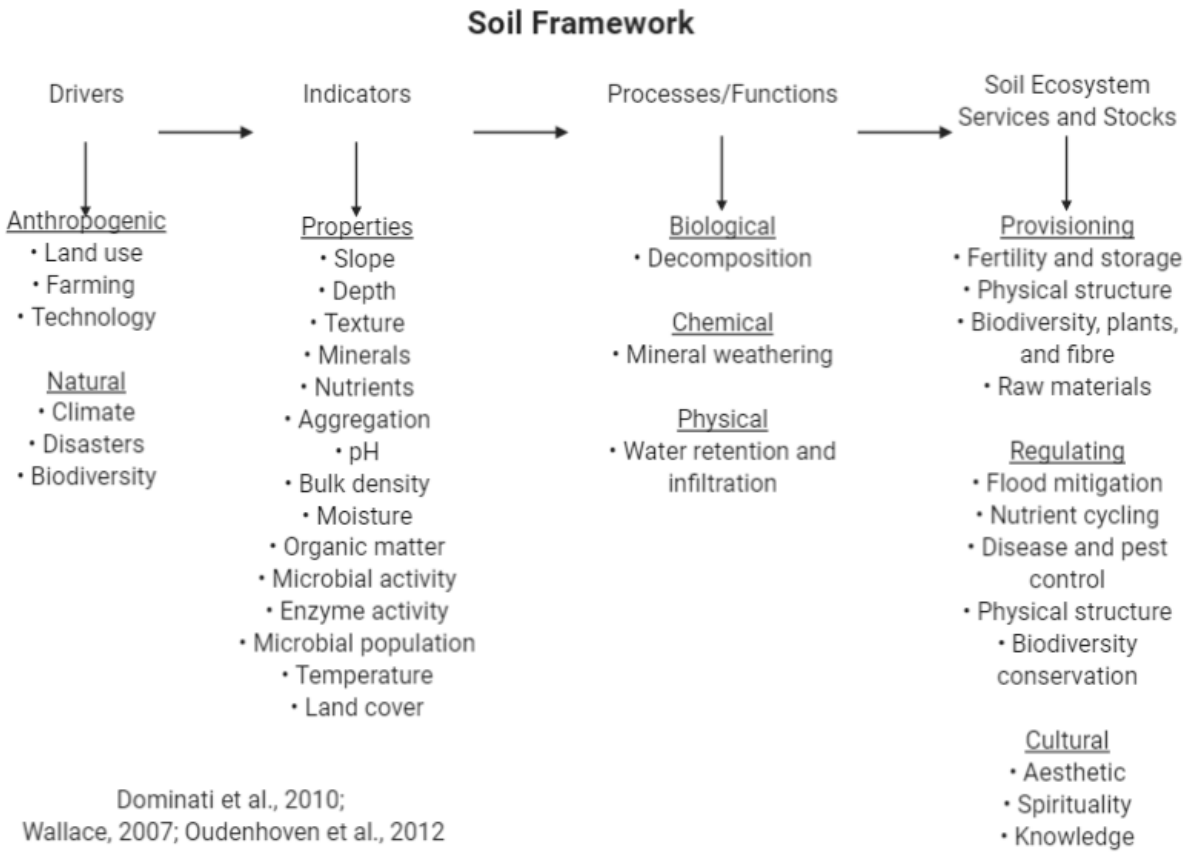

Figure 1.2. Overview of soil framework based on drivers, indicators, processes/functions, and soil ecosystem services adapted from Dominati et al., 2010; Wallace, 2007; and Oudenhoven et al., 2012.

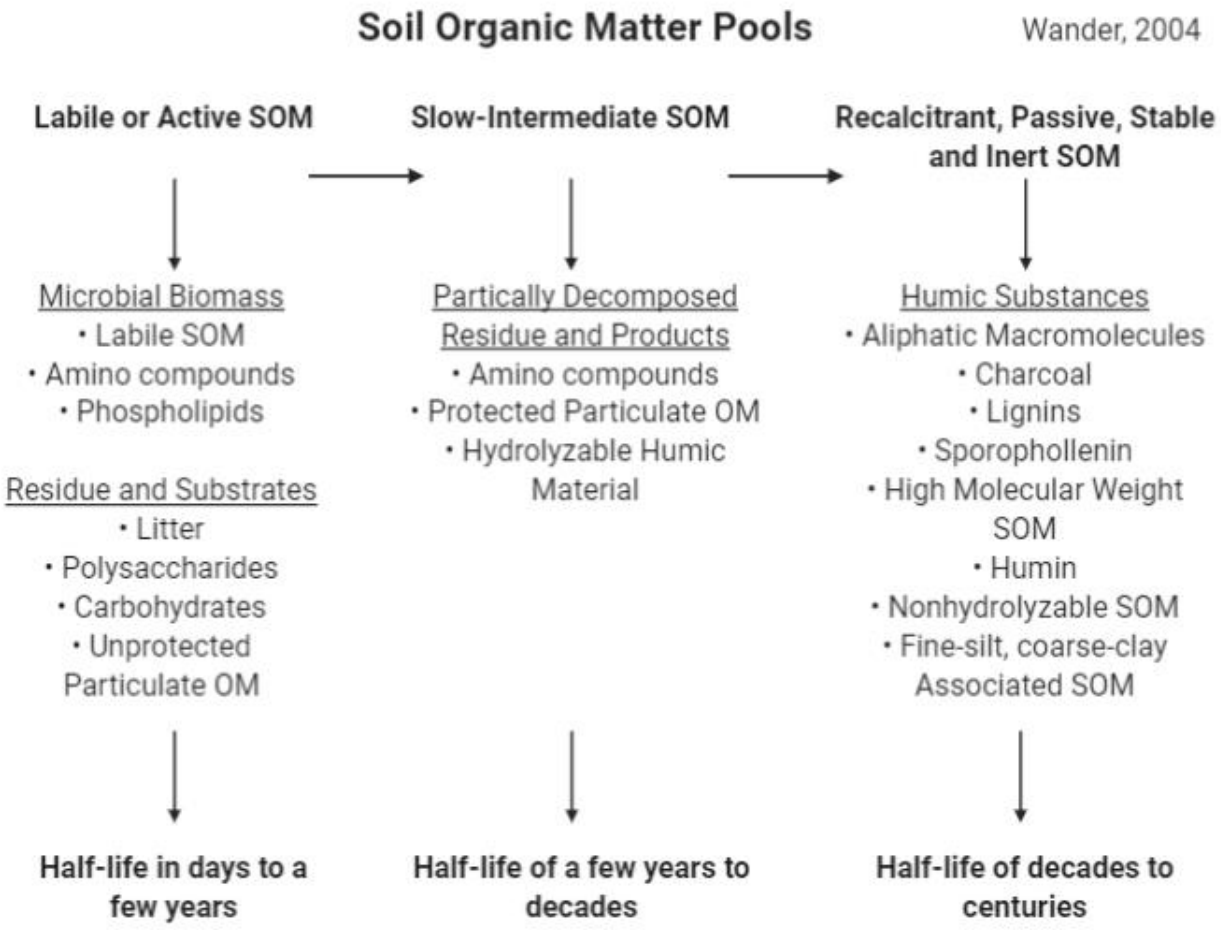

Figure 1.3. Soil organic matter pools and half-life of each pool adapted from Wander (2004).

Chapter 2 - Comparison of wet sieving soil aggregate methods

Abstract

This study compares methods that assess soil aggregate stability based on differences in relative timeliness, cost, and interpretability using soils from a precipitation gradient across Kansas to 1-meter depth. The three different mean annual precipitation regimes, Tribune (483 mm yr^{-1}), Hays (579 mm yr^{-1}), and Manhattan (850 mm yr^{-1}), KS, had different land management types at each site, specifically, native prairie, conventional tillage agriculture, and no-till with variations in cover crops. All methods used fresh soils separated along natural breaks with large stones and organic matter removed. The modified Kemper and Rosenau (1986) by Mikha and Rice (2004) uses 100 grams of air-dried 8-mm sieved soil to determine the percent aggregate size fractions >2 mm, 2-0.25 mm, 0.25-0.053 mm, and 0.053-0.02 mm using a Yoder wet-sieving apparatus under a 10-min water submergence and 10 min wet-sieving action. While Kemper and Rosenau (1986) method used by USDA Agricultural Resource Service is a 5-min water oscillation to determine the same percent aggregate size fractions. The Soil Survey Staff (2014) method used by the Natural Resources Conservation Service uses 3 grams of air-dry soil sieved between 2-1 mm agitated 20 times in 40 seconds after overnight submergence on a 0.5 mm sieve. The aggregate size distribution method by Mikha and Rice (2004) was recommended as the primary standardized laboratory-based wet sieving aggregate stability method performed for testing based on this study. Strong correlations and similar trends in aggregate stability were picked up by each of the methods. The overestimation from the Kemper and Rosenau (1986) based on a Bland-Altman plot and loss in sensitivity from the Soil Survey Staff (2014) method may be used for a general understanding of soil physical stability and structure under time or cost constraints. The Soil Survey Staff (2014) method is not applicable for greater resolutions of

aggregate size distribution and is only practical for small or modest sample sizes that can be completed by a single person.

Introduction

With increasing concerns with global environmental changes, there is a need for healthy soils and a strong emphasis to increase soil organic carbon (SOC) for productive, climate-resilient soils while managing nutrient turnover and stocks (Trumbore, 1997; Lai, 2004; Brussaard et al., 2007; Lorenz and Lal, 2018). The importance of soil aggregation is physical protection for soil organic matter (SOM) from microbial and enzymatic degradation (Rabot et al., 2018; Amézketa, 1999; Wissing et al., 2014; Chaplot and Cooper, 2015). Promoting high soil aggregate stability is crucial for maintaining soil biological productivity, carbon sequestration, SOM stabilization, and lessening soil degradation (Amézketa, 1999; Lorenz and Lal, 2018; Amezketa, 1999).

Soil aggregates are the basic unit of soil structure made up of soil particles or microaggregates (<0.25 mm dia.) bonded together by physical, chemical, and biological processes during pedogenesis. Biological and physical factors that influence soil aggregates include OM, soil fauna, mycorrhizal hyphae, and plant root entanglement (Totsche et al., 2018; Lehmann and Kleber, 2015; Tisdall and Oades, 1982; Bedel et al., 2018). Chemical binding agents include carbonates, cementing agents (oxides, hydroxides, and oxyhydroxides of Fe, Mn, Si, Al), cations (Ca, Mg), clay microstructures, precipitated solute cementation, and intermolecular attractive forces (Totsche et al., 2018; Lehmann and Kleber, 2015; Tisdall and Oades, 1982; Bedel et al., 2018; Basile-Doelsch et al., 2009; Han et al., 2016). Wet aggregate stability methods serve as a physical indicator of soil health that measures a soil's resistance to

runoff and water erosion (Nimmo and Perkins, 2002; Karlen and Stott, 1994). The stability of soil aggregates is related to water infiltration, surface sealing, runoff, water retention, and redistribution (Nimmo and Perkins, 2002; Loch, 1994; Emerson, 1967).

There are two complementary aspects within soil structure: the pore space for air and water and, the second is the solid phase, based on the processes related to soil aggregation (Robot et al., 2018; Amézketa, 1999). The differences in shape, size, and spatial arrangement of the pore space and solid phase indicate soil function and result from biological activity, climate, and management practices (Rabot et al., 2018). Porosity, pore distance, and pore connectivity rely on imaging techniques not widely accessible or affordable (Rabot et al., 2018), while different aggregate stability methods using rainfall simulation, wet sieving, ultrasonic vibration, and clay dispersion are found to be poorly correlated with one another. Thus, there is an unsupported standardization of methods (Almajmaie et al., 2017). Our focus was to compare different wet stability methods using water-stable aggregates (WSA), stable macro-and micro-aggregates (macroaggregates: 8-2 and 2-0.25 mm, and microaggregates: 0.25-0.053 and 0.053-0.02) retained in a specified fraction (Jastrow and Miller, 1991).

Soil aggregate analysis is important for evaluating the effect of various agricultural techniques or land management systems on stable aggregates (Nimmo and Perkins, 2002). The choice of aggregate stability method should be chosen to mimic the breakdown of field aggregates and consider soil type, cost, labor, time, and ease of replication (Herrick et al., 2001; Almajmaie et al., 2017). Early work by Kemper and Rosenau (1986) determined aggregate stability by wet sieving, which breaks down aggregates through slaking. Slaking is the process of rapidly wetting air-dry soil aggregates to rupture air trapped inside aggregates using varying types of internal stress, such as differential clay swelling, escaping air, the release of heat during

wetting, and movement of water (Truman et al., 1990; Loch, 1994). Individual soil clods broken along a natural fabric are wet sieved into smaller individual aggregates to quantify aggregate size distributions and cohesive strength. The fraction of soil material persisting at a certain diameter is directly related to the size distribution and stability. Wet sieving procedures do not consider the effect of raindrop bombardment and are conducted in a short duration that does not allow for measures of dispersion (Almajmaie et al., 2017).

The three methods chosen varied in ease of use, costs, labor, and time needed resulting in differences in sensitivities to treatments at different locations. The choice of using air-dry aggregates over moist aggregates was due to standardization and lack of time and labor in completing all soil samples after field sampling (Amézketa, 1999). Air-dry samples are known to be significantly less stable than moist aggregates due to the development of tensile stress from shrinkage in aggregates (Almajmaie et al., 2017; Amézketa, 1999; Kemper and Rosenau, 1984). Distilled (DI) water was used in all wet aggregate stability methods for standardization. Almajmaie et al. (2017) found no significant differences between DI water or irrigation water for wet sieving methods using sandy clay loam and sandy loam soils of Southern Tasmania, Australia.

Agricultural practices, such as no-till, conservation tillage, crop rotation, and cover crops control soil structure degradation and OM decomposition from microbial activity (Lorenz and Lal, 2018). Practices that cause slaking involve tillage, soil disturbance, harvesting, crop residue removal, and chemical applications that harm soil organisms (Lorenz and Lal, 2018). Native prairie soils compare the effects of agricultural cultivation (DeLuca and Zabinski, 2011). The objective of this study was to quantify and evaluate differences for three types of laboratory-based wet aggregate stability methods between 3 land management types, native prairie (NP),

no-till (NT), and conventional tillage (AG), across 3 locations of a Kansas precipitation gradient (Tribune, Hays, Manhattan, KS) to a 100 cm soil depth.

Materials and Methods

Soil sampling and processing

At each site, approximately 500 g of undisturbed soil was collected from the upper 0–5, 5-10, and 10-15 cm with a spade and placed in plastic zip-lock bags for transport. A six cm dia. plastic soil liner was used with a 6.35 cm dia. metal Giddings probe (Giddings Machine Company, Windsor, CO, USA) and separated by genetic horizon. After soil sampling, the fresh soil samples were separated along with natural breaks, air-dried for at least 24 h, and homogenized through an 8 mm dia. size sieved fraction while removing large visible stones, plant material, and soil animals. Air-drying soils at room temperature are preferred before testing to standardize soil conditions for post-test comparison.

Site descriptions

This study was conducted across an environmental gradient of Kansas with three land uses (native prairie-NP, enhanced agriculture-EA, and conventional tillage-AG). Each land use at each location (Manhattan, Hays, Tribune, KS) had the same or similar land mapping units, while location mapping units varied due to precipitation regimes (Table 2.1 and 2.2). Sampling time varied based on weather, farmer availability, equipment availability, and field conditions.

Manhattan, KS

Native prairie and AG were sampled on 13 September 2019 at the Konza Prairie Biological Station (KPBS) (Table 2.1 and 2.2). Six cores were taken for each replicate to a depth of 90 cm. Samples were separated by 0-5, 5-10, 10-15, 15-29, 29-59, 59-90 cm in native prairie

treatments, while samples were separated by 0-5, 5-10, 10-15, 15-26, 26-47, 47-71, 71-90 cm in conventional agriculture treatments based on Natural Resource Conservation Service (NRCS) proposed field sampling method of collecting 0-5, 5-10, 10-15, and by genetic horizon to a depth of 100 cm. Native prairie area was dominated by perennial C4 grasses (big bluestem (*Andropogon gerardi*), Indiangrass (*Sorghastrum nutans*), and switch grass (*Panicum virgatum*)) and C3 herbaceous forb species in Reading silt loam (Fine-silty, mixed, superactive, mesic Pachic Argiudoll) (Heisler-White et al., 2009; Freeman, 1998). Conventional tillage treatments were cultivated since the 1960s with soybean (*Glycine max*), wheat (*Triticum aestivum*), and grain sorghum (*Sorghum bicolor*) in Reading silt loam (Fine-silty, mixed, superactive, mesic Pachic Argiudoll) with tillage and local fertilizer and pesticide application practices (Kamlesh et al., 2010). The field was in soybean production Enhanced agriculture was sampled on 21 October 2021 after corn harvest, with 6 cores taken per replicate to a depth of 90 cm at a private farm with no-till corn-soybean rotation. The soils were separated by 0-5, 5-10, 10-15, 15-25, 25-50, 50-75, 75-90 cm. The EA was a Tully silt clay loam (Fine, mixed, superactive, mesic Pachic Argiustolls).

Hays, KS

Native prairie and EA were sampled on 20 September 2019 near Hays Agricultural Research Center (Table 2.1 and 2.2). Six cores were taken to a depth of 90 cm. Samples were separated by 0-5, 5-10, 10-15, 15-40, 40-60, 60-90 cm in native prairie (NP), while samples were separated by 0-5, 5-10, 10-15, 15-45, 45-65, 75-90 cm in the enhanced agriculture (EA). Native prairie consisted of mixed-grass prairie plants such as buffalo grass (*Buchloe dactyloides*), western wheatgrass (*Agropyron smithii*), blue grama (*Bouteloua gracilis*); side- oats grama (*Bouteloua curtipendula*), little bluestem (*Andropogon scoparius*), and big bluestem

(*Andropogon gerardi*) (Jones, 1960). Conventional agriculture samples were taken on 15 October 2021, with a Giddings probe (Giddings Machine Company, Windsor, CO, USA) to a depth of 90 cm at Hays Agricultural Research Center. Conventional agriculture treatments were separated by 0-5, 5-10, 10-15, 15-45, 45-65, 65-75, and 75-90 cm. The sampled AG had sorghum residue based on a wheat-sorghum-fallow rotation. All land uses at Hays were Harney silt loam (Fine, smectitic, mesic Typic Argiustolls) the AG field started in the late 1960s (Blanco-Canqui et al., 2011).

Tribune, KS

Native prairie, AG, and EA treatments were sampled on 19-20 August 2019 to a depth of 90 cm at the Southwest Research Center- Tribune Unit (Table 2.1). Samples were separated by 0-5, 5-10, 10-15, 15-40, 40-75, 75-90 cm. The site was sampled in a randomized strip block design, excluding the irrigation treatment. Native prairie vegetation type consisted of C3 and C4 grasses with the dominant species being buffalo grass (Buchloe dactyloides). Conventional agriculture and EA were a sampled after wheat harvest in a wheat-grain sorghum-fallow rotation with tillage and no-till in AG and EA, respectively. Soil at Tribune was classified as Richfield silt loam (fine-smectitc, mesic Aridic Argiustolls). The experiment was started in 1989 with treatments imposed in native prairie (Blanco-Canqui et al., 2011).

Only soils samples from Manhattan AG, NP; Hays AG, NP; and Tribune AG, EA, and NP, IR were sampled from public research fields, while Manhattan and Hays EA were sampled from private farmer fields with no-till and cover crop (Table 2.2). Only Hays EA had a cover crop mix planted with no-till. Native prairie from each of the locations was used as reference sites to be compared with agricultural management. Local NRCS soil scientists classified soil pedons for genetic horizon separation.

Methods

Water stable aggregates (20-minute method)

The 20 min method for aggregate stability used the Yoder wet-sieving apparatus modified for recovery of all particle fractions as described by Kemper and Rosenau (1986) and Mikha and Rice (2004) (Fig. 2.1). Each soil sample was separated into four aggregate size classes (8-2 mm, 0.25-2 mm, 0.053-0.25 mm, and 0.020-0.053 mm diameter). The air-dried soil (100g) was placed on a 2 mm sieve above the 0.25 mm diameter sieve. Distilled (DI) water (1 L) was added to submerge the soil for 10 mins before the 10-min wet-sieving action. The oscillation time was at 10 min, stroke length at 4 cm, and frequency 30 cycles min^{-1}. After the soil was sieved, the sieves were poured into tins, and the oscillation container was poured into the finer sieves of 0.053- and 0.020-mm diameter then poured into tins. Floating organic matter was removed from the >2 mm fraction. The individual particle fractions were dried at 70 °C for 48 h until constant weight. Aggregate fractions >0.53 mm diameter classes were corrected for sand as described below. Five g of soil combined with a dispersing agent, sodium hexametaphosphate, at a 5-fold volume were left overnight (>12 h), orbital shaken at 325 rpm for 5 h, sieved through a 0.053 mm diameter sieve, and oven-dried for percent sand content. Each aggregate fraction was then corrected to determine the sand-free percent aggregate size fractions. Mean weight diameter (MWD) was calculated by the sum of the aggregate mass retained on each sieve multiplied by the mean aperture of adjacent sieves, expressed in mm. The equation below represents the MWD based on the four soil fractions used:

$$MWD\ (mm) = [(\mathbf{8 - 2\ mm\ WSA} * 5) + (\mathbf{2 - 0.25\ mm\ WSA} * 1.125) + (\mathbf{0.25 - 0.053\ mm\ WSA} * 0.1515) + (\mathbf{0.053 - 0.02\ WSA} * 0.0365)] /100$$

For reference, 8-2 mm WSA was the wet stable aggregate fraction in percent retained after wet sieving for soil aggregates greater than 2 mm diameter and less than 8 mm diameter. The mean aperture of the 8- and 2-mm diameter sieves was 5 mm.

Wet macroaggregate stability (5-minute method)

Wet macroaggregate stability henceforth as 5 min method, based on a modified version of Kemper and Rosenau (1986) by the Agricultural Research Service (ARS) was measured with a similar process as Mikha and Rice (2004) (Fig. 2.1). The MWD of each sample was calculated using modified sieve diameter sizes of 2 mm, 0.25 mm, 0.053 mm, and 0.020 mm (macroaggregates: 8-2 and 2-0.25 mm and microaggregates: 0.25-0.053 and 0.053-0.02). The original method used sieves with a diameter size of 2 mm and 0.25 mm stacked on top largest to smallest inside brackets that would fit in a large container filled with DI water. The remainder of the water was passed through a 0.053 mm diameter sieve after oscillation. Although the sieve size was adjusted for sieve size consistency, the method of no pre-submergence and 5 min oscillation time was kept the same. A modified quantity of 100 g instead of 25 g of air-dried 8-mm sieved soil was used for comparison testing. Sand correction was done as previously described. The top four soil layers were analyzed (0-5, 5-10, 10-15 cm, and 15 cm- to the next layer.

Wet aggregate stability (NRCS)

The air-dried natural fabric samples were crushed and sieved through a 2 mm diameter sieve and then a 1 mm diameter size sieve consecutively (Kellogg Soil Survey Staff, 2014) (Fig. 2.1). Approximately 3 (± 0.05) g of soil between the 2- and 1-mm sieve were distributed evenly on a 0.5 mm diameter sieve and submerged in DI water. The water level was 20 mm above the sieve screen. Samples soaked overnight (>12 h), after which the sieve was hand agitated by

raising and lowering 20 times in 40 secs inside the DI water without letting air enter underneath the sieve. The remaining soil on the 0.5 mm diameter sieve was placed on an aluminum tin and placed in an oven at 110 °C until dry, about 2-2.5 hr, and then weighed. Sand corrections were made as described previously. Aggregate stability was reported as the percent aggregates between 2- and 0.5-mm sieves. The equation below was used to calculate percent aggregates:

$$Aggregate(\%) = ((W_R - S_W)/\left\{\left[\frac{I_W}{\left(\frac{AD}{OD}\right)}\right] - S_W\right\}) * 100$$

For the equation, W_R is the total weight of aggregates retained on a 0.5-mm sieve, S_W is the weight of 2-0.5-mm sand content, I_W is the soil weight used (3 g), and AD/OD is the air-dry soil weight divided by the oven-dry weight of soil. For simplicity, NRCS Wet Aggregate Stability by Kellogg Soil Survey Staff (2014) will be referred to as the NRCS method.

Data analysis

Standard deviation is a poor estimate of dispersion for a small number of observations, so outliers were determined based on a 90% confidence range using Dixon's Q test (Dean and Dixon, 1951). The Q test was determined by the difference between a doubtful observation from its nearest neighbor, divided by the range of values (Dean and Dixon, 1951). Spearman correlation coefficient and coefficient of variation (CV) between methods measured the relationship between methods. Bland-Altman plots measured the difference between 20- and 5-minute methods. The significant differences in Spearman correlation of aggregate stability between procedures, CV, and Bland Altman plots were analyzed using R version 4.0.3 (R core Team 2020).

Spearman correlation and coefficient of variation

The 20- and 5-minutes aggregate stability methods were compared using the Spearman correlation coefficient (r) for samples collected in the top four soil layers from all land use by

location. The 20-minute and NRCS methods were correlated to the 100 cm depth. Correlations were present between the different methods for all samples, samples by location, and samples by location and treatment with α=0.05 significance level and product-moment correlation coefficients (r). Differences were determined at $p<0.001$, $p<0.01$, and $p<0.05$ significance level. The capacity of the three procedures (20-minutes, 5-minutes, and NRCS) to detect aggregate stability differences between sites were investigated using averages and coefficient of variation (CV) by location, land use, and depth since the NRCS method has different units. Lower average CV indicated analytical precision while higher by location CV favored discrimination between sites, methods, and treatments. The coefficient of variation for each sample by depth, land use, and location is determined by:

$$\mathrm{CV}_{i\,LU\,L} = (s_{i\,LU\,L}/\bar{x}_{i\,LU\,L}) \times 100$$

where s is the sample standard deviation and $\bar{x}$ is the average of the aggregate stability at depth i for each land use (LU) and location (L).

Bland-Altman Analysis

Before statistical analysis, assumptions of normality for the 20-and 5- minute MWD were examined with the Shapiro-Wilk test, and data were logarithmically transformed for meeting assumptions of normality (if $p>0.05$ accept normality) (Altman and Bland, 1983; Giavarina, 2015). Differences between the 20- and 5-minute method were used to test the Shapiro-Wilk normality test with natural log or non-standardized data. The A Bland-Altman plot determined the degree of agreement between the 20- and 5-minute method (Altman and Bland, 1983). The data evaluated the mean differences of the two methods to estimate a 95% agreement interval (Altman and Bland, 1983).

Results

Comparison of methods

The 20-minute method (23.26%) had the lowest mean CV compared to the 5-minute method (24.81%) and NRCS (35.89%) (Table 2.3). Comparing all three methods at specific soil depths, the NRCS method had 18 highest CV values compared to 20- and 5-min methods having 9 highest CV values each (Table 2.3). Comparing the 20-minute method and NRCS, the NRCS method had 35 highest CV values vs. the 20-minute method having 15 highest CV values.

Comparing CV values by range and value through soil depths by location and land use, the NRCS method had a higher CV, followed by the 5-min method, and, lastly, the 20-min method. For Manhattan AG, the NRCS method (5-89%) had a greater range and CV compared to 20-min (7-28%) and 5-min (11-26%) methods (Table 2.3). Manhattan NP and EA had variable CV for 20-minute (NP: 21-32%, EA: 6-28%), 5-minute (NP: 10-21%, EA: 6-44%), and NRCS (NP: 9-67%, EA:9-28%) methods. The NRCS method had the highest CV in NP, while the 5-minute method had the highest CV in EA at Manhattan. In Hays AG, the 5-min (24-75%) method had the highest CV, and range compared to 20 min (10-43%) and NRCS (10-43%) methods. Whereas Hays EA and NP had higher CV with the NRCS (EA: 16-104%, NP: 6-43%) method than 20-min (EA: 10-44%, NP: 8-21%) and 5-min (EA: 8-26%, NP: 13-21%) methods. For Tribune AG, NRCS (38-90%) method had higher CV than the 20-min (19-50%) and 5-min (17-42%) methods. For Tribune EA, all three methods had similar ranges, but NRCS (25-76%) method had the highest CV compared to 20-min (11-54%) and 5-min (18-60%). For Tribune NP, NRCS (8-54%) had higher CV than the20-min (12-39%) and 5-min (6-31%).

The correlation between each method pair had significant p-values less than or equal to 0.001 (Table 2.5). The Spearman correlation coefficient between different methods conducted on

air-dry aggregates was higher with 20-min and NRCS ($r=0.8$, $p<0.001$) followed by NRCS and 5 min ($r=76$, $p<0.001$), and, lastly, 20-minute and 5-minute ($r=0.65$, $p<0.001$). The correlation between each of the method pairs was higher in Manhattan and Hays compared to Tribune (Table 2.5).

The correlation between 20-min and 5-min based on macroaggregates 8-2 mm size fraction (Fig. 2.5 and Table 2.6) had a strong positive correlation ($r=0.7$; $p<0.001$). Correlation increased with increasing precipitation (Tribune<Hays<Manhattan: (r) 0.64<0.79<0.88). In contract, correlation between 20-min and 5-min based on macroaggregates 2-0.25 mm size fraction (Fig. 2.6 and Table 2.8) had a weak correlation ($r=0.31$; $p<0.001$).

Comparison of treatments

After separating the locations by land use, correlations of varying land uses had varying statistical significances at $p<0.05$ with varying correlations (Table 2.5, Fig. 2.3, and 2.4). Tribune AG, EA, and NP were not significantly correlated between methods except for EA with the 20-min vs. NRCS method. At Hays, all three methods were correlated except for Hays EA with the 20 vs. 5-min method. Manhattan AG, EA, and NP had statistically significant correlations at AG for 20 vs. 5-min and NRCS vs. 5-min; and for all treatments in 20-min vs. NRCS.

Bland-Altman analysis

Non-standardized differences between 20- and 5-min methods did not meet assumptions of normality based on the Shapiro-Wilk Normality test (Table 2.6). Thus, a natural log of the MWD for both 20-and 5-min methods transformed the data before calculating the difference and performing the Bland-Altman analysis (Table 2.5, 2.6, and Fig. 2.2). The Bland-Altman plot gives the mean bias ± SD between the natural log of 20- and 5 mins MWD levels as -0.27 ± 0.49 with the 95% limits of agreement between -1.23 and 0.69.

Discussion

20-vs 5-minute method:

The 20-and 5-min MWD were strongly correlated ($r=0.65$, $p<0.001$) (Table 2.4). The difference between the methods was the soaking time and oscillation time. The 20-min method allowed for pre-soaking aggregates to field capacity, which increased the stability relative to direct oscillation action since slaking increases during direct oscillation action due to an increased rate of water entry into aggregates and a higher degree of air compression (Almajmaie et al., 2017). Slow wetting air-dry aggregates for 10 min before direct oscillation allowed for water to enter aggregate through capillary flow and reduce swelling (Almajmaie et al., 2017). Soil aggregates subjected to quick oscillation without pre-soaking does not allow for gravitational or capillary flow of water movement through the aggregate, thus creating greater disruption from air compression and swelling (Almajmaie et al., 2017; Jastrow and Miller, 1991). At the cost of reduced time needed, the 5-min method overestimated MWD compared to the 20-min method. Both methods had 9 highest CV values out of 36 soil averages by location, land use, and depth.

Correlation of 20-and 5-min macroaggregate 8-2 mm size fraction (Fig. 2.5 and Table 2.6) followed similar trends in correlation as MWD with higher correlations with precipitation. In contrast, the 20-and 5-min macroaggregate 2-0.25 mm size fraction correlation (Fig. 2.6 and Table 2.7) was weak. As 20-min method increased with 2-0.25 mm fraction, 5-min method stayed relatively the same, and the linear regression line only increased slightly in Manhattan and Hays, while Tribune regression line was flat. This indicates aggregate fractions for the 5-min method may be misleading and not accurately estimate macroaggregates <2 mm.

20-minute method and NRCS

The 20-min and NRCS methods were strongly correlated ($r=0.80$, $p<0.001$) (Table 2.4). Of the 59 soil layers from each location and land use, the NRCS method had the highest CV in 35 of the soil layers compared to 20-minute and 5-minutes having only 15 and 9, respectively. The higher CV and greater quantity of high CV in the NRCS method makes for more variability present in the same soils completed with the 20-min method. The Yoder-type multiple-sieve machine used by the 20-and 5-min method is commercially available for purchase but has a higher upfront cost and learning curve (Table 2.7 and 2.8), while only sieves need to be purchased for the NRCS method. The NRCS method conducts wet-sieving analysis by hand, thus is lower costs. However, the drawback was hand sieving can have variable stroke lengths and speeds from person to person performing the protocol (Jastrow and Miller, 1991; Kellogg Soil Survey Staff, 2014). For this study all wet sieving was done by one person to minimize variation in stroke length and oscillation speed. A timer was set, and close attention was paid to the stoke height of the sieve. Only relying on one individual for all NRCS aggregate analysis may not be practical for large quantities of soil samples but is acceptable for modest amounts of samples. The high variability of the NRCS method may be due to greater physical manipulation during the sample preparation. The NRCS method only gives one value, but the 5-min and 20-min methods provide more information on the aggregate size distribution (Fig. 2.5 and 2.6).

NRCS and 5-minute method

The NRCS and 5-min methods were significantly correlated ($r=0.76$; $p<0.001$) (Table 2.4). The NRCS method required soaking overnight (>12 hr) prior to hand sieving, which is different from the 5-min method of exposing aggregates to sudden immersion. This is important for allowing aggregate to equilibrate to field capacity for standardization and avoid unwanted

compression and expansion of entrapped air (Almajmaie et al., 2017; Nimmo and Perkins, 2002). Lower soil depths increase the effect of water immersion on soil immersion, which contributes to disaggregated soil particles from clay swelling, air entrapment, and dispersion (Almajmaie et al., 2017). Sudden immersion wet-sieving methods are likely better for soils that undergo sudden intense rainfall events, flooding, or irrigation since aggregates at these locations are already exposed to such forces (Almajmaie et al., 2017).

Comparison of methods

All methods were positively correlated with each other with similar trends in aggregate stability. The 20-min standard method allows for pre-soaking and slow-wetting. At the same time, 5-min takes less time and NRCS requires lower costs and fewer materials. Differences in correlation may be due to the type and level of disruptive energy the air-dry aggregates (Almajmaie et al., 2017).

The average CV (Table 2.3) for the 20-min method was 23% and 24% for the 5-min method, while the NRCS method was 36%. In addition, the slopes of correlation between methods vary by soil type and land use at different locations (Fig. 2.3 and 2.4).

The 20-and 5-min methods determine wet-aggregate size distribution (%) and mean weight diameter (mm), while the NRCS method only determines % aggregates in the 2-0.5 mm category (Fig. 2.5 and 2.6). Greater sources of error are also introduced with increasing procedural requirements, such as pre-sieving moist aggregates for air-drying, separating the aggregate size fractions, and hand oscillations. Overall, it is best to consider the final expression of aggregate stability, the repeatability of the method, and the type of soil completed on, while costs, materials, and time limitations should be deliberated for practicality. Almajmaie et al. (2017) compared aggregate stability using rainfall simulation, wet sieving, clay dispersion, and

ultrasonic vibration. The study found no single method was suitable for all soils and no levels of disruptive energy can adequately simulate field conditions (Almajmaie et al., 2017).

Bland-Altman analysis

Adequate methods for interchangeability that measure the same variable should have good correlations with samples covering a wide range of properties (Giavarina, 2015; Earthman, 2015). For most method comparisons, p-values were generally significant, and correlations can be used to describe linear relationships between two methods (Table 2.4). However, the agreement between the two methods was not verified (Giavarina, 2015). Unfortunately, strong correlations do not always imply that a laboratory method can be replaced with another one. Correlation analysis links the relationship between variables without answering whether the relationship is meaningful or incidental and if there is any probability of error in the results (Doğan, 2018). Overall, highly correlated data with significant p-values could have a poor agreement, so using correlation is not a recommended method for study method comparability (Doğan, 2018; Giavarina, 2015; Earthman, 2015). Additionally, the correlation graphs between the methods have different slopes at each location which means varying levels of disaggregation resulted from different soil types. Bland-Altman analysis has been used for method comparisons to compare two measurement methods or one measurement method against a reference standard based on continuous variables (Giavarina, 2015).

The Bland-Altman analysis tested the comparability of 20-min to 5-min methods (Table 2.6). The mean difference between the two methods was -0.27 with agreement limits between -1.23 and 0.69, which means that the MWD from the 20-min method was 0.69 units below or 1.23 units above the 5-min method. The Bland-Altman plot quantifies the mean difference and range of agreement within 95% of the differences. Overall, the 20- and 5-min methods agree

with random relative error since the plot shows no proportional bias trends. The 5-min method may overestimate MWD compared to the 20-minute method based on the Bland-Altman plot, but the advantage of the 5-min method would be more time saved.

Conclusions

In specifying the differences in soil aggregate stability methods, three methods used had differences in the condition of wet aggregate stability testing, the disruptive force or energy applied, and the size distribution of aggregates measured. Based on Spearman correlation, CV, and Bland-Altman plots, although the 20-min method is more costly, time-consuming, and labor-intensive, it is more sensitive to land management systems and less variable compared with NRCS. The 5-minute method is similar in costs and labor but may take less time than the 20-minute method. The NRCS method is less costly and labor-intensive but takes much longer to complete. The aggregate size distribution method by Mikha and Rice (2004) is a modified version of Kemper and Rosenau (1986) that was recommended as the primary standardized laboratory-based wet sieving aggregate stability method performed for testing based on this study. However, there were strong correlations and similar trends in aggregate stability by each of the methods. The overestimation from the 5-minutes method and loss in sensitivity from the NRCS method may be used for a general understanding of soil physical stability and structure under time or cost constraints. Overall, we need to understand how soil management influences aggregation to make suitable modifications to farming practices to enhance soil structural stability.

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Tables

Table 2.1. Field IDs, latitude, longitude, field conditions during sampling, sample date, 30 years mean annual precipitation, sampling method, and soil type. MAP: mean annual precipitation; MAT: mean annual temperature.

Field IDs	Latitude	Longitude	Field condition	Sample date	MAP	MAT	Sampling Method	Soil Type
Manhattan AG	39°06'13.6"N	96°36'26.1"W	Soybean	13-Sep-19	850	12.7	Giddings	Reading silt loam
Manhattan EA	39°25'33.5"N	96°46'03.9"W	Post-corn harvest	21-Oct-21	850	12.7	Giddings	Tully silt clay loam
Manhattan NP	39°06'17.9"N	96°36'38.3"W	Mesic tallgrass prairie	13-Sep-19	850	12.7	Giddings	Reading silt loam
Hays AG	38º50’34.1 N	99º18’52.9 W	Post-sorghum harvest	15-Oct-21	579	12.1	Giddings	Harney soil loam
Hays EA	38°46'16.3 N	99°15'07.5 W	Post-sorghum harvest	20-Sep-19	579	12.1	Giddings	Harney soil loam
Hays NP	38°50'09.2"N	99°18'24.0"W	Mixed grass prairie	20-Sep-19	579	12.1	Giddings	Harney soil loam
Tribune AG	38°28'10.1"N	101°46'53.4"W	Wheat-grain, sorghum-fallow	20-Aug-19	472	11.1	Giddings	Richfield silt loam
Tribune EA	38°28'10.1"N	101°46'53.4"W	Fallow	20-Aug-19	472	11.1	Giddings	Richfield silt loam
Tribune NP	38°28'10.1"N	101°46'53.4"W	Native sod prairie	20-Aug-19	472	11.1	Giddings	Richfield silt loam
Tribune IR	38°34'47.1"N	101°44'48.0"W	Post-sorghum harvest	4-Nov-19	472	11.1	Pit	Richfield silt loam

Table 2.2. Field management history of selected fields across Kansas. Corn (*Zea mays*), Soybean (*Glycine max*), Wheat (*Triticum aestivum*), Grain Sorghum (*Sorghum bicolor*). Cover crop mix varies with Triticale (*Triticale hexaploide* Lart.), oats (*Avena sativa*), alfalfa (*Medicago sativa*)

Field	Distance between Pedons (m)	Year 2000	Year 2010	Year 2020
Hays AG	40	Wheat-sorghum-fallow rotation, tillage	Wheat-sorghum-fallow rotation, tillage	Wheat-sorghum-fallow rotation, tillage
Hays EA	40	Wheat-sorghum-cover crop mix rotation, no-till	Wheat-sorghum-cover crop mix rotation, no-till	Wheat-sorghum-cover crop mix rotation, no-till
Hays NP	20	Mixed-grass prairie	Mixed-grass prairie	Mixed-grass prairie
Manhattan AG	20	Soybean-wheat-grain sorghum rotation, tillage	Soybean-wheat-grain sorghum rotation, tillage	Soybean-wheat-grain sorghum rotation, tillage
Manhattan EA	30	Corn-soybean rotation, no-till	Corn-soybean rotation, no-till	Corn-soybean rotation, no-till
Manhattan NP	20	Tallgrass prairie	Tallgrass prairie	Tallgrass prairie

Table 2.3. Coefficient of variation for wet-sieving aggregate stability methods by location, treatment, and depth with average CV for each method. Bolded CV values are the higher CV of the three methods at each depth by location and land use. L: location; LU: land use; AG: conventional tillage; EA; enhanced agriculture; NP: native prairie; 20 min MWD: average (n=4) mean weight diameter (mm) for Mikha and Rice (2004); 5 min MWD: average (n=4) mean weight diameter (mm) for Kemper and Rosenau (1986); NRCS: percent (n=4) aggregate between 2 mm to 0.25 mm size fraction for Soil Survey Staff (2014); CV: coefficient of variation (%); Std Dev: standard deviation. Higher CV is bolded for comparison.

L	LU	Depth (cm)	Clay %	20 min MWD mm (Std Dev)	CV %	5 min MWD mm (Std Dev)	CV %	NRCS % (Std Dev)	CV %
Manhattan	AG	0-5	33.1	0.39 (0.11)	28.2	0.51 (0.08)	15.7	1.96 (1.75)	**89.3**
		5-10	33.1	0.46 (0.12)	26.1	0.74 (0.14)	18.9	4.82 (2.36)	**49.0**
		10-15	33.1	0.55 (0.13)	23.6	0.85 (0.22)	25.9	9.89 (6.99)	**70.7**
		15-25	34.9	1.06 (0.12)	11.3	1.2 (0.13)	10.8	37.6 (9.93)	**26.4**
		25-45	49.3	1.04 (0.16)	**15.4**			50.6 (2.65)	5.24
		45-70	49.3	1.09 (0.08)	**7.34**			48.4 (2.97)	6.13
		70-100	48.3	0.89 (0.08)	8.99			42.2 (6.2)	**14.7**
	EA	0-5	24.00	0.93 (0.19)	**20.4**	1.11 (0.08)	7.21	45.9 (4.35)	9.47
		5-10	24.00	0.84 (0.24)	**28.6**	1.39 (0.33)	23.7	32.1 (6.11)	19.0
		10-15	24.00	0.59 (0.12)	20.3	1.21 (0.53)	**43.8**	20.9 (5.5)	26.4
		15-25	28.00	0.57 (0.05)	8.77	0.87 (0.06)	6.90	13.3 (1.96)	**14.8**
		25-50	31.00	0.59 (0.04)	6.78			28.2 (2.55)	**9.06**
		50-75	37.00	0.75 (0.16)	21.3			29.4 (6.56)	**22.3**
		75-100	40.00	1.09 (0.2)	18.4			45.6 (12.8)	**28.1**
	NP	0-5	28.2	1.71 (0.55)	**32.2**	1.78 (0.38)	21.4	71.1 (9.45)	13.3
		5-10	28.2	1.41 (0.29)	**20.6**	1.9 (0.38)	20.0	61.8 (7.09)	11.5
		10-15	28.2	1.72 (0.38)	**22.1**	1.78 (0.2)	11.2	54.9 (9.87)	18.0
		15-30	32.3	1.93 (0.52)	**26.9**	2.39 (0.23)	9.62	64.5 (10.4)	16.2
		30-60	53.3	1.52 (0.36)	**23.7**			60.2 (5.45)	9.05
		60-85	49.6	1.07 (0.24)	22.4			40.8 (27.5)	**67.3**
		85-100	46	0.44 (0.13)	29.6			7.07 (2.34)	**33.1**

Table 2.1. Continued.

L	LU	Depth (cm)	Clay %	20 min MWD mm (Std Dev)	CV %	5 min MWD mm (Std Dev)	CV %	NRCS % (Std Dev)	CV %
Hays	AG	0-5	36.1	0.29 (0.07)	24.1	0.46 (0.11)	23.9	8.4 (2.54)	**30.2**
		5-10	36.1	0.3 (0.1)	33.3	0.44 (0.17)	**38.6**	6.4 (1.88)	29.4
		10-15	36.1	0.54 (0.23)	42.6	0.99 (0.74)	**74**.8	17.4 (10.79)	61.9
		15-45	43	0.67 (0.07)	10.5	1.62 (0.81)	**50.0**	33.7 (6.2)	18.4
		45-65	39.2	0.63 (0.1)	**15.9**			19.0 (1.99)	10.5
		65-75	35	0.37 (0.13)	35.1			10.5 (4.97)	**47.3**
		75-100	39.3	0.2 (0.03)	15.0			4.16 (1.53)	**36.8**
	EA	0-5	24.00	0.79 (0.08)	10.1	1.64 (0.14)	8.54	33.7 (5.48)	**16.3**
		5-10	24.00	0.62 (0.18)	29.0	1.04 (0.27)	26.0	7.6 (4.49)	**59.1**
		10-15	33.00	0.43 (0.08)	18.6	0.95 (0.08)	8.4	7.01 (5.78)	**82.5**
		15-45	39.00	0.53 (0.15)	28.3	1.06 (0.14)	13.2	21.9 (10.8)	**49.3**
		45-65	25.00	0.59 (0.17)	28.8			15.6 (12.7)	**81.3**
		65-75	25.00	0.41 (0.18)	43.9			5.77 (3.53)	**61.2**
		75-100	25.00	0.3 (0.06)	20.0			2.55 (2.67)	**105**
	NP	0-5	28.8	1.89 (0.39)	**20.6**	2.59 (0.33)	12.7	79.3 (5.15)	6.49
		5-10	28.8	1.7 (0.23)	13.5	2.85 (0.53)	**18.6**	67.1 (4.49)	6.70
		10-15	28.8	1.51 (0.26)	17.2	2.42 (0.42)	**17.4**	51.5 (8.31)	16.1
		15-40	28.8	0.87 (0.07)	8.05	1.6 (0.33)	**20.6**	26.4 (3.25)	12.3
		40-60	42.7	0.77 (0.15)	**19.5**			28.6 (4.36)	15.3
		60-100	38.8	0.58 (0.11)	19.0			18.0 (7.73)	**42.9**

Table 2.1. Continued.

L	LU	Depth (cm)	Clay %	20 min MWD mm (Std Dev)	CV %	5 min MWD mm (Std Dev)	CV %	NRCS % (Std Dev)	CV %
Tribune	AG	0-5	22.00	0.68 (0.34)	**50.0**	0.5 (0.21)	42.0	8.55 (3.29)	38.5
		5-10	22.00	0.77 (0.15)	19.5	0.6 (0.1)	16.7	5.72 (2.92)	**51.1**
		10-15	25.00	0.74 (0.19)	25.7	0.61 (0.34)	**55.7**	4.16 (2)	48.1
		15-40	32.00	0.38 (0.1)	26.3	0.82 (0.3)	36.6	16.0 (14.4)	**90.5**
		40-75	34.00	0.44 (0.1)	22.7			12.5 (5.19)	**41.6**
		75-100	32.00	0.27 (0.08)	29.6			3.68 (1.25)	**34.0**
	EA	0-5	22.00	0.7 (0.08)	11.4	0.87 (0.34)	39.1	18.1 (13.7)	**75.7**
		5-10	22.00	0.39 (0.09)	23.1	0.45 (0.11)	24.4	3.69 (2.03)	**55.0**
		10-15	25.00	0.41 (0.11)	26.8	0.74 (0.13)	17.6	4.31 (1.75)	**40.6**
		15-40	32.00	0.52 (0.22)	42.3	0.82 (0.49)	**59**.8	11 (3.03)	27.6
		40-75	34.00	0.54 (0.29)	**53.7**			6.87 (1.75)	25.5
		75-100	32.00	0.24 (0.04)	16.7			2.22 (0.59)	**26.6**
	NP	0-5	22.00	1.64 (0.64)	**39.0**	0.77 (0.09)	11.7	64.0 (5.33)	8.33
		5-10	22.00	1.41 (0.38)	27.0	0.82 (0.05)	6.1	35.8 (12.13)	**33.9**
		10-15	25.00	1.7 (0.27)	15.9	0.97 (0.3)	30.9	20.0 (10.77)	**53.9**
		15-40	32.00	1.7 (0.21)	12.4	1.45 (0.36)	24.8	43.5 (14.2)	**32.7**
		40-75	34.00	1.25 (0.32)	25.6			27.3 (13.1)	**48.0**
		75-100	32.00	1.08 (0.31)	28.7			9.5 (3.69)	**38.8**
				Mean CV (%)	23.3		24.8		35.9

Table 2.4. Average coefficient of variation of each depth by location and land use for 20- and 5-minute wet-sieving aggregate stability methods. Bolded CV values are the higher CV of the two methods at each depth by location and land use. 20 min: average (n=4) fraction for Mikha and Rice (2004); 5 min: average (n=4) fraction for Kemper and Rosenau (1986); NRCS: percent (n=4) aggregate between 2 mm to 0.25 mm size fraction for Soil Survey Staff (2014); CV: coefficient of variation (%); Std Dev: standard deviation. Higher CV is bolded for comparison.

Aggregate size fractions	20 min 8-2 mm	5 min 8-2 mm	20 min 2-0.25 mm	5 min 2-0.25 mm	20 min 0.25-0.053 mm	5 min 0.25-0.053 mm	20 min 0.053-0.02 mm	5 min 0.053-0.02 mm
				%				
Mean CV	44.77	42.08	24.94	25.87	22.12	27.22	37.62	30.77

Table 2.5. Spearman correlation coefficients (r) and p-values for wet-sieving aggregate stability methods, by location, and by treatment within location.

Spearman Correlation													
Methods	20 vs 5 minutes												
Location		Tribune				Hays				Manhattan			
Treatment			AG	EA	NP		AG	EA	NP		AG	EA	NP
R	**0.65**	**0.46**	0.041	0.44	0.12	**0.87**	**0.74**	0.49	**0.7**	**0.81**	**0.6**	0.44	0.46
p-value	**<0.001**	**0.001**	0.88	0.09	0.66	**<0.001**	**0.002**	0.057	**0.004**	**<0.001**	**0.032**	0.087	0.074
Methods	20 minutes vs NRCS												
Location		Tribune				Hays				Manhattan			
Treatment			AG	EA	NP		AG	EA	NP		AG	EA	NP
R	**0.8**	**0.68**	0.18	**0.64**	0.35	**0.86**	**0.7**	**0.75**	**0.86**	**0.92**	**0.9**	**0.8**	**0.62**
p-value	**<0.001**	**<0.001**	0.391	**<0.001**	0.098	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Methods	NRCS vs 5 minutes												
Location		Tribune				Hays				Manhattan			
Treatment			AG	EA	NP		AG	EA	NP		AG	EA	NP
R	**0.76**	**0.54**	0.29	0.38	-0.21	**0.87**	**0.84**	**0.73**	**0.6**	**0.85**	**0.8**	0.41	0.38
p-value	**<0.001**	**<0.001**	0.278	0.145	0.436	**<0.001**	**<0.001**	**0.002**	**0.015**	**<0.001**	**0.002**	0.114	0.145

Table 2.6. Spearman correlation coefficients (r) and p-values for 20-minute and 5-minute methods, by location, and by treatment within location for 8-2 mm percent size fraction.

8-2 mm Spearman Correlation													
Methods	20 vs 5 minutes												
Location		Tribune				Hays				Manhattan			
Treatment			AG	EA	NP		AG	EA	NP		AG	EA	NP
R	**0.7**	**0.64**	0.35	**0.62**	0.28	**0.79**	**0.49**	**0.63**	**0.59**	**0.88**	**0.82**	**0.56**	0.43
p-value	**<0.001**	**<0.001**	0.188	**0.012**	0.288	**<0.001**	**0.056**	**0.014**	**0.018**	**<0.001**	**<0.001**	**0.027**	0.43

Table 2.7. Spearman correlation coefficients (r) and p-values for 20-minute and 5-minute methods, by location, and by treatment within location for 2-0.25 mm percent size fraction.

2-0.25 mm Spearman Correlation													
Methods	20 vs 5 minutes												
Location		Tribune				Hays				Manhattan			
Treatment			AG	EA	NP		AG	EA	NP		AG	EA	NP
R	**0.31**	0.1	0.035	-0.044	0.31	**0.25**	**0.47**	**0.49**	-0.26	**0.4**	**0.55**	0.062	0.082
p-value	**<0.001**	0.48	0.9	0.874	0.249	**0.092**	**0.068**	**0.067**	0.332	**0.006**	**0.067**	0.822	0.763

Table 2.8. Test of normality based on Shapiro-Wilk normality test on the 20-and 5-minute method between non-standardized and natural log normalization. If the p-value is less than $\alpha = 0.05$, then the null hypothesis is rejected and there is evidence that the data tested are not normally distributed. Alternatively, if the p-value is greater than $\alpha = 0.05$, then the data is from a normally distributed population. Differences between the 20-and 5-minute method were used in the Shapiro-Wilk normality test with natural log or non-standardized data.

Test of Normality of Differences Assumption			
Difference	Shapiro-Wilk	Prob level	Decision ($\alpha = 0.05$)
Natural log	0.98	0.10	Accept normality
Non-standardized	0.96892	0.002678	Reject normality

Table 2.9. Bland-Altman statistics on the bias (mean) and limits of agreement for natural log mean weight diameter for 20-and 5-minute methods.

Bland-Altman Analysis: Bias and Limits of Agreement for 20- and 5-Minute method natural log mean weight diameter					
Parameter	Count	Value	Std Deviation	Lower LOA-95% LCL	Upper LOA-95% UCL
Bias (Difference)	141	-0.27	0.49	-1.23	0.69

LOA: limits of agreement; LCL: lower confidence level; upper confidence level.

Table 2.10. Comparison of commercially available wet sieving Yoder machines for aggregate stability

Comparison of Commercial Wet Sieving Yoder Machines				
Brand	Product name	Model	Price	URL
MGM	MG Scientific Wet Sieve Shaker (Yoder Type)	MS911	$827.40	https://www.amazon.com/Scientific-Sieve-Shaker-Yoder-Perfect/dp/B01FW6MQGM
Yatherm Scientific	Wet Sieve Shaker Yoder	Yoder – 8Y	$1,250	https://yatherm.com/testing-equipments/wet-sieve-shaker-yoder/
Bionics Scientific	Wet Sieve Shaker Yoder Type	BST-WSY80	Quote required	http://www.bionicsscientific.com/sieve-shakers/wet-sieve-shaker-yoder-type.html
Macro Scientific	Wet Sieve Shaker (Yoder Type)	MSW-324	Quote required	https://www.macroscientificworks.com/product/wet-sieve-shaker-yoder-type-mac-msw-324#
K.S. Jandu & Sons	Wet Sieve Shaker	KSJ	$750	https://www.ksjandusons.com/sieve-shaker.html#wet-sieve-shaker
Zeal International	Wet Sieve Shaker (Yoder Type)	3083	$900	http://www.zealinternational.com/materialtesting/soil/sieve-shaker/wet-sieve-shaker

Table 2.11. Cost of commercially available Wet Aggregate Stability sieves based on Soil Survey Staff (2014) specifications.

Sieves for NRCS Method (Soil Survey Staff (2014))					
Brand	Product name	Model	Opening Size	Price	URL
Gilson	6" Sieve, All Stainless, Full Height, No. 10	V6SF #10	2 mm	$126.50	https://www.globalgilson.com/6-inch-sieve-all-stainless-full-height-number-10
Gilson	6" Sieve, All Stainless, Full Height, No. 18	V6SF #18	1 mm	$126.50	https://www.globalgilson.com/6-inch-sieve-all-stainless-full-height-number-18
Gilson	6" Sieve, All Stainless, Full Height, No. 35	V6SF #35	0.5 mm	$126.50	https://www.globalgilson.com/6-inch-sieve-all-stainless-full-height-number-35

Figures

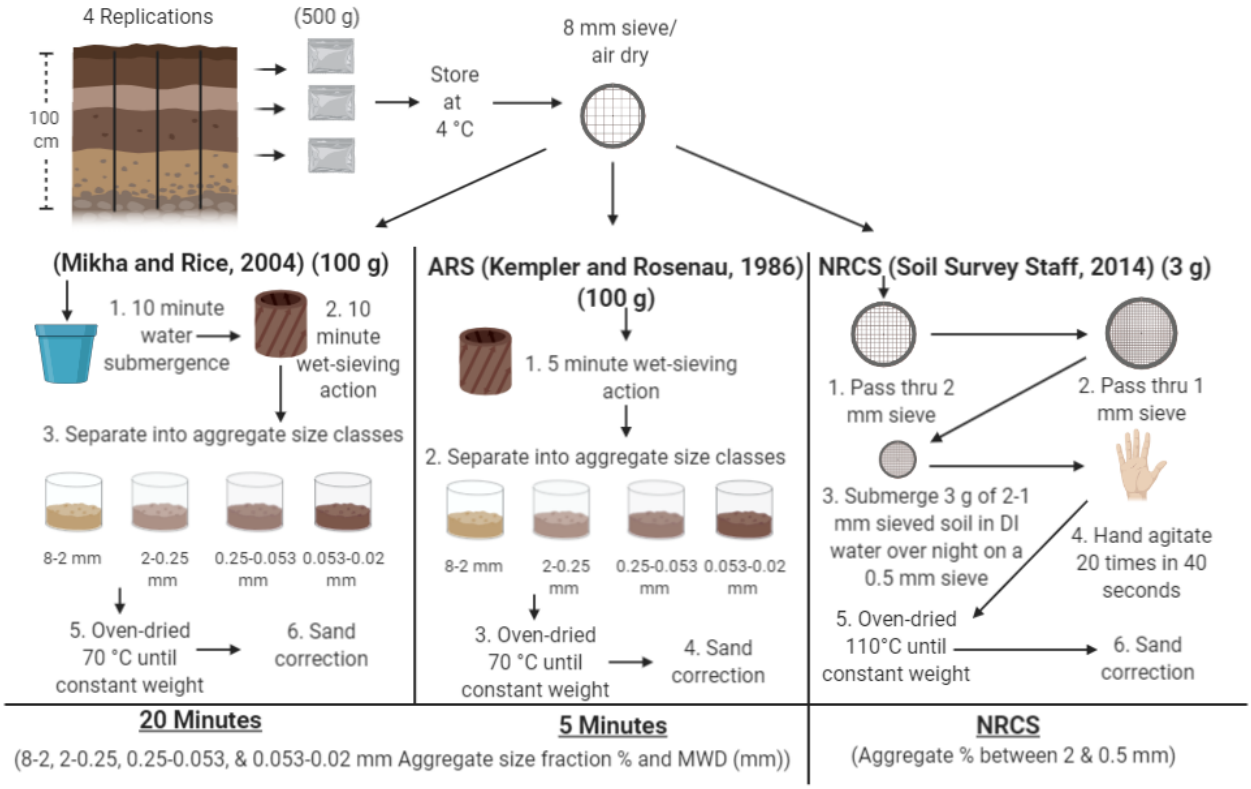

Figure 2.1. Simplified soil aggregate stability and size class methods for comparison. MWD: mean weight diameter (mm); ARS: Agricultural Research Service; NRCS: Natural Resources Conservation Service.

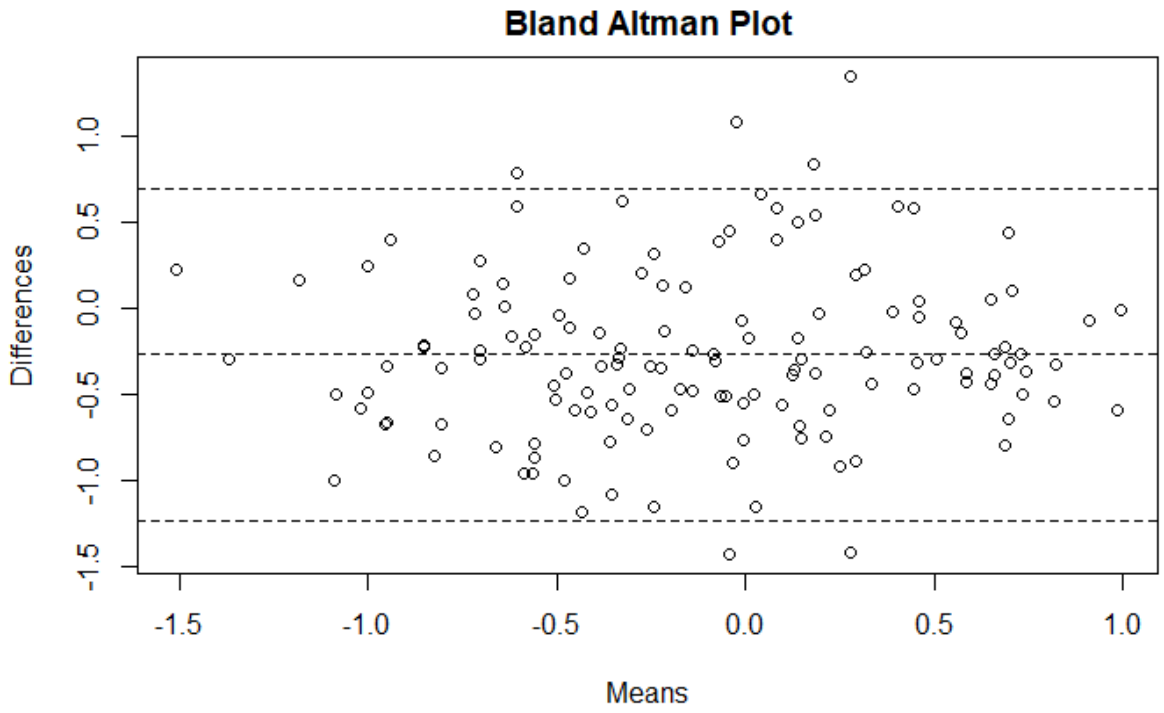

Figure 2.2. Bland-Altman plot of differences and mean differences of the 20-and 5-minute method. The agreement between the natural log of 20-minute mean weight diameter and natural log 5-minute mean weight diameter indicates a 95% confidence interval for measured differences.

Differences: logarithmic 20-min MWD – logarithmic 5-min MWD; Means: (logarithmic 20-min MWD – logarithmic 5-min MWD)/2.

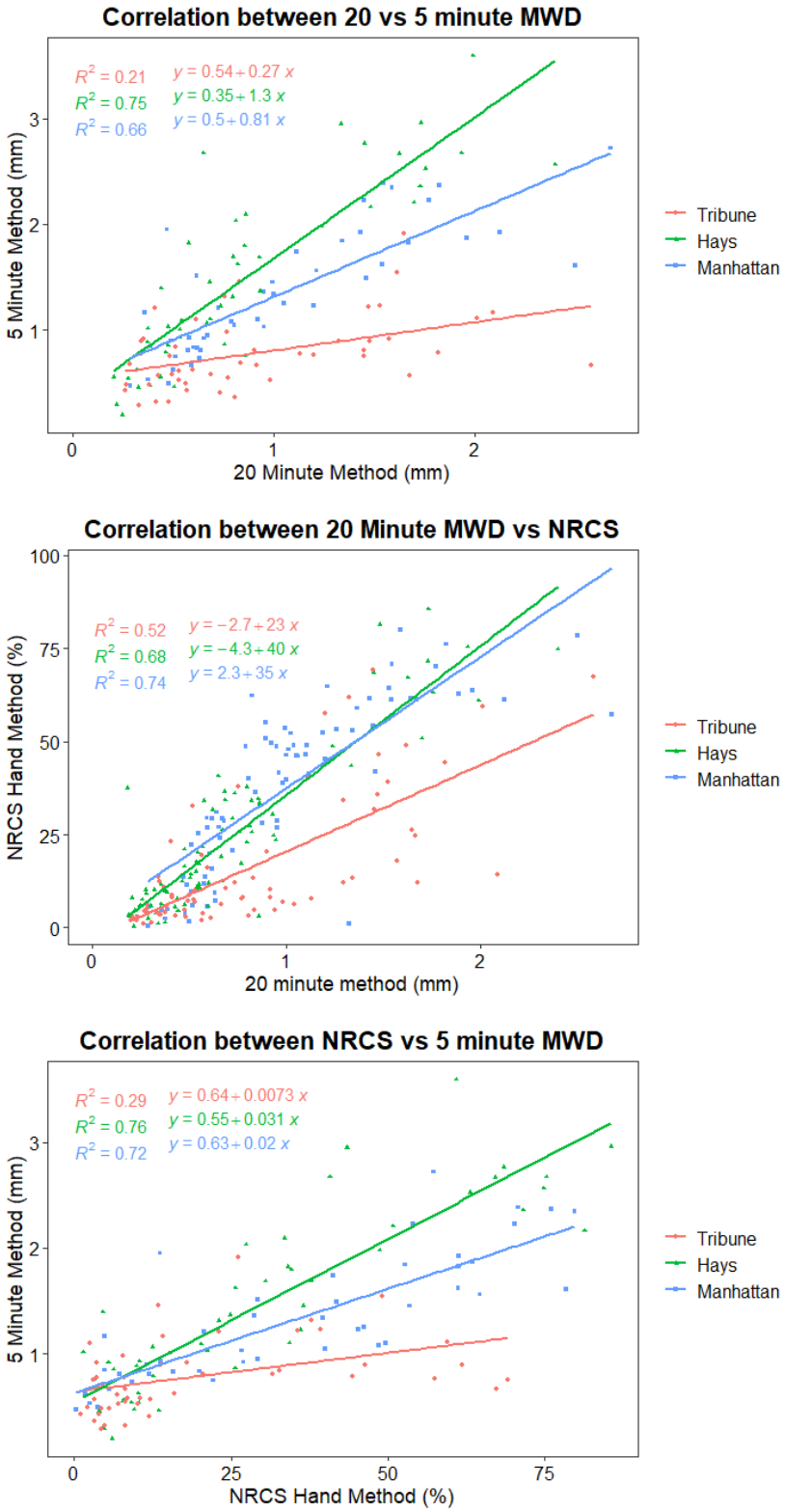

Figure 2.3. Scatterplot for wet-sieving aggregate stability methods by locations. Coefficient of determination (r^2) and linear regression fitted by location.

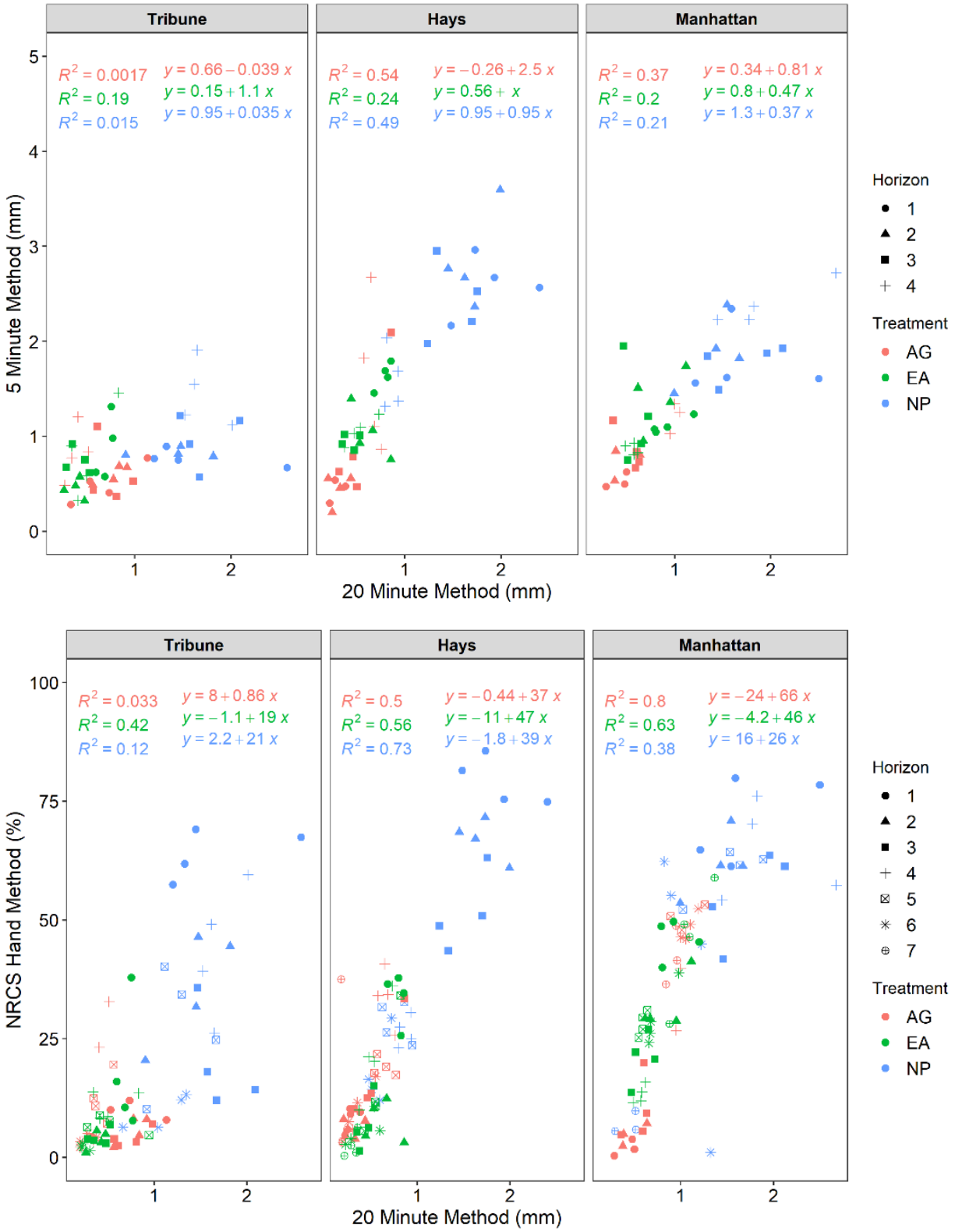

Figure 2.4. Scatterplot for wet-sieving aggregate stability methods faceted by location with treatment and horizons for soil samples.

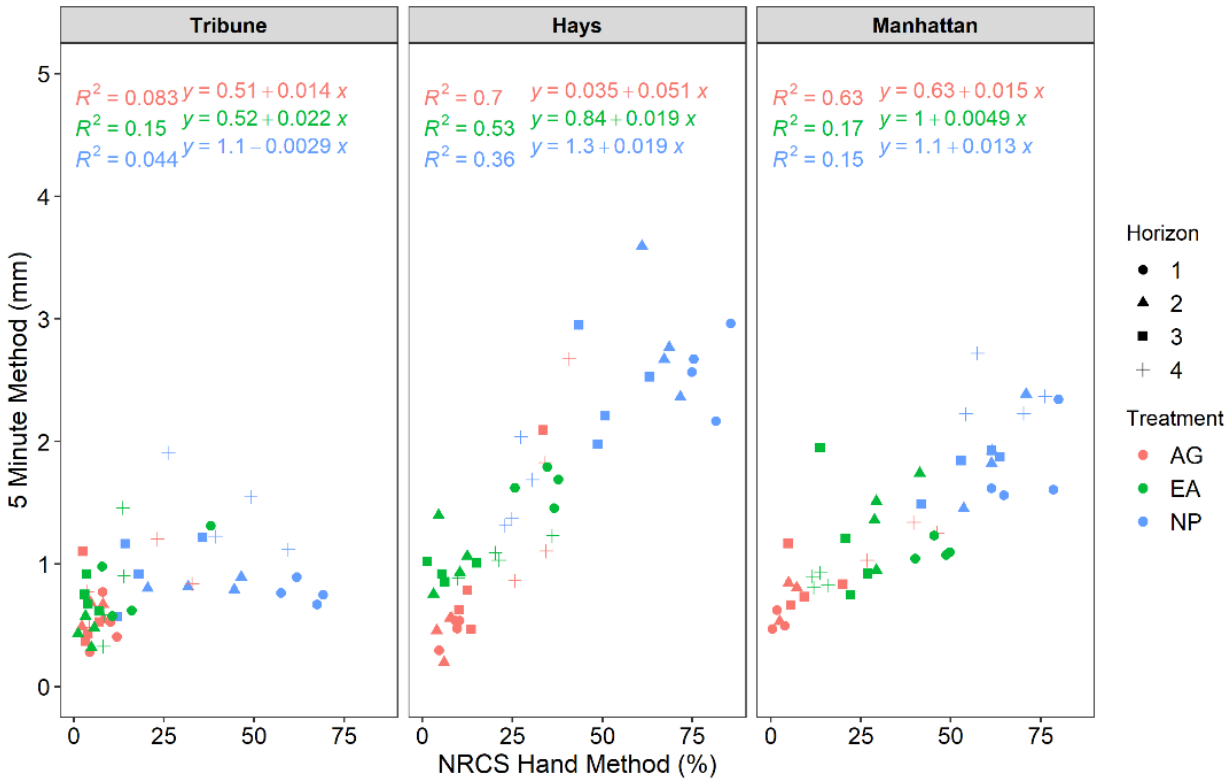

Figure 2.4. Continued

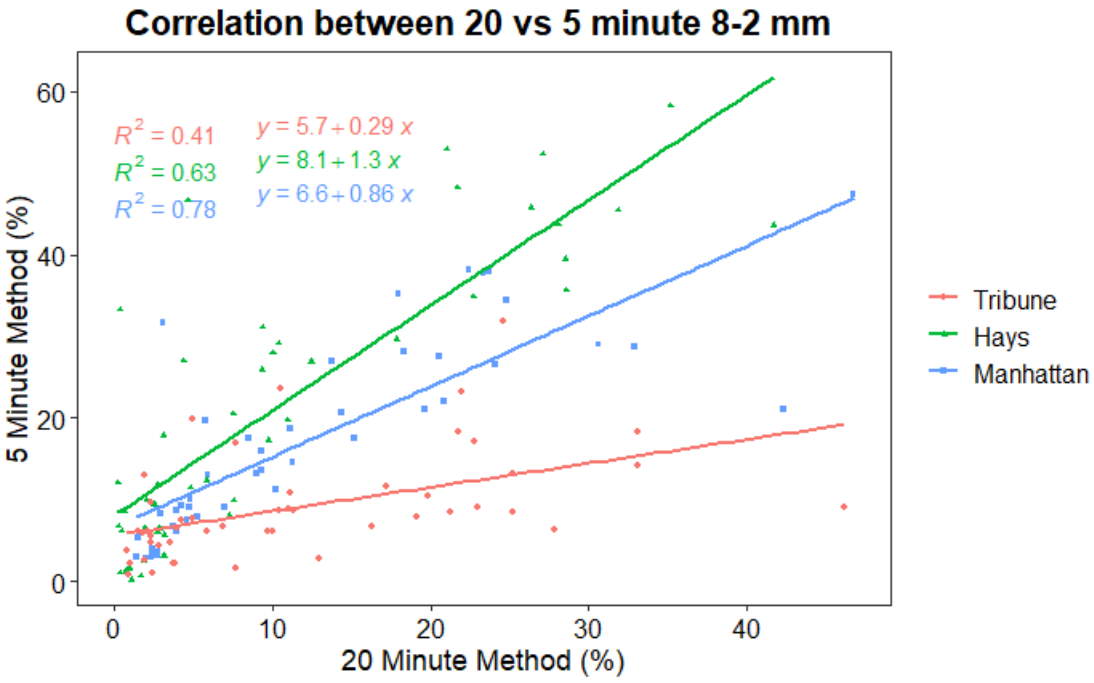

Figure 2.5. Scatterplot for wet-sieving aggregate stability methods by locations for macroaggregate 8-2 mm size fraction. Coefficient of determination (r^2) and linear regression fitted by location.

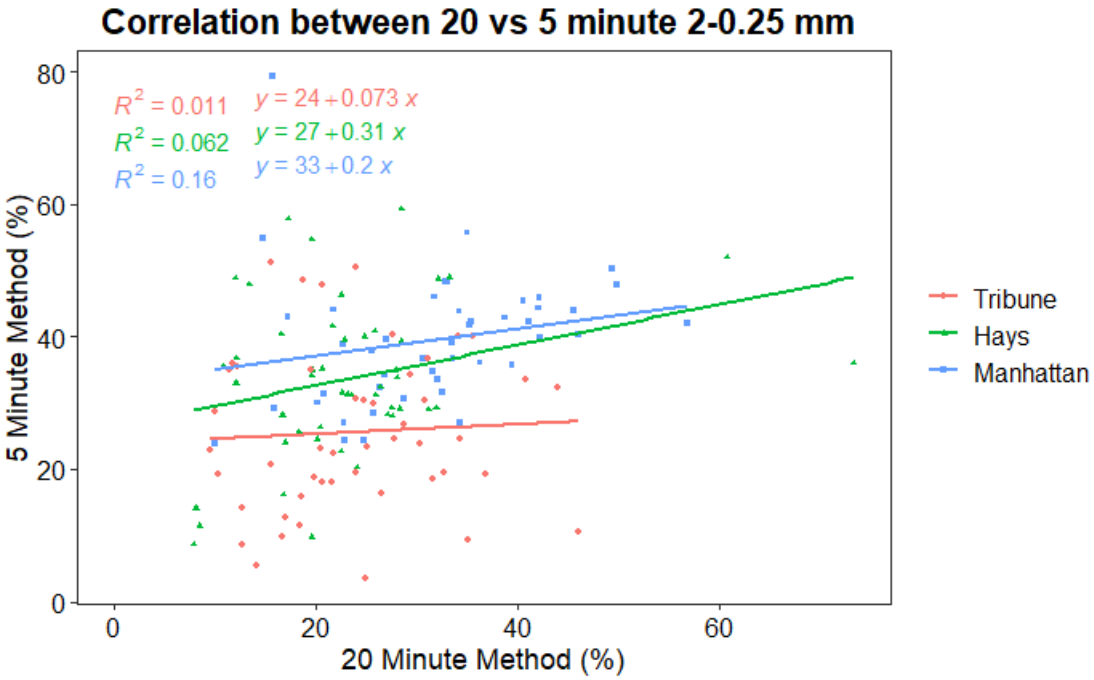

Figure 2.6. Scatterplot for wet-sieving aggregate stability methods by locations for macroaggregate 2-0.25 mm size fraction. Coefficient of determination (r^2) and linear regression fitted by location.

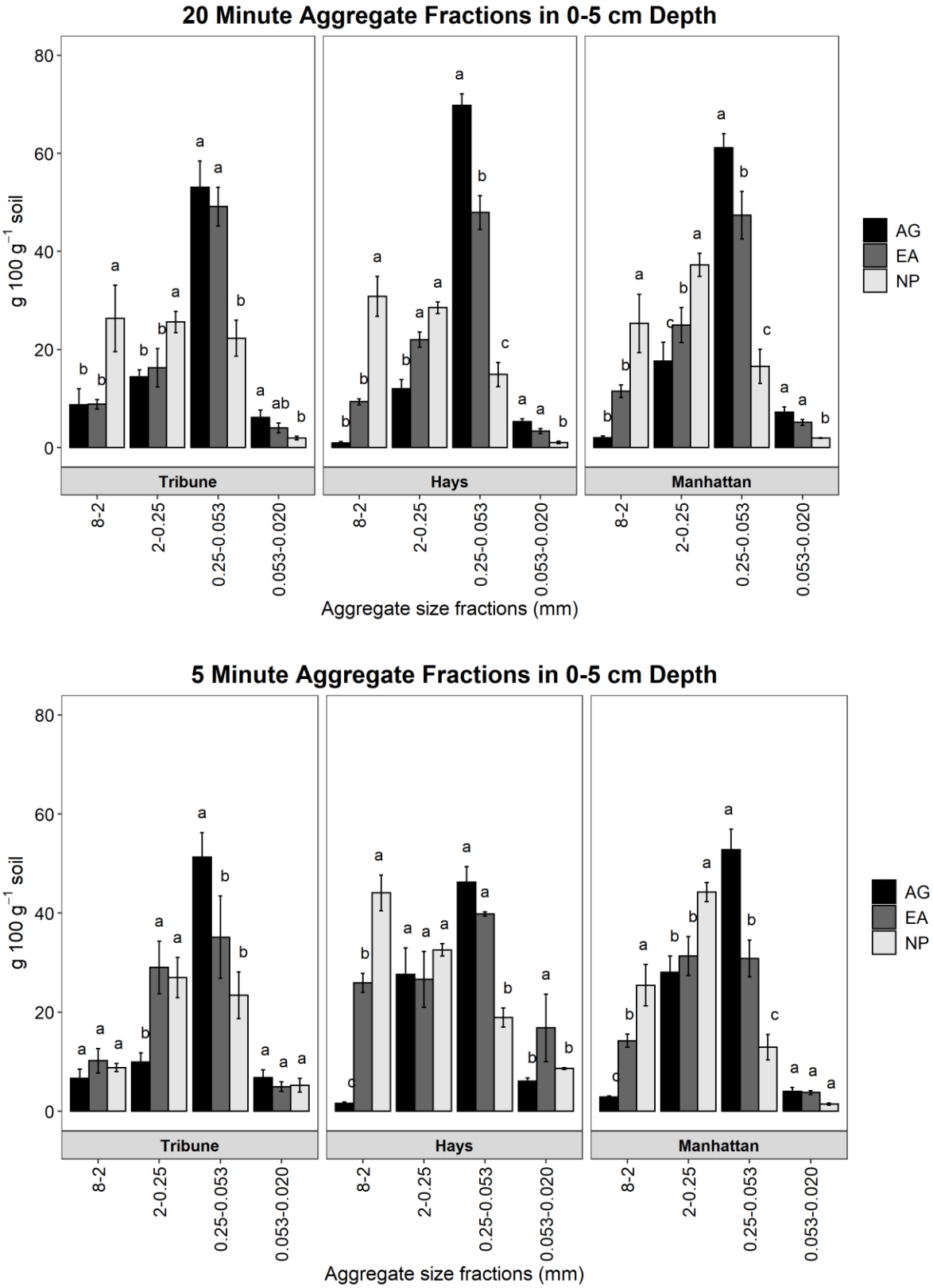

Figure 2.7. Aggregate results for each method showing the level of detail and results between 20- and 5-minutes.

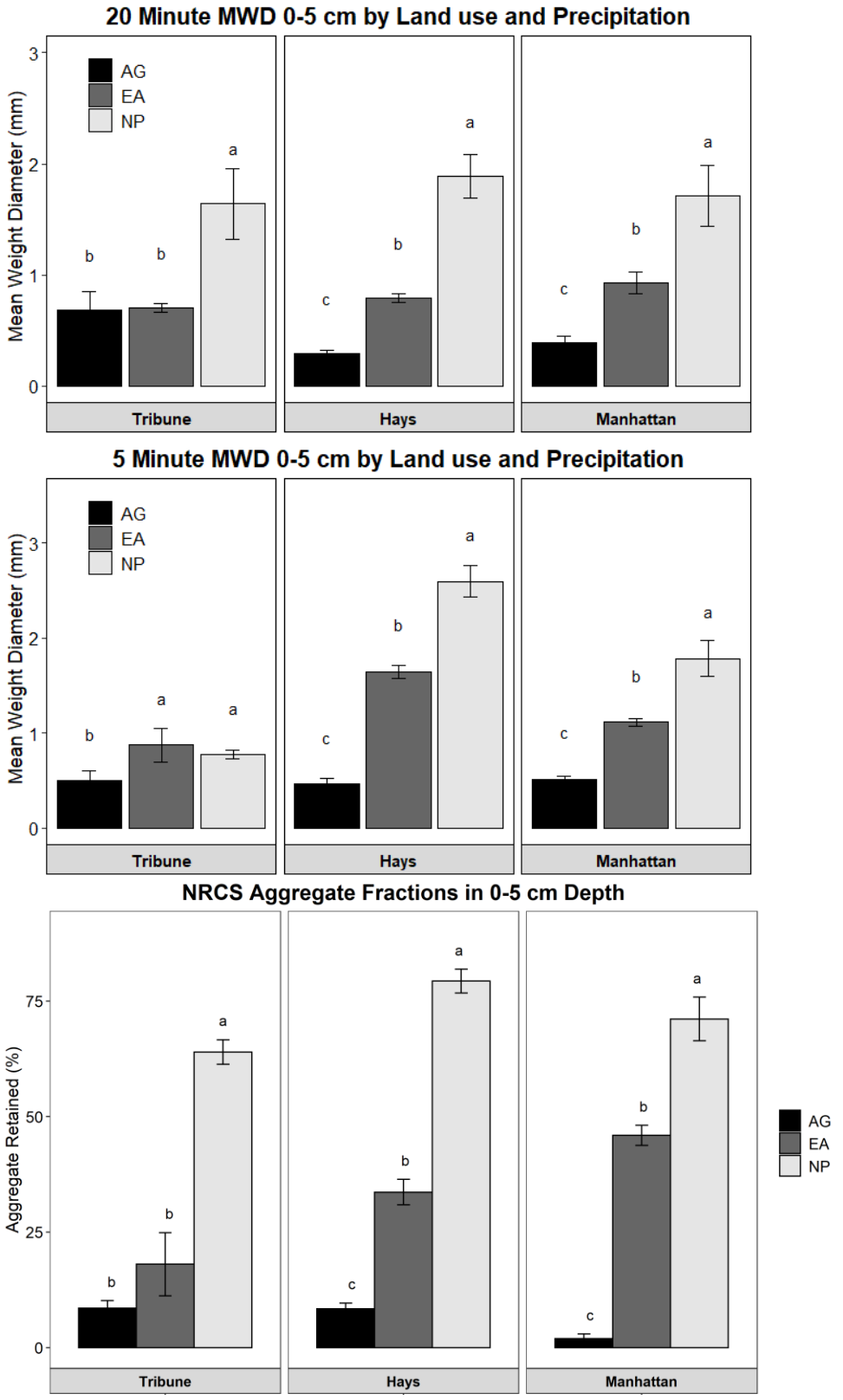

Figure 2.8. Aggregate results for each method showing the level of detail and results between 20- and 5-minutes.

Chapter 3 - Soil health within the topsoil

Abstract

This study evaluated a set of soil health (SH) metrics using soils from a precipitation gradient across Kansas to 15 cm. The three mean annual precipitation regimes included Tribune (483 mm/yr), Hays (579 mm/yr), and Manhattan (850 mm/yr), KS. At each location, three land uses were sampled, native prairie, conventional tillage agriculture, and no-till agriculture . The measured soil health metrics included aggregate stability, soil organic carbon (SOC), total nitrogen (TN), SOC and TN stocks, soil cations and metals, soil respiration, permanganate-oxidizable carbon, autoclaved citrate extractable protein, six enzyme assays, and phospholipid fatty acid analysis. Several soil health metrics distinguished differences among land use in the surface 15 cm with greater effects of soil disturbance as preciptiation increased. No significant difference was found for MWD, macroaggregates, and bulk density between AG and EA. Native prairie generally had higher soil health parameters than cropping systems. The surface soil generally had greater soil health values for all land uses than 5-10 and 10-15 cm. Cropping systems impacted soil pH, nutrients, microbial activity, and enzyme production. Comparing a single time point across agricultural fields is difficult because of differences in soil type, climate, land management, crops and, time since cultivation. Therefore monitoring soil health parameters on a single field is recommended to understand changes in soil health.

Introduction

Conservation practices, such as no-till, crop rotation, and crop diversity, improve soil physical properties (aggregation, erosion resistance, infiltration, and aeration) (Bottinelli et al., 2017; Nunes et al., 2018; Mikha and Rice, 2004); improve soil biological properties (microbial

biomass and composition and activity) (Crotty et al., 2016; Aziz et al., 2013; Frey et al., 1999); and enhance soil chemical properties (soil C and N, pH, nutrients) (West and Post, 2002; Skaalsveen et al., 2019; Yoo et al., 2016). Soil management effects on soil health parameters are confounded by other factors, including time in management, inherent soil properties, and climate (Zuber et al., 2015). Given enough time for management effects, changes in soil properties arise after long-term management (McVay et al., 2006).

Soil physical, chemical, and biological properties have been identified to characterize soil health and assess the impacts of land-use change (Schindelbeck et al., 2016; Kellogg Soil Survey Staff, 2014; Soil Survey Staff, 2014). The soil health metrics identified include aggregate stability, soil organic carbon (SOC) and total nitrogen (TN), soil respiration, permanganate-oxidizable carbon, autoclaved citrate extractable (ACE) protein content, six enzyme assays (β-glucosidase, N-acetyl-β-glucosaminidase, alkaline and acid phosphomonoesterase, phosphodiesterase, and arylsulfatase), and phospholipid fatty acid analysis. The objective of this research was to characterize the soil health parameters in the top 15 cm based on land use (LU), location (L), and land use*location interaction (LU*L). The location effect was based on precipitation with increasing mean annual precipitation from western Kansas to eastern Kansas. We hypothesized that i) soil health parameters would decrease with increasing soil disturbance, ii) soil health parameters would increase with increasing precipitation, and iii) greater impact on soil health parameters with soil disturbance as precipitation increased.

Materials and Methods

Soil sampling

A Giddings probe (Giddings Machine Company, Windsor, CO, USA) with a 6.35 cm dia. metal tube and a six cm dia. plastic soil liner were used to determine soil bulk density (Fig. 3.2). For aggregation, the 0-15 cm of soil was sampled by shovel and divided into 0-5, 5-10, and 10-15 cm while maintaining the natural fabric. Additional moist soil samples were separated into two groups, 25 g for PLFA analysis and 500 g for other soil tests. All samples from the cores and by shovel were replicated four times. Six cores were taken for each replication and homogenized for a composite sample. Soil samples were stored at 4°C until analysis except for soils for PLFA. Phospholipid fatty acid samples were stored at -4°C until analysis.

Site descriptions

This study was conducted across an environmental gradient of Kansas with three land uses (native prairie-NP, enhanced agriculture-EA, and conventional tillage-AG). Each land use at each location (Manhattan, Hays, Tribune, KS) had similar land mapping units, while location mapping units varied across to precipitation regimes (Table 3.1 and 3.2).

Manhattan, KS

Native prairie and AG were sampled 13 September 2019 at the Konza Prairie Biological Station (KPBS) (Table 3.1 and 3.2). Native prairie was dominated by perennial C4 grasses (big bluestem (*Andropogon gerardi*), Indiangrass (*Sorghastrum nutans*), and switch grass (*Panicum virgatum*)) and C3 herbaceous forb species (Heisler-White et al., 2009; Freeman, 1998). The soil was a Reading silt loam (Fine-silty, mixed, superactive, mesic Pachic Argiudoll). The conventional tillage site was cultivated since the 1960s with soybean (*Glycine max*), wheat (*Triticum aestivum*), and grain sorghum (*Sorghum bicolor*) in Reading silt loam (Fine-silty,

mixed, superactive, mesic Pachic Argiudoll) with tillage and local fertilizer and pesticide application practices (Kamlesh et al., 2010) (Table 3.2). At the time of soil sampling soybean was in the field. Enhanced agriculture was sampled on 21 October 2021 after corn harvest at a private farm with no-till corn-soybean rotation. The soil was a Tully silt clay loam (Fine, mixed, superactive, mesic Pachic Argiustolls).

Hays, KS

Native prairie and EA were sampled on 20 September 2019 near Hays Agricultural Research Center (Table 3.1 and 3.2). Native prairie consists of mixed-grass prairie plants such as buffalo grass (*Buchloe dactyloides*), western wheatgrass (*Agropyron smithii*), blue grama (*Bouteloua gracilis*); side- oats grama (*Bouteloua curtipendula*), little bluestem (*Andropogon scoparius*), and big bluestem (*Andropogon gerardi*) (Jones, 1960). Conventional agriculture samples were taken on 15 October 2021 at Hays Agricultural Research Center. The AG site was previously planted to in a wheat-sorghum-fallow rotation. All land uses at Hays had Harney silt loam soils (Fine, smectitic, mesic Typic Argiustolls). Overall, Manhattan and Hays EA were sampled from private farmer fields with no- till (Table 3.2).

Tribune, KS

Native prairie, AG, and EA sites were sampled on 19-20 August 2019 at the Southwest Research Center- Tribune Unit (Fig. 3.1, Table 3.1, and 3.2). The experiment was sampled in a randomized strip block design with four replications. The experiment was initiated in 1989 with tillage treatments imposed in native prairie. Native prairie vegetation consisted of C3 and C4 grasses with the dominant species being buffalo grass (*Buchloe dactyloides*). Conventional agriculture and EA had a wheat-grain sorghum-fallow rotation with tillage and no-till in AG and EA, respectively. Soil at Tribune were classified as Richfield silt loam (fine-smectitc, mesic

Aridic Argiustolls). The experiment was started in 1989 with treatments imposed in native prairie (Blanco-Canqui et al., 2011).

Laboratory assessments

Physical soil properties

Bulk density

Plastic soil core liners with freshly collected soils were sectioned by the appropriate depths. Moist soil was oven-dried at 105°C for 1 week. The oven-dry soil mass was divided by the volume of the soil core segment to calculate soil bulk density.

Water stable aggregates

The fresh soil samples were separated along natural breaks, air-dried for at least 24 h, and sieved with an 8- mm diameter sieve while removing large stones and organic matter for aggregate analysis (Fig. 3.4). Soil (100g) was weighed and placed in a Yoder wet-sieving apparatus modified for recovery of all particle fractions as described by Kemper and Rosenau (1986) modified by Mikha and Rice (2004). Each soil sample was separated into four aggregate size classes (8-2 mm, 0.250-2 mm, 0.053-0.25 mm, and 0.02-0.053 mm diameter). The air-dried soil was placed on the top sieve >2 mm, above the 0.25-2 mm, and 1 liter of distilled (DI) water was added to submerge the soil in water for 10 min. The oscillation time was at 10 min, stroke length at 4 cm, and frequency 30 cycles min^{-1}. After the soil was wet-sieved, the sieves were poured into tins and the oscillation container was poured into the finer sieves of 0.053- and 0.02-mm diameter, then poured into tins. Floating organic matter was removed in the >2 mm fraction sieve. The individual particle fractions were dried at 70°C for 24 h until the water completely evaporated. Each dried fraction was then weighed to determine the percent aggregate size fraction. Aggregates from each tillage treatment were fractionated into macroaggregate

(>2 and 0.25–2 mm) and microaggregate (0.053–0.25 and 0.020–0.053 mm) size classes. Mean weight diameter (MWD) was calculated by the sum of the aggregate mass retained on each sieve multiplied by the mean aperture of adjacent sieves, expressed in mm. The equation below represents the MWD based on the four soil fractions used:

$$MWD\ (mm) = [(8 - 2\ mm\ WSA * 5) + (2 - 0.25\ mm\ WSA * 1.125) + (0.25 - 0.053\ mm\ WSA * 0.1515) + (0.053 - 0.02\ WSA * 0.0365)]/100$$

For reference, 8-2 mm WSA was the wet stable aggregate fraction in percent retained after wet sieving for soil aggregates greater than 2 mm diameter and less than 8 mm diameter. The mean aperture of the 8- and 2-mm diameter sieves was 5 mm.

Chemical soil properties

Soil nutrients

The soil samples from each depth and treatment were homogenized, air dried, roots removed, passed through 2 mm sieves, and then sent to the Kansas State University Soil Testing Laboratory for soil pH and chemical analysis on plant-available micro-and macro-nutrients in soils. The Mehlich-3 extractable phosphorus was extracted with glacial acetic acid, ammonium nitrate, ammonium fluoride, and nitric acid and then, analyzed using Lachat Quickchem 8000 colorimetric analysis (Frank et al., 1998). The exchangeable cations, calcium, potassium, magnesium, and sodium were analyzed by Inductively Coupled Plasma (ICP) Spectrometer (Model 720-ES ICP Optical Emission Spectrometer, manufactured by Varian Australia Pty Ltd, Mulgrave, Vic Australia) after extraction with ammonium acetate (1 M, pH 7.0) and filtered through low-sodium filter paper (Warncke and Brown, 1998).

Soil organic carbon and total nitrogen

Soil organic carbon (SOC) and total nitrogen (TN) was determined by a LECO TruSpec Carbon/Nitrogen combustion analyzer (LECO Corporation, St. Joseph, MI, 2005) that reports total levels (inorganic and organic) of C and N on a weight percent basis. Total C was considered soil organic carbon for soils with pH <7.2, while soils with pH >7.2 were pretreated for carbonates using a second LECO combustion sample with dilute Phosphoric Acid. Carbonates are released as CO_2 from calcium and magnesium carbonates in calcareous soils, leaving only the soil organic carbon present. Soil organic carbon and TN was converted to g C kg^{-1} soil and mg N kg^{-1} soil by multiplying 10 and 100, respectively.

Soil pH

Soil pH was determined with a 1:1 slurry method of 10 g <2 mm sieved air-dry soil and 10 ml of DI water is used (Watson and Brown, 1998). All pH measurements were made with a Skalar SP50 Robotic Analyzer (Skalar Inc., Buford, Georgia).

Soil metals

Soil metals for iron, zinc, copper, and manganese were diethylenetriaminepentaacetic acid (DTPA) extracted using an Inductively Coupled Plasma (ICP) Spectrometer (Model 720-ES ICP Optical Emission Spectrometer, manufactured by Varian Australia Pty Ltd, Mulgrave, Vic Australia) as described by (Whitney, 1998).

Biological soil properties

Microbial phospholipid analysis

The total lipids were extracted from freeze-dried soil using a modification of the Bligh and Dyer lipid extraction method (Fig. 3.3) (Bligh and Dyer, 1959; White and Ringelberg, 1998; White and Rice, 2009). Briefly, phospholipid fatty acids (PLFA) were separated from the

total lipid extract using silicic acid chromatography. The fatty acids were cleaved from the glycerol backbone using KOH saponification, and the harvested fatty acids were methylated to form fatty acid methyl esters (FAME). The resulting FAMEs were analyzed using a Thermo Scientific Trace GC-ISQ mass spectrometer (Thermo Fisher Scientific, Waltham, Massachusetts, USA) equipped with a DB5 MS column (30m x 250 µm i.d. x 0.25 µm film thickness, Agilent Technologies, Santa Clara, California, USA). The FAME peaks were identified by comparison with a total of 32 biomarkers, 26 biomarkers from a bacterial acid methyl esters mix (BAME; Matreya 1114; Matreya LLC, Pleasant Gap, Pennsylvania, USA) and six additional FAMEs were custom made for 10Me16:0 (Cayman Chemical 24823; Cayman Chemical Company; Ann Arbor, Mississippi, USA), 10Me18:0 (Larodan 21-1810; Larodan AB; Solna, Sweden), a17:0 (Matreya 1614; Matreya LLC, Pleasant Gap, Pennsylvania, USA), C16:1:11 (Matreya custom synthesis; Matreya LLC, Pleasant Gap, Pennsylvania, USA), C18:1:11:cis (MilliporeSigma 17264; MilliporeSigma; Burlington, St. Louis, Missouri, USA), and C20:0 (MilliporeSigma 10941; MilliporeSigma; Burlington, St. Louis, Missouri, USA). Peak concentration was quantified using the internal standard methyl nonadecanoate (19:0 FAME) (MilliporeSigma N5377; MilliporeSigma; Burlington, St. Louis, Missouri, USA). Fatty acids were grouped into Gram-positive (+) bacteria (i15:0, a15:0, i16:0, i17:0, and a17:0), Gram-negative (-) bacteria (19:0:delta9,10; C18:1:11:cis; 17:0:delta9,10; C10:0:2-OH, C12:0:2-OH, C12:0:3-OH, C14:0:2-OH, C14:0:3-OH, C16:1:0:cis, C16:0:2-OH), actinomycetes (10Me16:0 and 10Me18:0), arbuscular mycorrhizal fungi (AMF) (C16:1:11), and fungi (C18:2:9,12) (White and Rice, 2009). Phospholipid fatty acid abundance was reported as nmol per gram of dry soil. Total microbial biomass was estimated using the sum of all PLFA biomarkers and the common biomarkers in microbes with FAMEs for C11:0; C12:0; C13:0; C14:0; C15:0; C16:0; C17:0; C18:0; and C20:0.

The fungal to bacterial ratio was calculated by dividing the sum of AMF and saprophytic fungi by the sum of Gram (+), Gram (-), and actinomycetes.

Soil respiration

Soil respiration was based on a modified version of Schindelbeck et al. (2016) (Fig. 3.5). Twenty (±0.05) g of 8-mm-sieved air-dried soil was placed in a perforated aluminum weigh boat then placed in a 1000 mL wide-mouth Ball Mason jar with 2 Whatman No. 42 filter paper place on the bottom. The soil was rewet from the bottom by pipetting 7.5 mL of DI water onto the filter paper and incubated for 4-days at 25 ℃. Jars were sealed with a modified flat screw-top ring with a rubber septum and Dow Corning high vacuum grease. After incubation, 10 mL gas were taken twice per incubation jar. A 0.5 mL sample of each gas sample was analyzed for CO_2 content on a Shimadzu Gas Chromatograph-8A (Shimadzu Scientific Instruments Inc., Columbia, MD). The gas chromatograph was equipped with a thermal conductivity detector and a 2-m Porapak Q column (0.318 id). The column temperature was 75 ℃ with an injection temperature of 75 ℃. Helium (14-mL min^{-1}) was used as the carrier gas. An incubation with no soil was used to correct for CO_2 present before soil incubation. The equation below details the process:

$$\frac{\text{mg CO2}}{\text{g of soil}} = \left((\mu\text{g } CO_2 \text{ sample} - \mu\text{g } CO_2 \text{ control}) * \left(1000 \text{ mL} \frac{\text{volume}}{0.5} \text{mL gas sample} \right) \right.$$

$$\left. * \left(\frac{1}{20} \text{g soil} \right) * \left(\frac{1}{1} + \text{ soil moisture} \right) * \left(\frac{1\ mg}{1000\ \mu g} \right) \right)$$

Autoclavable extractable protein content

Autoclaved citrate extractable (ACE) protein content was measured following Schindelbeck et al. (2016) based on Wright and Upadhyaya (1996) with modifications by Hurisso et al. (2018) (Fig. 3.6). Air-dried soil (3 g) was combined with 24 mL 20 mM sodium

citrate at a pH of 7.0 in a 50 mL centrifuge tube, shaken for 5 min at 180 OSC/min and then autoclaved for 30 min at 120 °C at 15 psi. Following autoclaving, soils were shaken for 3 min, the solution clarified by transferring 1 mL to a microcentrifuge and centrifuged at 10,000 RPM for 3 min. Following centrifugation, 10 µL was transferred to a 96-well plate with 200 µL of pre-made protein assay reagent of bovine serum albumin standard pre-diluted set (23208, Thermo Fisher Scientific, Waltham, Massachusetts, USA). The 96-well plates were sealed and incubated for 1 hr at 61.5 ℃. A pre-diluted set of protein assay standards, bovine serum albumin were used to generate a standard curve. Varioskan LUX Multimode Microplate Reader (3020, Thermo Fisher Scientific, Waltham, Massachusetts, USA) was used to measure the absorbance of each well in the 96-well plate at 562 nm.

Permanganate-oxidizable carbon

Permanganate-oxidizable carbon (POXC) was based on a modified version of Weil et al. (2003) by Kellogg Soil Survey Staff (2014) (Fig. 3.7). POXC was determined from 2.5 g soil (< 2 mm) was combined with 10 mL 0.02 M $KMnO_4$ into 50 mL plastic screw top centrifuge tubes (06-443-20, Thermo Fisher Scientific, Waltham, Massachusetts, USA). Each tube was vortexed and let to settle for 10 min before centrifuging for 10 min at 2000 rpm. A 0.5 mL sample of the supernatant was transferred to another centrifuge with 49.5 mL of DI water for dilution. The absorbance of the solution was determined on a Genesys 20 Visible Spectrophotometer (Thermo Fisher Scientific, Waltham, Massachusetts, USA) at 550 nm. The reactive soil organic carbon was reported as mg of oxidizable C kg^{-1} of soil. The equation below is the calculation for POXC:

$$\text{mg reactive C } kg^{-1} \text{ of soil}$$

$$= \left(\left(0.02\,\frac{\text{mol}}{\text{L}}\,\text{KMn}O_4\right) - (\text{a} + \text{b} * \text{ABS})\right) * \left(\frac{9000\text{ mg C}}{\text{mol KMn}O_4}\right) * \left(\frac{0.02\text{ L solution}}{0.0025\text{ kg}}\right) * \left(\frac{\text{AD}}{\text{OD}}\right)$$

Enzyme assay

Six soil enzymes were assayed using p-nitrophenyl linked substrates and analyzed colorimetrically (Kellogg Soil Survey Staff, 2014; Acosta-Martínez and Tabatabai, 2011) (Table 3.3 and 3.4). β-glucosidase (Eivazi and Tabatabai, 1988) (Fig. 3.8), N-acetyl-β-glucosaminidase (Parham and Deng, 2000) (Fig. 3.9), acid phosphatase, alkaline phosphatase (Tabatabai and Bremner, 1969; Eivazi and Tabatabai, 1977) (Fig. 3.10), phosphodiesterase (Browman and Tabatabai, 1978) (Fig. 3.11), and arylsulfatase (Tabatabai and Bremner, 1970) (Fig. 3.12) are extracellular enzymes related to C, N, P, and S cycling, respectively. Three sets of 0.5 g air-dried 2-mm-sieved soil were placed in 20-mL glass screw-top vials with 2 mL of buffer. Two vials had 0.5 mL of p-nitrophenyl linked substrate added and one vial served as a control with no reagent. Flasks were capped and incubated for 1 h at 37 ºC. Following incubation, 0.5 mL of 0.5 M $CaCl_2$ and 2 mL of stop buffer were added to each flask. The control had 0.5 mL of p-nitrophenyl linked substrate added after all the reagents. Samples were filtered using Whatman 2V 9.0-cm diameter filter paper and absorbance measured using a Genesys 20 Visible Spectrophotometer (Thermo Fisher Scientific, Waltham, Massachusetts, USA) at 400 nm. Sample solutions with absorbances over 1.5 Au were diluted with nanopore water at a 3 to 5-fold dilution.

For the standard curve, the p-nitrophenol (PNP) standard solution was prepared with 1 g of PNP in 100 L of water, then 1 mL of the PNP standard solution was diluted with 99 mL of DI water. A calibration curve with 0, 2, 4, 6, 8, and 10 µg PNP was produced by adding 0, 1, 2, 3, 4,

and 5 mL the diluted PNP standard solution to a 50 mL volumetric flask with water and then 0.5 mL of 0.5 M $CaCl_2$ and 2 mL of stop buffer were added to terminate the reaction. The solutions were filtered and measured using a spectrophotometer at a wavelength of 400 nm.

Oven-dried air-dried soil content

Soil metrics (soil respiration and POXC) that require moisture correction for using air-dried samples had oven-dried air-dried measurements calculated using the equation:

$$Oven\ dried\ air\ dry\ soil = \frac{Air\ Dry\ Soil\ Sample\ (g) -\ Oven\ Dry\ Soil\ (g)}{Oven\ Dry\ Soil\ (g)} * 100$$

Data analysis

Custom-written scripts in R version 4.0.3 (R core Team 2020) were used for statistical analysis. Linear mixed-effect models were used with the fixed effects of land use and different locations of Kansas with its interactions, while random effects included randomized, repeated measures. The differences in measured variables among land use and location were tested using type 3 two-way analysis of variance (ANOVA) with Satterthwaite's method. All error bars were reported as standard errors. Differences were determined at $p<0.05$ significance level using least-squares means separation (LSMEANS) Tukey's Honest Significant Difference (HSD) adjustment for multiple comparisons. A correlation matrix was used to assess correlations between individual soil health metrics using Spearman Correlation. A biplot was constructed with a principal component analysis (PCA) plot based on positive correlations in the correlation matrix for soil microbial composition and enzyme activity clustered by land use to show variation in datasets with loadings (arrows) and scores (data points) (Gabriel, 1971).

Results

Physical soil properties

Mean weight diameter (MWD) was significantly affected by land use at all depth (Table 3.5 and Fig. 3.13). NP had higher MWD than both the agricultural sites. Location did not affect MWD.

Macroaggregates between 8-2 mm (Fig. 3.14, 3.15) were significantly higher in NP than both cropping systems for all depths. Cropping systems were not significantly different for the 8-2 mm macroaggregates. Location was not a significant at any depth (Table 3.6). Macroaggregates between 2-0.25 mm (Fig. 3.16) were significantly greater in NP than in both cropping systems for all depth with no difference between cropping systems. The 0-5 cm had more discernible trends where 2-0.25 mm aggregates increased with increasing precipitation, while for the 5-10 and 10-15 cm depths the 2-0.25 mm aggregates varied with precipitation.

Chemical soil properties

The ANOVA for the chemical properties is reported in Table 3.7. Soil pH was significantly affected by precipitation and land use and the interaction at all depths. Soil pH significantly increased in AG with increasing precipitation at 0-5 cm depth (Fig. 3.17). Enhanced agriculture and NP at Manhattan and Hays had similar soil pH, while EA and AG soil pH was significantly lower at Tribune in 0-5 cm. Manhattan AG had significantly higher soil pH than Tribune and Hays AG at 5-10 cm. There was no significant difference in soil pH in NP at any location at 5-10 cm. Soil pH in Manhattan AG was significantly higher than all land uses at each depth. As precipitation increased, soil pH in NP significantly decreased at 10-15 cm. For AG, soil pH significantly increased from Tribune and Hays to Manhattan at 10-15 cm depth. Manhattan EA had significantly lower soil pH than both Tribune and Hays in 10-15 cm depth.

Location and land use interaction was observed for SOC at all depths (Table 3.7 and Fig. 3.19). Soil organic carbon increased with increasing precipitation in NP which was significant at 5-10 and 10-15 cm. The effect of precipitation was not significant for EA, while AG had varying SOC levels between locations.

Total nitrogen was higher in NP than in both cropping systems across locations which was significant at 5-10 cm (Table 3.7 and Fig. 3.20). The land use and location interaction was significant at all depths where NP was higher than cropping systems at all locations, but did not increase with precipitation. There was no difference in TN for EA at all locations, while TN decreased for AG from Tribune to Hays and increased from Hays to Manhattan at 5-10 cm.

Soil available P was significantly affected by land use and location interaction at all depths (Table 3.7 and Fig. 3.21). In general, NP had lower soil available P than the cropping systems. The land use and location interaction of AG was variable with increasing precipitation, while P in EA declined with precipitation. Soil available P was significantly higher at Tribune compared to Hays and Manhattan.

Biological soil properties

The ANOVA for the biological properties is reported in Table 3.8. Most biological properties were significantly affected by the interaction of land use and location at all depths. In general, the biological properties were greater in NP than AG and EA. Biological properties increased with increasing precipitation for NP, while AG and EA did not consistently respond to precipitation (Fig. 3.22-3.37).

β-glucosidase (bG) (Fig. 3.22) was significantly higher in Hays than Tribune and Manhattan, which were not significantly different at 0-5. Cropping systems were not significantly different at 5-10 and 10-15 cm and did not vary with precipitation.

Land use significantly affected N-acetyl-b-D-glucosaminidase for all three depth. A land use and precipitation interaction occurred at 10-15 cm (Fig. 3.23). N-acetyl-b-D-glucosaminidase increased with decreased soil disturbance at all locations at 0-5 cm. The NP had significantly higher NAG while AG had the lowest NAG activity. The NAG activity was not significantly different in NP at each location until 10-15 cm where it increased with precipitation, while NAG activity decreased with increasing precipitation in AG at 0-5 cm. At 5-10 cm, NAG decreased with increasing precipitation for AG, while NAG activity did not change with precipitation. At 10-15 cm, there were no significant differences with NAG activity in both cropping systems with increasing precipitation.

Acid phosphatase was significantly affected by the interaction between land use and location at all depths (Fig. 3.24). At all depths, AP activity was significantly higher in NP than the cropping systems at each location. In addition, NP Hays had significantly higher AP than both NP Tribune and Manhattan. The AP activity in AG decreased with increasing precipitation, while AP activity did not significantly change with EA at each location at 5-10 cm.

All three depths had a land use and precipitation interaction for alkaline phosphatase (Fig. 3.25). Alkaline phosphatase was not affected by increasing precipitation in NP until 10-15 cm where it decreased with precipitation. Soil ALK was significantly higher for NP than the cropping system at 0-5 cm. At 0-5 cm, Manhattan AG ALK activity was significantly higher than that of Hays and Tribune, while EA ALK was highest in Hays followed by both Manhattan and Tribune which were not significantly different. At 5-10 cm, ALK activity in EA and NP was not significantly different between locations, but NP had significantly higher ALK activity than EA. Alkaline phosphatase activity was not significantly different at Tribune and Hays AG, but Manhattan AG had significantly higher ALK activity at 5-10 cm. At 10-15 cm, ALK activity was

similar at Tribune and Hays NP and EA, but ALK significantly decreased at Manhattan for both NP and EA. In addition, ALK activity was similar in Tribune and Hays but significantly increased in Manhattan AG.

Phosphodiesterase had a land use and precipitation interaction at all depths (Fig. 3.26) and increased with decreasing precipitation at 0-5 cm. At 5-10 cm, PHO activity significantly increased with increased precipitation in NP, while there was no significant difference in PHO activity in EA. Phosphodiesterase activity was similar in Tribune and Hays but significantly increased in Manhattan for AG at 5-10 cm. At 10-15 cm, PHO activity was similar in Manhattan and Hays, but significantly lower in Tribune for NP. Phosphodiesterase activity was not significantly different for EA at 10-15 cm, while PHO activity in AG was similar at Tribune and Hays with a significant increase at Manhattan.

Arylsulfatase had a land use and precipitation interaction at all depths (Fig. 3.27) and significantly increased with decreasing soil disturbance at 0-5 cm. At 5-10 and 10-15 cm, ARY activity increased with increasing precipitation in NP. Native prairie also had significantly higher ARY activity than the cropping systems at all depths. Arylsulfatase activity was not significantly different for EA at all locations. Arylsulfatase activity increased slightly with increasing precipitation at 5-10 cm for AG. At 10-15 cm, ARY activity increased significantly in NP with increasing precipitation, while precipitation did not affect ARY activity for both cropping systems.

Autoclaved-citrate extractable protein content had a land use and precipitation interaction at 0-5 and 5-10 cm and a land use effect at 10-15 cm (Fig. 3.28). Protein content was variable for NP with Manhattan and Tribune greater than Hays, while EA was opposite in trend. At 5-10

cm, protein content significantly decreased for AG with increasing precipitation, while ARY in EA was not significantly different between locations.

Permanganate-oxidizable carbon content had a land use and precipitation interaction at all depths (Fig. 3.29). Permanganate-oxidizable carbon content significantly increased with increasing precipitation in EA, while both NP and AG significantly increased from Tribune to Hays and then significantly decreased to Manhattan for all depths.

Soil respiration had a land use and precipitation interaction at all depths (Fig. 3.30). Respiration at EA significantly increased from Tribune to Hays and then significantly decreased from Hays to Manhattan at 5-10 and 10-15 cm. Soil respiration in NP Tribune was significantly less than NP in Hays and Manhattan at all depths.

Land use and precipitation interaction occurred at all depths for microbial biomass (Fig. 3.31). Microbial biomass was significantly higher in NP than cropping systems at each location while cropping systems were not significantly different at all locations at 0-5 cm. Similar results occurred at 5-10 cm, except Manhattan AG which was significantly higher than EA. At 10-15 cm, NP was significantly higher for both Hays and Manhattan than the cropping systems, while microbial biomass was not significantly different between land use. Hays EA microbial biomass was significantly higher than that of AG at 10-15 cm.

Land use and precipitation interaction occurred at all depths for Gram (+) bacteria (Fig. 3.32). Gram (+) bacteria was significantly greater in NP than the cropping systems at all locations at 0-5 cm. Hays EA had higher Gram (+) bacteria than AG at all depths, while Manhattan AG had higher Gram (+) bacteria than EA at 5-10 and 10-15 cm. The cropping systems at Tribune had similar Gram (+) bacteria at all depths.

Gram (-) bacteria had a land use and precipitation interaction at all depths (Fig. 3.33). Gram (-) bacteria was significantly higher in Manhattan and Hays than Tribune for NP at 0-5 cm. Gram (-) bacteria was higher in NP than cropping systems at all locations for 5-10 cm while cropping systems had variable Gram (-) bacteria trends between Manhattan (AG>EA) and Hays (AG<EA). Gram (-) bacteria at Tribune were not different between cropping systems at all depths. The 10-15 cm soil depth had similar trends with the 5-10 cm soil depth, except Tribune land use which were not significantly different.

Actinomycetes had a land use and precipitation interaction at all depths (Fig. 3.34). Actinomycetes were significantly higher in order of Hays, Manhattan, and Tribune for AG at 0-5 cm, while EA did not change with precipitation. At 10-15 cm, actinomycetes were highest at Hays AG and Manhattan NP, while actinomycetes at Tribune were not affected by land use. No difference in actinomycetes abundance occurred between Hays EA and NP, but Manhattan AG had significantly higher actinomycetes than EA which was opposite of Hays at 10-15 cm.

Arbuscular mycorrhizal fungi had a land use and precipitation interaction at all depths (Fig. 3.35). Arbuscular mycorrhizal fungi were significantly higher in NP in Manhattan and Hays than the cropping systems for all depths, while AMF was not different between cropping systems at Tribune at all depths. For 5-10 and 10-15 cm, AMF had contrasting concentrations at Hays (EA>AG) and Manhattan (AG>EA).

Land use and precipitation interaction occurred for all depths for saprophytic fungi (Fig. 3.36). Saprophytic fungi increased with precipitation at 0-5 cm for NP. Saprophytic fungi was not different between land uses at Tribune or cropping systems at Manhattan, while Hays AG had significantly higher fungi than Hays EA at 0-5 cm. Saprophytic fungi at 5-10 and 10-15 cm were not significantly different between Hays AG and EA. At 5-10 cm, saprophytic fungi was

similar for all land uses in Tribune, while NP had higher saprophytic fungi than the cropping systems at Manhattan and Hays. At 10-15 cm, fungal abundance in NP was significantly higher than cropping systems at all locations, with no significant difference in fungal abundance between cropping systems. Differences in fungal to bacteria ratio (Fig. 3.37) had a land use and precipitation interaction at 0-5, while 10-15 cm had only a land use effect.

Correlation

There were strong correlations between biological, SOC, TN, respiration, protein, soil microbial community composition, and enzyme activity (Fig. 3.38 and 3.39). Phosphorus and bulk density were negatively correlated with biological properties. The first two principal components explain 80.3% of the variability in the data. The land use groupings from the PCA biplot indicate more variability in NP followed by EA and then AG. Variables were more strongly correlated the closer the vectors are to each other. Thus, Gram (+), Gram (-), microbial biomass, and AMF; phosphodiesterase, arylsulfatase, and soil respiration; and glucosaminadase, acid phosphatase, and total nitrogen were highly correlated. Variables with vectors with a 90° angle were uncorrelated, so actinomycetes and soil proteins were the most uncorrelated biological variables tested.

Discussion

Soil productivity and longevity are directly related to SOM dynamics and biogeochemical cycles sensitive to climate and land use (Cerri et al., 2007). As a result, SOC, TN, pH, soil fertility, and microbial dynamics are important parameters to measure changes in management over local and regional scales. Variations in cultivation, crop rotation, crop intensity, and soil disturbance are compared to NP. In general, NP had higher measures of

physical, chemical, and biological properties than both cropping systems.. The 5-10 and 10-15 cm depths were more similar than the 0-5 cm depth regarding soil health properties by land use. The 0-5 cm depth generally had greater soil health values for all land uses than 5-10 and 10-15 cm depth. In addition, EA had higher measures of physical, chemical, and biological than AG systems. Enhanced agriculture had greater MWD, macroaggregates, TN, β-glucosidase, N-acetyl-b-D-glucosaminidase, and acid phosphatase than AG.

Physical soil properties

Tillage loosens the soil, redistributes macroaggregates into microaggregates, and exposes labile soil organic carbon to decomposition (Kumar et al., 2014; Six et al., 2000; Mikha and Rice, 2004). Conceptually, macroaggregates (>0.25 mm) are bound from roots and hyphae while microaggregates are bound from residues, hyphal debris, and clay microstructures (0.053-0.02 mm) or larger fungal and plant debris (0.25-0.053 mm) (Wilson et al., 2009l; Rasmussen et al., 2018). Microaggregate binding agents are more persistent, reduced materials of humic moieties that are less sensitive to decomposition than macroaggregate binding agents (Miller and Jastrow, 2000). Hays and Manhattan EA had similar physical properties (MWD and macroaggregates) that were greater than AG, primarily in 0-5 cm (Fig. 3.13, 3.14, 3.15, 3.16). Aggregate stability and macroaggregates were greatest in NP at all locations compared to cropping systems. Cropping systems and tillage affect water-stable aggregate distribution and stability. The continuous growth of plants (perennials) with low soil disturbance promoted greater macroaggregates, added more C, and promoted greater microbial biomass and metabolic diversity (Vezzani et al., 2018; Wardle et al., 2018; Wang et al., 2016). Plants increase soil aggregation through physically binding roots and chemically stabilizing soil with root exudates (Vezzani et al., 2018). A lack of plants in fallow and tillage reduces macroaggregates (>2 mm)

and increased microaggregates (<0.25 mm) (Beare et al., 1994; Huang et al., 2015; Vezzani et al., 2018). No-till influences SOC and TN more in 8-2 mm aggregate fraction than microaggregate fractions (Vezzani et al., 2018). Carbon in no-till is physically protected inside stable aggregate structures compared to conventional tillage (Beare et al., 1994; Wardle et al., 2018).

Chemical soil properties

Soil acidity (Fig. 3.17) increased with decreasing precipitation in AG at 0-5 cm likely due to the generation of hydrogen ions from fertilizer application and mineralization (Bolan et al., 2003; Kunhikrishnan et al., 2016). Higher pH was due to higher levels of free calcium carbonate in Manhattan NP (Zhou et al., 2009; Wehmueller, 1996). Overall, soil pH was sensitive to climate and land use as it varies with N fertilizer applied, rainfall, drainage, biomass removal, and crop management (Hazelton and Murphy, 2016)

Soil organic carbon is a key indicator of soil health because it is positively correlated with lower bulk density, improve soil aggregation, greater nutrient availability, higher water holding capacity, and higher cation exchange capacity (Zuber, 2015; Varvel and Wilhelm, 2011; Arshad and Coen, 1992; Hsiao et al., 2018). The increase in SOC with increasing precipitation was likely due to increased plant production and crop residue return (Jenny, 1994; Don et al., 2017). The variability in SOC with changing precipitation was likely due to differences in crop management, time in cultivation, and crop rotation (Wade et al., 2018). Land use change and management is assumed to be the driving factor of SOC change with SOC storage in grassland>cropland (Wiesmeier et al., 2019; Oades, 1988). However, the variation in crop management practices complicates SOC as an indicator when comparing different management systems. This study found variations in SOC among locations comparing AG and EA (explained

later) (Fig. 3.19). Several studies have found SOC increases at depth with greater C inputs and accumulation in the surface soil (Carter et al., 2003; Six et al., 2000; West and Post, 2002). Nicoloso et al. (2018) observed accumulation of SOC in lower depths after C accumulation stabilized asymptotically over two decades of organic compost application and saturation in the top 0-5 cm. In general, SOC is highly sensitive to land use and varies in storage with land management and climate (Wiesmeier et al., 2019).

Nitrogen availability in soil is dynamic and influenced greatly by weather, land use, soil conditions, microbial activity, and organic matter (Gerber et al., 2010; Galloway et al., 2004). Total nitrogen (Fig. 3.20) was significantly higher in NP than in both cropping systems for all locations. This study found contrasting NT results with precipitation for different cropping systems. Higher TN was expected in EA due to tillage differences contributing to levels of nutrient storage and release (Reicosky et al., 1995). Less precipitation reduced TN differences between tillage systems, indicating that in drier areas, cultivation impacts on soil health parameters would be reduce or take longer time for differences to occur. Total nitrogen was higher in EA than AG at all locations for 0-5 cm. However, a shift in TN occurred at 10-15 cm in Manhattan, where AG was greater than EA. Cropping type (perennial vs annual) and fertilization influences residue input and SOM storage (Omay et al., 1997). Overall, NP had higher TN than both cropping systems, while both cropping systems had contrasting results (explained later).

Soil organic carbon to nitrogen ratios can be used to determine changes with land use, depth, and climate. Several studies reported that C:N ratios increased with increasing precipitation (Jenny, 1981; Zhou et al., 2002; Jobbágy and Jackson, 2000). Manhattan NP had a higher SOC:TN ratio than Tribune NP most likely due to greater plant biomass and residue return from higher precipitation (Zhou et al., 2009). Generally, trends in C:N can be influenced

by the balance between aboveground production with decomposition, resulting in differences in SOC:TN ratios (Zhou, et al., 2009). The lack of a trend in SOC:TN ratio for AG was most likely due to differences in agricultural management, such as vegetation and other inherent differences in soil properties (Zhou et al., 2009; Jobbágy and Jackson, 2000).

Extractable phosphorus (Fig. 3.21) was significantly higher in both cropping systems than NP likely due to P fertilizer application for crop production. Extractable P decreased with increasing precipitation for EA and NP in the 10-15 cm depth. This was likely due to greater P uptake and plant growth with more precipitation. High soil moisture increases Mehlich-P in soil (Roden and Edmonds, 1997). In addition, available P ions ($H_2PO_4^-$, HPO_2^{2-}) are more available in neutral soils with pH 6-7.5 (Hinsinger, 2001). Thus, P is not a strong indicator of land use and management without considering soil moisture, change in P speciation, and soil pH.

Biological soil properties

Phospholipid fatty acid analysis was used to profile the microbial communities present with different land use and precipitation (Willers et al., 2015). The disadvantage commonly cited with PLFA is the coarse taxonomic resolution (Yao et al., 2015). Total PLFAs correspond to total viable microbial biomass, which is correlated with other measures of microbial biomass methods including chloroform-fumigation extraction and substrate-induced respiration (Willers et al., 2015; Leckie et al., 2004). All microbial groups and total microbial biomass responded to land use and precipitation, specifically higher microbial biomass with less disturbance (Fig. 3.31, 3.32, 3.33, 3.34, 3.35, 3.36). Microbial profiling also followed similar trends for the top 15 cm, but 0-5 cm had higher microbial biomass due to greater nutrient and moisture availability. Other studies have found microbial biomass to increase with SOM and decrease with disturbance

(Lagerlöf et al., 2014; Montecchia et al., 2011). Thus, PLFA was a good indicator of overall microbial community and microbial biomass in response to precipitation and management.

Microbial biomass (Fig. 3.31), Gram (+) bacteria (Fig. 3.32), Gram (-) bacteria (Fig. 3.33), and arbuscular mycorrhizal fungi (Fig. 3.35) were significantly greater in NP than cropping systems while cropping systems were not different for all locations at 0-5 cm. Similar results appeared at 5-10 cm, except Manhattan AG was significantly higher than EA. This could be due to more active rhizosphere in the AG soil as soybean crop was growing, while Manhattan EA was just harvested for corn (Wieland and Backhaus, 2001). Hays EA was significantly higher than AG in the 10-15 cm. This could be due to cover crops providing higher microbial activity than AG, and less soil disturbance promoting greater macropores (Sun et al., 2020). No significant differences in microbial biomass, Gram (+) bacteria, Gram (-) bacteria, actinomycetes, arbuscular mycorrhizal fungi, and saprophytic fungi for the Tribune cropping systems may be due to less microbial activity from low soil water and optimal growing conditions. Temperature and moisture can significantly affect decomposition for optimal aerobic chemoautotrophic activity (White and Rice, 2009). Actinomycetes also responded marginally compared with the other microbial populations.

The structure of the microbial community is governed by the quality and quantity of the available substrate (Griffiths et al., 1998; Bini et al., 2003). Plant type contributes to different qualities and quantities of above and below ground plant material that affect soil microbes (de Vries et al., 2012). Higher aboveground biomass is associated with higher SOC (De Deyn et al., 2008). Lower soil nutrients or moisture availability may facilitate the growth of fungi over bacteria, since fungi have a competitive advantage for water, N, and P absorption (van der Heijden et al., 2008).

Native prairie was expected to have higher AMF than cropping systems due to phosphorus fertilizer application and tillage (Xiang et al., 2014; Bainard et al., 2014; Jansa et al., 2002; Dai et al., 2013). In addition, higher plant diversity was correlated with greater AMF abundance (König et al., 2010). Other abiotic influencers on AMF abundance include soil pH (Dumbrell et al., 2010), soil texture, nutrient availability (Moebius-Clune et al., 2013; Bainard et al., 2014), and climate (Dumbrell et al., 2011). Native prairie was expected to have greater saprophytic fungi due to greater plant biomass production and decomposition than cropping systems (Van Groenigen et al., 2010). Pikul et al. (2009) found greater fungal growth and greater water stable aggregation in NT than conventional tillage. A higher amount of actively metabolizing fungi could result in the accumulation of recalcitrant metabolites, and lead to C sequestration (Six et al., 2000; White and Rice, 2009). The higher fungal to bacterial ratio in the topsoil with increasing precipitation may be due to greater water availability for fungal growth and greater primary production (Zhou et al., 2018; Knapp and Smith, 2001; Manzoni et al., 2012; Zeglin et al., 2013). Fungi may exhibit greater water stress tolerance, but greater shifts between F:B ratios may not be significant in the surface soils if growth rates in wetter regions are higher than drier regions (Manzoni et al., 2012).

Extracellular enzymes are produced and excreted mainly by microorganisms that can be useful indicators of nutrient cycling and are influenced by land use (Luo et al., 2017, Caldwell, 2005). Microbial growth depends on enzymes to decompose SOM (Allison and Vitousek, 2005). Different enzymes are responsible for catalyzing reactions for C (β-glucosidase), N (N-acetyl-β-glucosaminidase), P (phosphodiesterase, phosphatase), and S (arylsulfatase) (Acosta-Martínez et al., 2019; Allison and Vitousek, 2005). However, enzyme activity is associated with mineral stabilized enzymes that do not directly reflect or correlate with microbial biomass or activity

(Dick, 1994). Thus, enzyme activity is the potential for nutrient cycling and not in situ activity (Dick, 1994).

In this study, higher β-glucosidase (Fig. 3.22) in NP compared to other cropping systems in 0-5 cm was due to more plant biomass in NP, requiring greater demand for enzymatic mineralization. Similarly, N-acetyl-b-D-glucosaminidase (Fig. 3.23) was more sensitive to land use where native prairie had greater NAG activity at all depths than the cropping systems at all locations. For Ag, the change in soil depth decreased enzyme activity, while increasing precipitation decreased NAG activity (Acosta-Martínez et al., 2019). Acid phosphatase (Fig. 3.24), alkaline phosphatase (Fig. 3.25), phosphodiesterase (Fig. 3.26), and arylsulfatase (Fig. 3.27) were significantly higher in NP Hays than Tribune and Manhattan at all depths. This was likely due to a more active microbial community and plant demand for P in Hays releasing phosphatase enzymes (Luo et al., 2017). Cropping systems also had lower phosphatase activity due to higher inorganic P present in the soil, likely from fertilization. Phosphorus fertilizer will generally suppress phosphatase enzyme since they are induced when nutrient supply is low (Olander and Vitousek, 2000). However, Manhattan AG had significantly high inorganic P with high P cycling enzymes (alkaline phosphatase and phosphodiesterase). This may have been due to soybeans taking up P and stimulating microbial releases fo P enzymes. Alkaline phosphatase is only produced by microbes (Lou et al., 2017). This study found trends in arylsulfatase (Fig. 3.27) activity, specifically significantly increased with decreasing soil similar to other enzymes. In addition, arylsulfatase activity increased with increased precipitation for NP, while NP had significantly higher activity than the cropping systems. Cropping systems decrease biological properties overtime. Cotton and Acosta-Martínez (2018) found a rapid decrease in soil health after one month of grassland conversion to conventional tillage in a semiarid Southern Plains of

Texas (470 mm yr-1). The study found a reduction of 52% microbial biomass carbon, 33% of SOC, 30% of TN, and 70% of β-glucosidase and phosphodiesterase activities in the top 10 cm (Cotton and Acosta-Martínez 2018).

Additional biological indicators for microbial activity, potentially available organic N, and labile C were quantified for sensitivity to management and precipitation. Autoclaved-citrate extractable protein content (Fig. 3.28) is the primary pool of organically bound N in soil available for mineralization (Hurisso et al., 2018). Autoclaved citrate extractable protein content was highest in Tribune. It decreased with increasing precipitation and depth, likely due to higher microbial activity for mineralization with increasing precipitation. Protein content significantly decreased in AG with increased precipitation due to higher microbial activity in wetter locations. Enhanced agriculture was expected to have higher ACE protein than AG since ACE protein is sensitive to tillage (Nicholas and Millar, 2013; Hurisso et al., 2018). However, only the Manhattan location had a significantly greater ACE protein in EA than AG at 5-10 cm. Protein content was not significantly different in EA at all locations, indicating that precipitation may not be a factor in no-till. For NP, ACE protein significantly decreased from Tribune to Hays and then significantly increased from Hays to Manhattan.

Permanganate-oxidizable carbon (Fig. 3.7) significantly increased with increasing precipitation in EA for all depths. This was likely due to greater carbon storage and accumulation with increasing precipitation since POXC represents long-term carbon sequestration and stock (Culman et al., 2012; Hurisso et al., 2018; Weil et al., 2003). For both NP and AG, POXC significantly increased from Tribune to Hays and then significantly decreased from Hays to Manhattan in the 0-5, 5-10, and 10-15 cm. This variation in labile soil C at each location and land use was unexpected. Several studies reveal POXC to be sensitive to land management (Weil

et al., 2003). However, Hays had higher POXC in AG than EA, while Manhattan had higher POXC in EA than AG; Tribune had no significant differences in POXC for the three depths. Thus, precipitation may not be the only factor influencing labile soil C, but also substrate diversity, C inputs, and soil type (Culman et al., 2012; Morrow et al., 2016). Iron and manganese minerology and speciation in soils may also bind labile carbon to form siderophores for microbial acquisition of metals (Bundy et al., 2018). However, extractable Fe and Mn concentrations did not follow POX trends and were not likely factors in labile carbon metabolism. Overall, our study found POXC to be not useful.

Soil respiration was based on rewetting air-dry soil to measure the potential microbial activity of mineralized SOM. Soil respiration (Fig. 3.5) increased with increasing precipitation in AG both 5-10 and 10-15 cm. Soil respiration did not follow similar trends between locations, indicating respiration was not sensitive to land management. Soil respiration in NP Tribune was significantly less than NP in Hays and Manhattan, which were both similar in soil respiration in the 5-10 and 10-15 cm depths.

Correlation and principal component analysis

The correlation matrix of soil properties in the top 15 cm shows strong correlations between soil microbial composition biological variables, respiration, protein, soil microbial community composition, and enzyme activity (Fig. 3.38). The correlation between microbial composition and enzyme indicators was likely due to soil microorganisms driving decomposition through the production of extracellular enzymes in a high organic matter environment (Don et al., 2017; Hsiao et al., 2018; Burns et al., 2013; Stone et al., 2014). A principal component analysis biplot of the biological soil properties described 80.3% of the variance (Fig. 3.39). The PCA biplot land use groupings had more variability in NP followed by EA and then AG, likely

due to plant diversity and soil microbial activity in NP leading to greater nutrient cycling and net primary productivity compared to cropping systems with reduced total microbial biomass (Don et al., 2017; Jangid et al., 2010). Biological properties were not significantly correlated with extractable P likely due to available P being negatively associated with the release of phosphatase and phosphodiesterase (Margalef et al., 2017; Lou et al., 2017).

Arbuscular mycorrhizal fungi and aggregation

Mycorrhizal fungi form symbiotic associations with the roots of more than 80% of land plants (Smith and Read, 1997). Simple linear regression (Table 3.7 and 3.8) for AMF and MWD (Fig. 3.40) and 8-2 mm (Fig. 3.41) aggregates by land use and location in the top 15 cm were highly correlated for wetter, less disturbed sites. The abundance of AMF and aggregate stability were highly correlated in NP compared to cropping systems, similar to Wilson et al. (2009). This indicates AMF abundance was a contributing factor to soil aggregation (Wilson et al., 2009; Nichols and Millar, 2013). Macroaggregates (>0.25 mm) comprised a significantly larger proportion of total aggregates in NP than the cropping systems. In general, AMF plays a major role in C translocation and sequestration (Finlay 2008; Wilson et al., 2009; Zhu and Miller, 2003).

Inconsistencies

There were aberrations between Hays and Manhattan for AG and EA. Hays EA had higher alkaline phosphatase, phosphodiesterase, arylsulfatase, protein, respiration, microbial biomass, Gram (+) bacteria, Gram (-) bacteria, AMF, than Hays AG. While Hays AG was higher than EA in actinomycetes, saprophytic fungi, and F: B ratio. Several biological and chemical properties at Manhattan AG were higher than Manhattan EA, inverse to trends at Hays AG an EA, causing a deviation in trends between Hays and Manhattan cropping systems. Manhattan

AG had greater pH, SOC, TN, P, alkaline phosphatase, phosphodiesterase, soil respiration, microbial biomass, Gram (+) bacteria, Gram (-) bacteria, actinomycetes, AMF, saprophytic fungi, F:B ratio, and C:N ratio, than that of Manhattan EA. Tribune AG and EA generally had similar trends in soil health properties. This may be due to the variation in cropping systems, particularly with crop rotation and intensity under different management practices. In our study, higher biological properties, SOC, and TN were found in Hays EA which was no-till with cover crops in rotation. These findings were similar to other studies (Sainju et al., 2003; Villamil et al., 2006; Olson et al., 2014; Mazzoncini et al., 2011). A meta-analysis from 60 studies on cover crops concluded cover crops to enhance microbial abundance, activity, and diversity (Kim et al., 2020). Cover crops also enhance near-surface soil physical properties and SOC (Blanco-Canqui et al., 2011). Blanco-Canqui et al. (2015) indicated that cover crops benefit agricultural systems by increasing SOC stocks, reducing erosion, suppressing weeds, reducing nutrient leaching, increasing crop yields, reducing runoff, lessening compaction, improving soil structure, and promoting microbial activity and biomass.Tthe Tribune site was converted from prairie into cultivation in 1989, whereas Hays and Manhattan AG began cultivation at least before 1960s, making conventional tilled cultivation >60 yrs (Jangid et al., 2010; Blanco-Canqui et al., 2011). The variation between cropping systems make it difficulty to compare single measurements in time without similar management history and time in cultivation. Soil health parameter should be monitored within a field for documenting soil health changes.

Recommendation

Based on soil health metrics measured within the top 15 cm, this study recommends a condensed set of metrics with the same 3 soil subdivisions of 0-5, 5-10, and 10-15 cm. However, 5-10 and 10-15 cm soil depths may be combined to reduce sampling size and labor. This study

recommends a reduced set of soil health metrics, specifically soil pH, SOC, TN, water-stable aggregates, PLFA, multi-enzyme assay (β-glucosidase, N-acetyl-β-glucosaminidase, phosphodiesterase, arylsulfatase), soil respiration, and autoclavabled extractable protein content. These soil metrics are sensitive to land use and climate (Cardoso et al., 2013). Soil pH, SOC, and TN can provide insight into soil fertility and nutrient availability. Water-stable aggregates can give insight to C sequestration and soil structure. Phospholipid fatty acid can profile soil microbial communities at a phenotypic level and give community structure and abundance. At the same time, enzyme assays can be linked with SOM cycling and nutrient availability. Soil respiration can convey potential biological activity from mineralization of SOM and autoclaved-extractable protein content can distinguish the available organic nitrogen pool for N mineralization to inorganic N.

Conclusions

In summary, land use and precipitation impact soil health parameters with greater effects in wetter areas of soil disturbance. No significant differences were found for MWD, macroaggregates, and bulk density between AG and EA. Native prairie generally had the highest soil health parameters than cropping systems (Beniston et al., 2014; DuPont et al., 2014; Jackson et al., 2003). The 0-5 cm soil depth generally had greater soil health values for all land uses than 5-10 and 10-15 cm. Cropping systems impacted soil pH, nutrient cycling, microbial activity, and enzyme production. Hays and Manhattan cropping systems had opposite biological and chemical properties between AG and EA. This suggests difficulty in comparing single time point measurements with varying management history and cultivation times. Overall, the differences in soil type, climate, land management, and vegetation were contributing factors in soil health that provide insight into the importance of biological, chemical, and physical interactions in soil.

The metrics used assessed soil health between land uses and locations, but management histories in cropping systems complicated soil health intrepretations.

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Tables

Table 3.1. Field IDs, latitude, longitude, field conditions during sampling, sample date, 30 years mean annual precipitation, sampling method, and soil type. MAP: mean annual precipitation; MAT: mean annual temperature.

Field IDs	Latitude	Longitude	Field condition	Sample date	MAP	MAT	Sampling Method	Soil Type
Manhattan AG	39°06'13.6"N	96°36'26.1"W	Soybean	13-Sep-19	850	12.7	Giddings	Reading silt loam
Manhattan EA	39°25'33.5"N	96°46'03.9"W	Post-corn harvest	21-Oct-21	850	12.7	Giddings	Tully silt clay loam
Manhattan NP	39°06'17.9"N	96°36'38.3"W	Mesic tallgrass prairie	13-Sep-19	850	12.7	Giddings	Reading silt loam
Hays AG	38º50’34.1 N	99º18’52.9 W	Post-sorghum harvest	15-Oct-21	579	12.1	Giddings	Harney soil loam
Hays EA	38°46'16.3 N	99°15'07.5 W	Post-sorghum harvest	20-Sep-19	579	12.1	Giddings	Harney soil loam
Hays NP	38°50'09.2"N	99°18'24.0"W	Mixed grass prairie	20-Sep-19	579	12.1	Giddings	Harney soil loam
Tribune AG	38°28'10.1"N	101°46'53.4"W	Wheat-grain, sorghum-fallow	20-Aug-19	472	11.1	Giddings	Richfield silt loam
Tribune EA	38°28'10.1"N	101°46'53.4"W	Fallow	20-Aug-19	472	11.1	Giddings	Richfield silt loam
Tribune NP	38°28'10.1"N	101°46'53.4"W	Native sod prairie	20-Aug-19	472	11.1	Giddings	Richfield silt loam
Tribune IR	38°34'47.1"N	101°44'48.0"W	Post-sorghum harvest	4-Nov-19	472	11.1	Pit	Richfield silt loam

Table 3.2. Field management history of selected fields across Kansas. Corn (*Zea mays*), Soybean (*Glycine max*), Wheat (*Triticum aestivum*), Sorghum (*Sorghum bicolor*). Cover crop mix varies with Triticale (*Triticale hexaploide* Lart.), oats (*Avena sativa*), alfalfa (*Medicago sativa*)

Field	Distance between Pedons (m)	Year 2000	Year 2010	Year 2020
Hays AG	40	Wheat-sorghum-fallow rotation, tillage	Wheat-sorghum-fallow rotation, tillage	Wheat-sorghum-fallow rotation, tillage
Hays EA	40	Wheat-sorghum-cover crop mix rotation, no-till	Wheat-sorghum-cover crop mix rotation, no-till	Wheat-sorghum-cover crop mix rotation, no-till
Hays NP	20	Mixed-grass prairie	Mixed-grass prairie	Mixed-grass prairie
Manhattan AG	20	Soybean-wheat-grain sorghum rotation, tillage	Soybean-wheat-grain sorghum rotation, tillage	Soybean-wheat-grain sorghum rotation, tillage
Manhattan EA	30	Corn-soybean rotation, no-till	Corn-soybean rotation, no-till	Corn-soybean rotation, no-till
Manhattan NP	20	Tallgrass prairie	Tallgrass prairie	Tallgrass prairie

Table 3.3. Phospholipid fatty acid biomarker designations based on different naming methods and product sources. Common: biomarker shared by most microbial groups, MW: molecular weight, Gram +: Gram (+) bacteria, Gram -: Gram (-) bacteria, actin: Actinomycetes. Chemist nomenclature uses delta system, where location of double bonds is noted by delta #, where # is the number of C atoms from carboxylic acid group. Ecologist nomenclature uses the omega system, where location of the double bond is w#, where # is the number of C atoms from the end of the fatty acid carbon chain. Delta notation conversion to omega notion is based on the difference between the total number of C atoms in the fatty acid and the location of the double bond.

Chemists	**Ecologist**	**Microbial group**	**Chemical name**	**MW**	**Product**
C11:0	11:0	common	methyl undecanoate	200	Matreya 1114
C12:0	12:0	common	methyl dodecanoate	214	Matreya 1114
C13:0	13:0	common	methyl tridecanoate	228	Matreya 1114
C14:0	14:0	common	methyl tetradecanoate	242	Matreya 1114
C15:0	15:0	common	methyl pentadecanoate	256	Matreya 1114
C16:0	16:0	common	methyl palmitate	270	Matreya 1114
C17:0	17:0	common	methyl heptadecanoate	284	Matreya 1114
C18:0	18:0	common	methyl stearate	298	Matreya 1114
C20:0	20:0	common	methyl eicosanoate	326	MilliporeSigma 10941
iso-C15:0 (i15:0)	i15:0	Gram +	methyl 13-methylhexadecanoate	256	Matreya 1114
anteiso-C15:0 (a15:0)	a15:0	Gram +	methyl 12-methyltetradecanoate	256	Matreya 1114
iso-C16:0 (i16:0)	i16:0	Gram +	methyl 14-methylpentadecanoate	270	Matreya 1114
iso-C17:0 (i17:0)	i17:0	Gram +	methyl 15-methylhexadecanoate	284	Matreya 1114
anteiso-C17:0 (a17:0)	a17:0	Gram +	methyl 14-methylhexadecanoate	284	Matreya 1614
iso-C17:1_delta 10	i17:1w7c	desulfovibrio bac		282	Matreya 1114
C16:1_delta 9 (C16:1:0:cis)	16:1w7	Gram -	methyl cis-9-hexadecanoate	268	Matreya 1114
C17:0_delta 9,10 (17:0:delta9,)	cy17:0	Gram - & +	methyl cis-9,10-methylenehexadecanoate	282	Matreya 1114

Table 3.3. Continued.

C19:0_delta 9,10 (19:0:delta9,10)	cy19:0	Gram - & +	methyl cis-9,10-methyleneoctadecanoate	310	Matreya 1114
C18:1_delta 11 (C18:1:11:cis)	18:1w7	Gram -	methyl cis-11-octadecenoate	294	MilliporeSigma 17264
2-OH C10:0 (C10:0:2-OH)	2-OH 10:0	Gram -	methyl 2-hydroxydecanoate	202	Matreya 1114
2-OH C12:0 (C12:0:2-OH)	2-OH 12:0	Gram -	methyl 2-hydroxydodecanoate	230	Matreya 1114
3-OH C12:0 (C12:0:3-OH)	3-OH 12:0	Gram -	methyl 3-hydroxydodecanoate	230	Matreya 1114
2-OH C14:0 (C14:0:2-OH)	2-OH 14:0	Gram -	methyl 2-hydroxytetradecanoate	258	Matreya 1114
3-OH C14:0 (C14:0:2-OH)	3-OH 14:0	Gram -	methyl 3-hydroxytetradecanoate	258	Matreya 1114
2-OH C16:0 (C16:0:2-OH)	2-OH 16:0	Gram -	methyl 2-hydroxyhexadecanoate	286	Matreya 1114
C16:1_delta 11 (C16:1:11)	16:1w5c	AMF, G-	methyl cis-11-hexadecenoate	268	Matreya custom synthesis
C18:1_delta 9	18:1w9c	Fungi & bac	methyl oleate	296	Matreya 1114
C18:2_delta 9,12 (C18:2:9,12)	18:2w9,12c	Fungi	methyl linoleate	294	Matreya 1114
C18:2_delta 6,9,12	18:2w6,9,12	Fungi	methyl 6,9,12-octadecatrienoate	292	Matreya 1114
10 Methyl C16:0 (10Me16:0)	10Me 16:0	Actin	methyl 10-methylhexadecanoate	284	Cayman Chemical 24823
10 Methyl C18:0 (10Me18:0)	10Me18:0	Actin	methyl 10-methyloctadecanoate	312	Larodan 21-1810
C19:0	19:0	Internal standard	methyl nonadecanoate	312	MilliporeSigma N5377

Table 3.4. Multi-enzyme function, common substrates, and indicators.

Enzyme	abbr.	Enzyme function	Common substrates	Indicator
β-glucosidase	bG	Release β-D-glucose from cellulose	cellulose	C-cycling
N-acetyl-glucosaminidase	NAG	Hydrolysis of glycosidic (N-acetyl-β-glucosaminide) bonds in chitin	chitin & peptidoglycan	Semi-quantitative indicator of soil fungal biomass, both C/N cycling
Acid phosphatase	AP	Release phosphate groups	phospholipids, phosphosaccharides	P-cycling
Alkaline phosphatase	ALP	Release phosphate groups	phospholipids, phosphosaccharides	P-cycling
Phosphodiesterase	PHO	Degradation of nucleic acids	nucleotides	nucleic acid cycling
Arylsulfatase	ARY	Release of SO_4	Arylsulfate	S-cycling

Table 3.5. Multi-enzyme substrate, start buffer, and supporting references.

Enzyme	Substrate	Catalog number (Sigma-Aldrich, St. Loius, MO, USA)	Buffer and pH	Reference
β-Glucosidases	p-Nitrophenyl-β-d-glucopyanoside (0.05 M, 1.506 g/100 mL buffer)	N-7006	MUB, pH 6.0	Eivazi and Tabatabai, 1988
β-glucosaminidase	p-Nitrophenyl-N-acetyl-β-dglucopyanoside (0.01 M, 0.342 g/100 mL buffer)	N-9376	0.1 M acetate buffer, pH 5.5	Parham and Deng, 2000
Phosphodiesterase	Bis-p-Nitrophenyl phosphate (0.05, 1.82 g/ 100 buffer)	N-3002	0.05 THAM, pH 8.0	Browman and Tabatabai, 1978
Acid Phosphate	p-Nitrophenyl phosphate disodium hexahydrate (0.05 M, 1.85 g/ 100 buffer)	N-2645	MUB, pH 6.0	Tabatabai and Bremner, 1969; Eivazi and Tabatabai, 1977
Alkaline Phosphate	p-Nitrophenyl phosphate disodium hexahydrate (0.05 M, 1.86 g/ 100 buffer)	N-2645	MUB, pH 11.0	Tabatabai and Bremner, 1969; Eivazi and Tabatabai, 1977
Arylsulfatase	p-Nitrophenyl sulfate (0.05 M, 1.228 g/100 mL buffer)	N-3877	0.5 M acetic buffer, pH 5.8	Tabatabai and Bremner, 1970

Table 3.6. Summary of the p-values from ANOVA for effects of land use and precipitation on physical soil properties in the 0-5, 5-10, and 10-15 cm depth. MWD: mean weight diameter; WSA: water-stable aggregates.

*, **, *** Significant at 0.05, 0.01, and 0.001 probability levels, respectively.

0-5 cm	MWD	WSA 8-2 mm	WSA 2-0.25 mm	WSA 0.25-0.053 mm	WSA 0.053-0.02 mm	Bulk Density
Land Use (LU)	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **
Location (L)	0.984	0.839	**0.018 ***	0.609	0.069	0.082
LU*L	0.327	0.396	0.344	**0.022 ***	0.926	0.072
5-10 cm	MWD	WSA 8-2 mm	WSA 2-0.25 mm	WSA 0.25-0.053 mm	WSA 0.053-0.02 mm	Bulk Density
Land Use (LU)	**<0.001 *** **	**<0.001 *** **	**0.001 ** **	**<0.001 *** **	**<0.001 *** **	0.092
Location (L)	0.878	0.697	**<0.001 *** **	0.6	0.299	**0.002 ** **
LU*L	**0.002 ** **	**0.007 ** **	**0.002 ** **	**0.007 ** **	**<0.001 *** **	0.901
10-15 cm	MWD	WSA 8-2 mm	WSA 2-0.25 mm	WSA 0.25-0.053 mm	WSA 0.053-0.02 mm	Bulk Density
Land Use (LU)	**<0.001 *** **	**<0.001 *** **	**0.024 ***	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **
Location (L)	0.268	0.22	0.298	0.389	0.351	0.141
LU*L	0.483	0.584	0.401	0.308	**0.029 ***	0.409

Table 3.7. Summary of the p-values from ANOVA for effects of land use and precipitation on chemical soil properties in the 0-5, 5-10, 10-15 cm depth. SOC: soil organic carbon; TN: total nitrogen; Ca: calcium; Cu: copper; Mg: magnesium; Mn: Manganese; Na: sodium; P: phosphorus; K: potassium; Zn: zinc; Fe: iron.

*, **, *** Significant at 0.05, 0.01, and 0.001 probability levels, respectively.

0-5 cm	pH	SOC	TN	Ca	Cu	Mg
Land Use (LU)	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **
Location (L)	**<0.001 *** **	0.249	0.057	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **
LU*L	**<0.001 *** **	**0.006 ** **	**0.007 ** **	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **
0-5 cm	Mn	Na	P	K	Zn	Fe
Land Use (LU)	0.539	0.172	**<0.001 *** **	0.178	**<0.001 *** **	**<0.001 *** **
Location (L)	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **	**0.030 * **	0.834
LU*L	**0.001 ** **	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **	**0.02 * **	**<0.001 *** **
5-10 cm	pH	SOC	TN	Ca	Cu	Mg
Land Use (LU)	**0.019 * **	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **	**0.002 ** **	**<0.001 *** **
Location (L)	**0.003 ** **	**<0.001 *** **	0.104	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **
LU*L	**<0.001 *** **	**<0.001 *** **	**0.028 * **	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **
5-10 cm	Mn	Na	P	K	Zn	Fe
Land Use (LU)	0.196	**0.007 ** **	**<0.001 *** **	**0.016 * **	**<0.001 *** **	**<0.001 *** **
Location (L)	**0.001 ** **	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **	0.226	**0.001 ** **
LU*L	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **
10-15 cm	pH	SOC	TN	Ca	Cu	Mg
Land Use (LU)	0.203	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **	0.715	**<0.001 *** **
Location (L)	0.476	**<0.001 *** **	0.144	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **
LU*L	**<0.001 *** **	**<0.001 *** **	**0.004 ** **	**0.001 ** **	0.417	**<0.001 *** **
10-15 cm	Mn	Na	P	K	Zn	Fe
Land Use (LU)	0.079	**0.047 * **	**0.003 ** **	**0.021 * **	0.101	**0.003 ** **
Location (L)	**0.049 * **	**0.007 ** **	**<0.001 *** **	**<0.001 *** **	0.148	**<0.001 *** **
LU*L	**0.002 ** **	**0.003 ** **	**0.009 ** **	**0.046 * **	0.147	**<0.001 *** **

Table 3.8. Summary of the p-values from ANOVA for effects of land use and precipitation on biological soil properties in the 0-5, 5-10, and 10-15 cm depth. bG: β-glucosidase; NAG: N-acetyl-β-glucosaminidase; AP: acid phosphatase; ALP: alkaline phosphatase; ARY: arylsulfatase; PHO: phosphodiesterase; ACE P: autoclaved citrate extractable protein; POXC: permanganate-oxidizable carbon; MB: microbial biomass; Gram +: Gram-positive bacteria; Gram -: Gram-negative bacteria; AMF: arbuscular mycorrhizal fungi; F:B: ((Gram+)+(Gram-)+(Actinomycetes))/(AMF + Fungi). *, **, *** Significant at 0.05, 0.01, and 0.001 probability levels, respectively.

0-5 cm	bG	NAG	AP	ALP	PHO	ARY	ACE P	POXC
Land Use (LU)	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****
Location (L)	**<0.001 *****	0.069	**<0.001 *****	**.014 ***	**<0.001 *****	**<0.001 *****	**0.003 ****	**<0.001 *****
LU*L	**<0.001 *****	0.036	**<0.001 *****	**<0.001 *****	**0.02 ***	**<0.001 *****	**<0.001 *****	**<0.001 *****
0-5 cm	Respiration	MB	Gram +	Gram -	Actinomycetes	AMF	Fungi	F: B
Land Use (LU)	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**0.007 ****
Location (L)	**<0.001 *****	**0.008 ****	**0.022 ***	**0.008 ****	**<0.001 *****	**<0.001 *****	**0.044 ***	**0.006 ****
LU*L	**<0.001 *****	**<0.001 *****	**0.003 ****	**0.021 ***	**0.002 ****	**<0.001 *****	**0.004 ****	0.104
5-10 cm	bG	NAG	AP	ALP	PHO	ARY	ACE P	POXC
Land Use (LU)	0.123	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****
Location (L)	0.245	0.989	**<0.001 *****	**0.008 ****	**<0.001 *****	**<0.001 *****	**0.0179 ***	**<0.001 *****
LU*L	0.231	0.001 **	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**0.011 ***	**<0.001 *****
5-10 cm	Respiration	MB	Gram +	Gram -	Actinomycetes	AMF	Fungi	F: B
Land Use (LU)	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	0.341
Location (L)	**<0.001 *****	**0.0133 ***	**0.011 ***	0.076	**<0.001 *****	**<0.001 *****	**0.036 ***	0.182
LU*L	**<0.001 *****	**0.003 ****	**<0.001 *****	**0.037 ***	**<0.001 *****	**<0.001 *****	**0.01 ***	0.265
10-15 cm	bG	NAG	AP	ALP	PHO	ARY	ACE P	POXC
Land Use (LU)	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****
Location (L)	**<0.001 *****	**0.016 ***	**<0.001 *****	0.09	**0.0139 ***	**.041 ***	0.781	**<0.001 *****
LU*L	**0.015 ***	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	0.573	**<0.001 *****
10-15 cm	Respiration	MB	Gram +	Gram -	Actinomycetes	AMF	Fungi	F: B
Land Use (LU)	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****
Location (L)	**<0.001 *****	**<0.001 *****	**<0.001 *****	0.034	**<0.001 *****	**<0.001 *****	**<0.001 *****	0.06
LU*L	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	**<0.001 *****	0.07

Figures

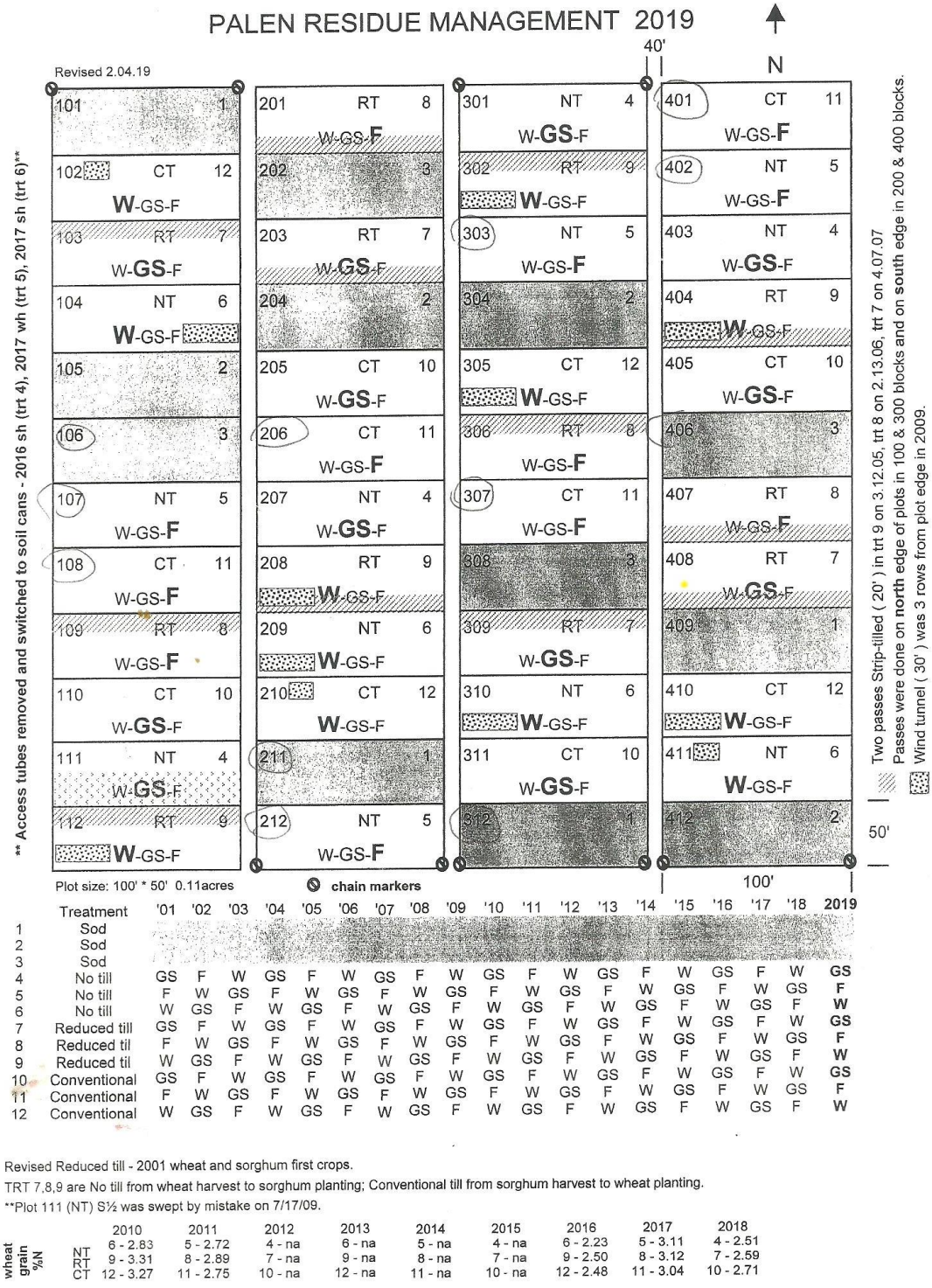

Figure 3.1. Tribune, KS randomized split block design.

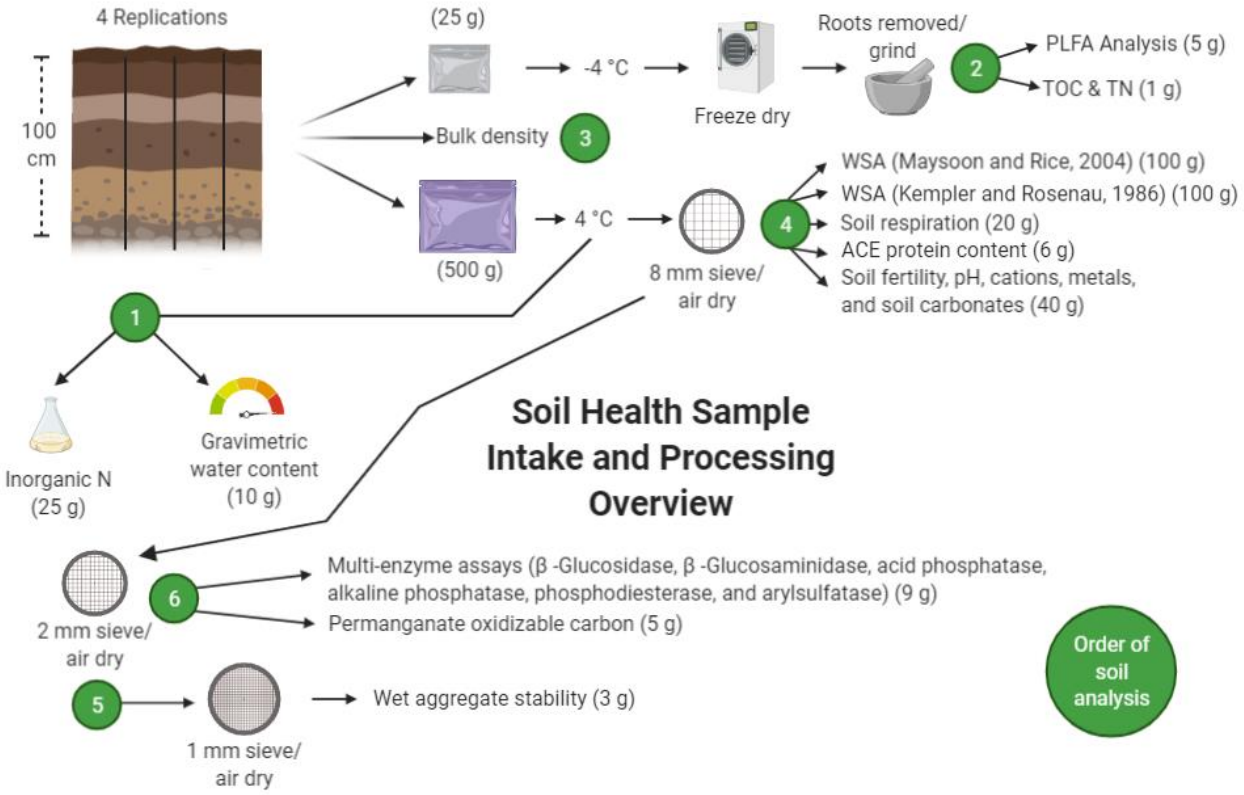

Figure 3.2. Soil sample intake and processing overview with the order of soil analysis and the relative amount of soil per sample needed for each analysis.

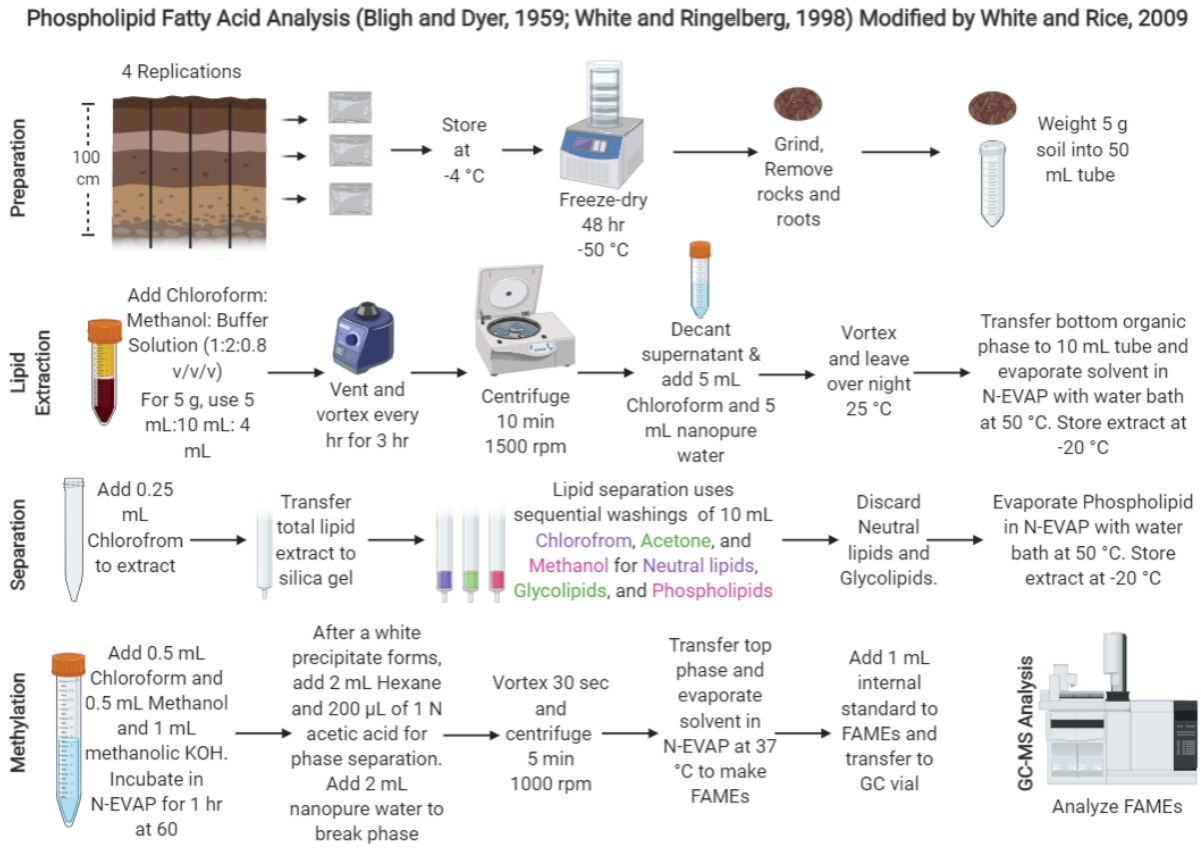

Figure 3.3. Phospholipid fatty acid analysis method based on White and Rice, 2009 modification of White and Ringelberg, 1998 modification of Blight and Dyer, 1959.

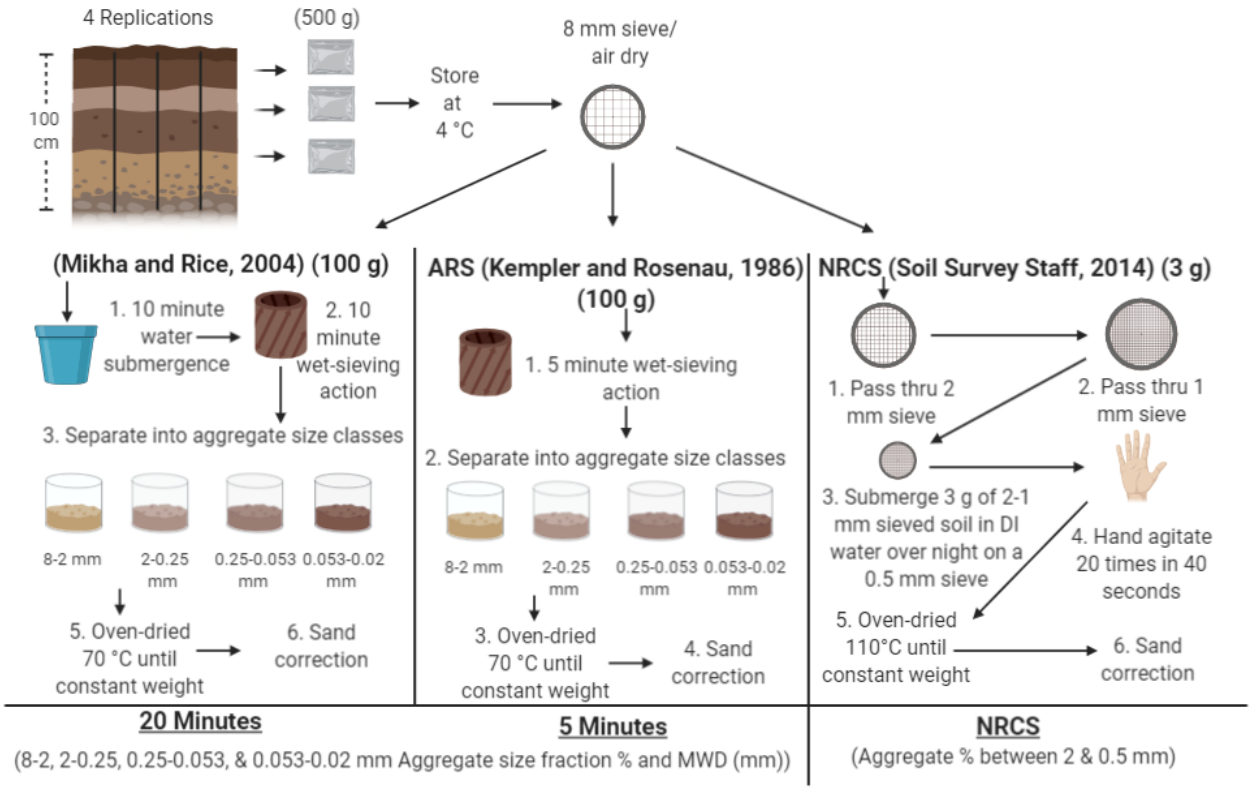

Figure 3.4. Simplified soil aggregate stability and size class methods for methods comparison.

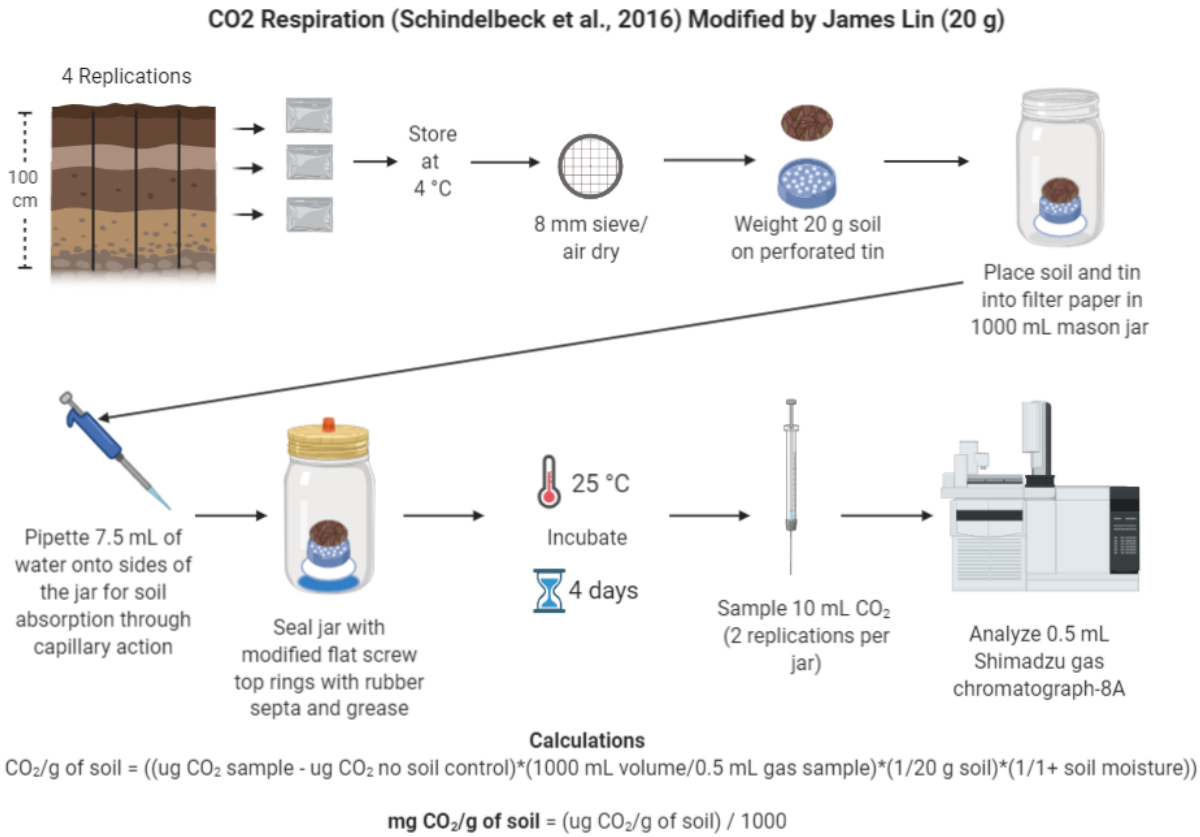

Figure 3.5. A modified version of the 4-day soil respiration method by Schindelbeck et al. (2016).

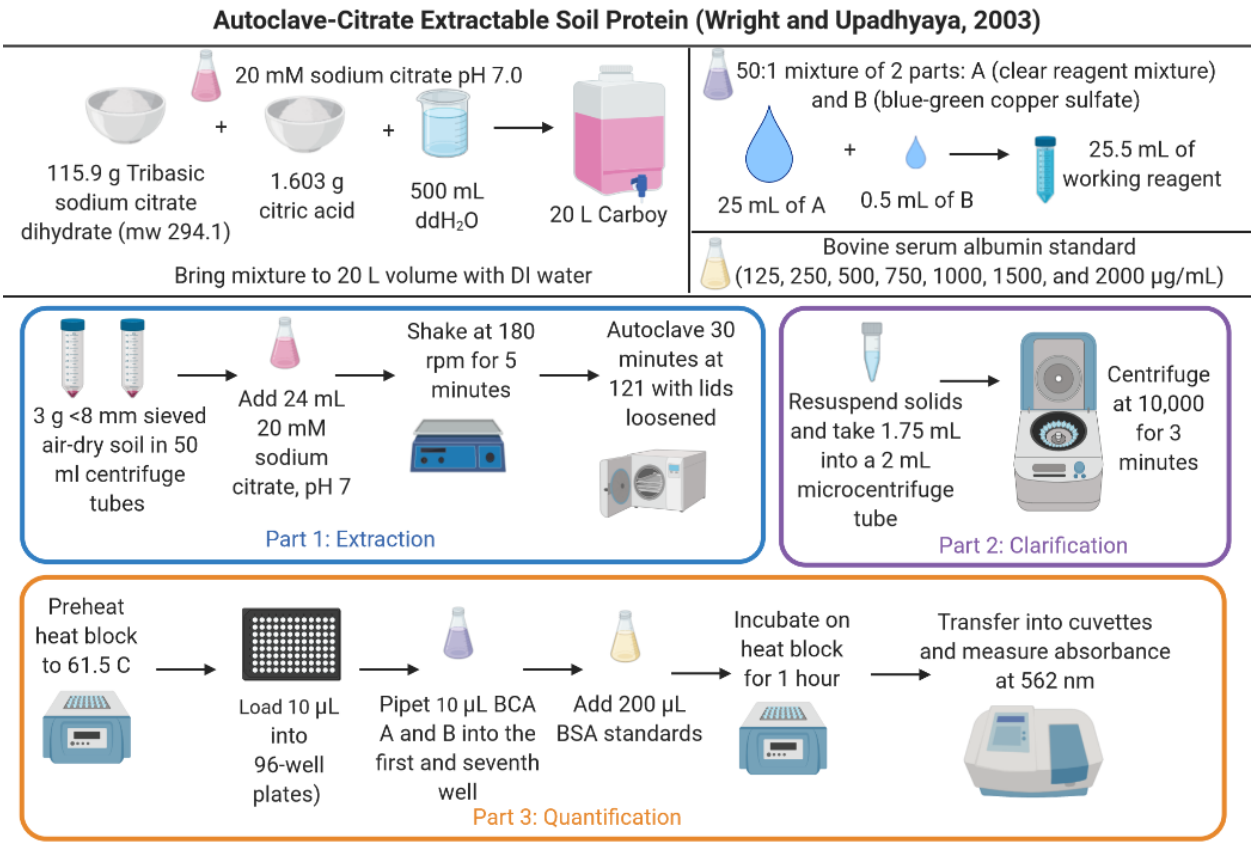

Figure 3.6. Autoclaved-citrate extractable soil protein method by Wright and Upadhyaya (2003).

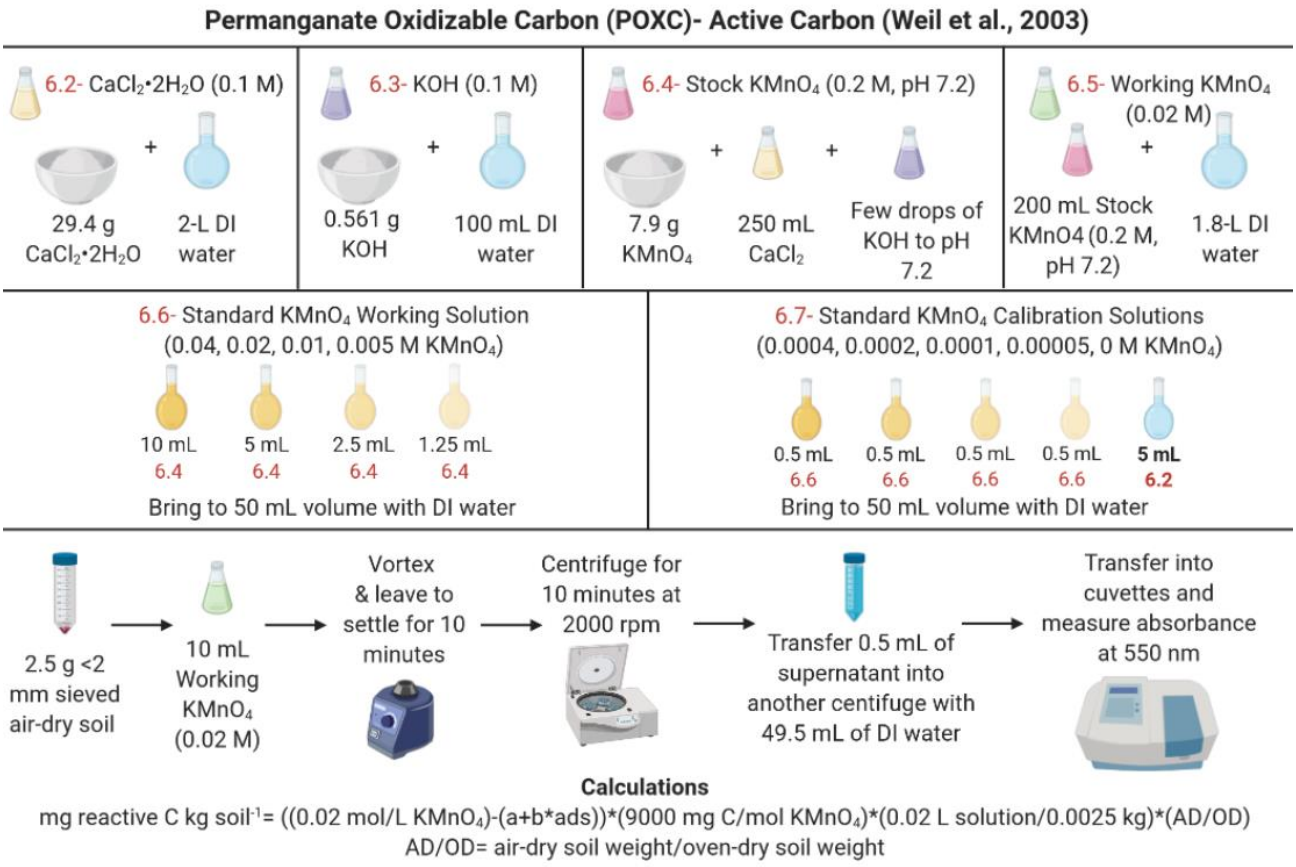

Figure 3.7. Permanganate-oxidizable carbon method by Weil et al. (2003).

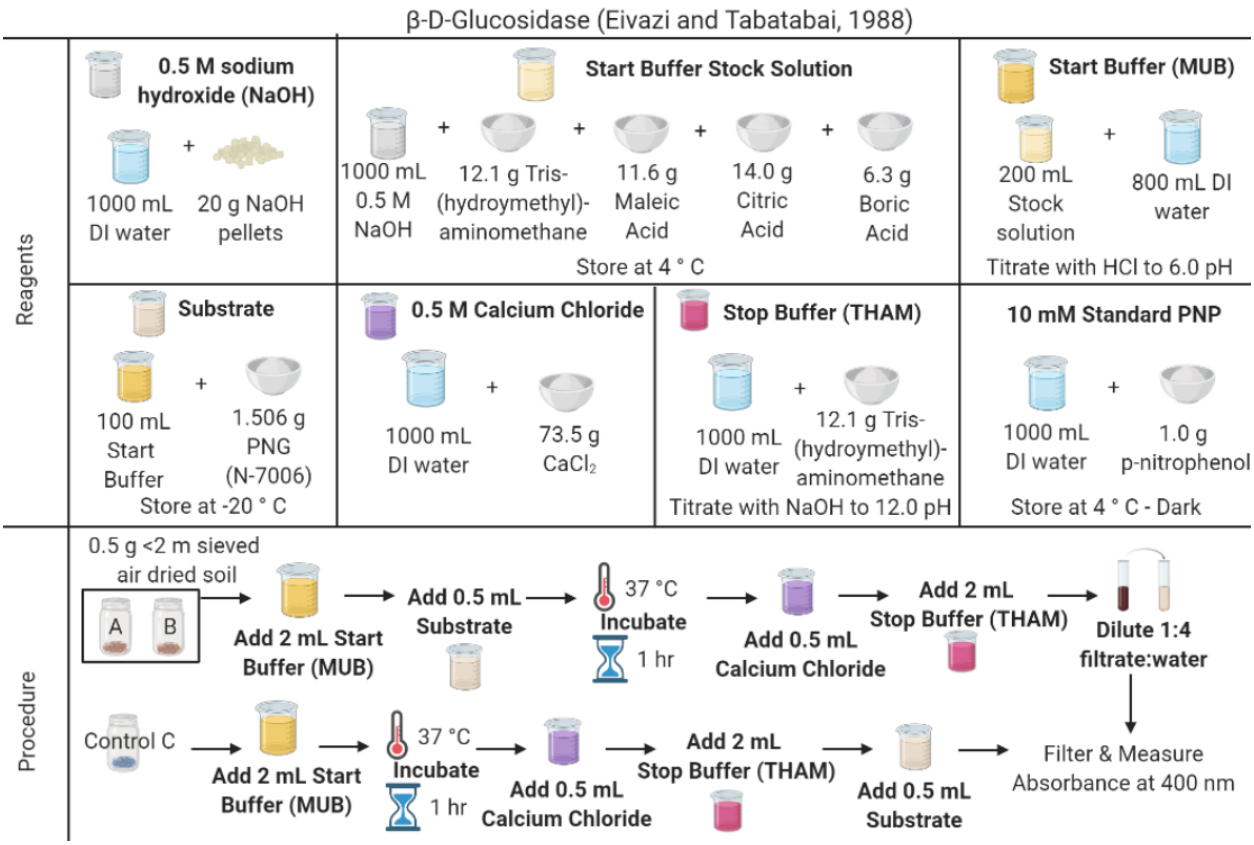

Figure 3.8. β-Glucosidase modified version from Eivazi and Tabatabai (1988).

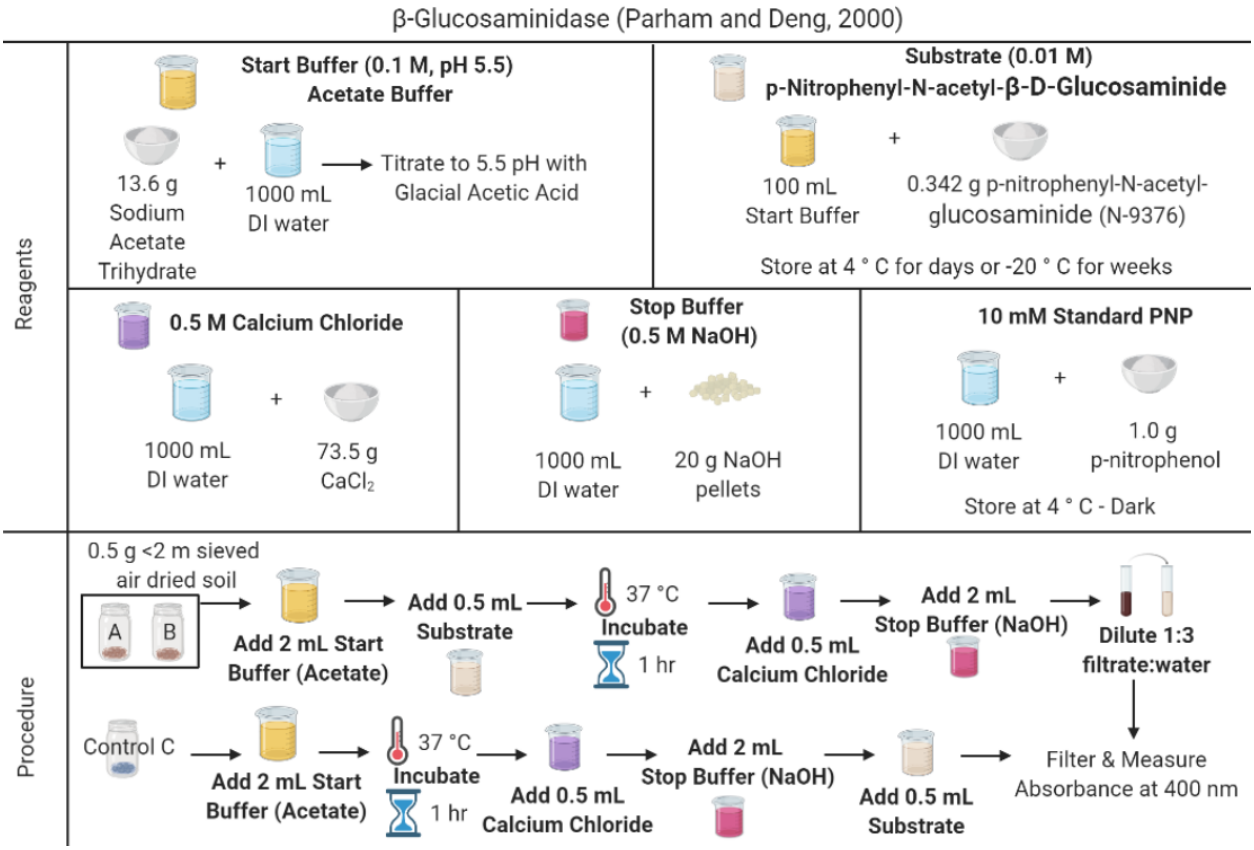

Figure 3.9. N-Acetyl-β-glucosaminidase modified version from Parham and Deng (2000).

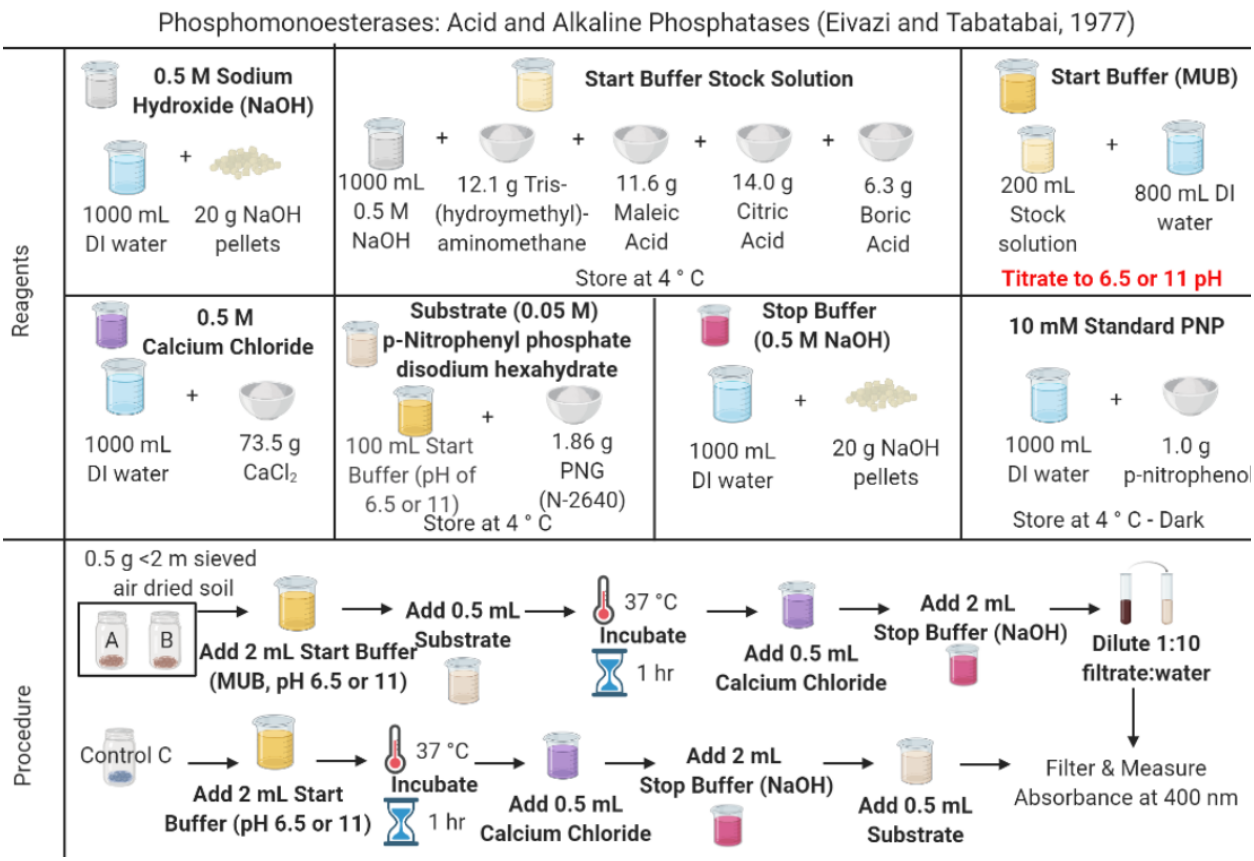

Figure 3.10. Acid and Alkaline Phosphatase modified version from Tabatabai and Bremner (1969), and Eivazi and Tabatabai (1977).

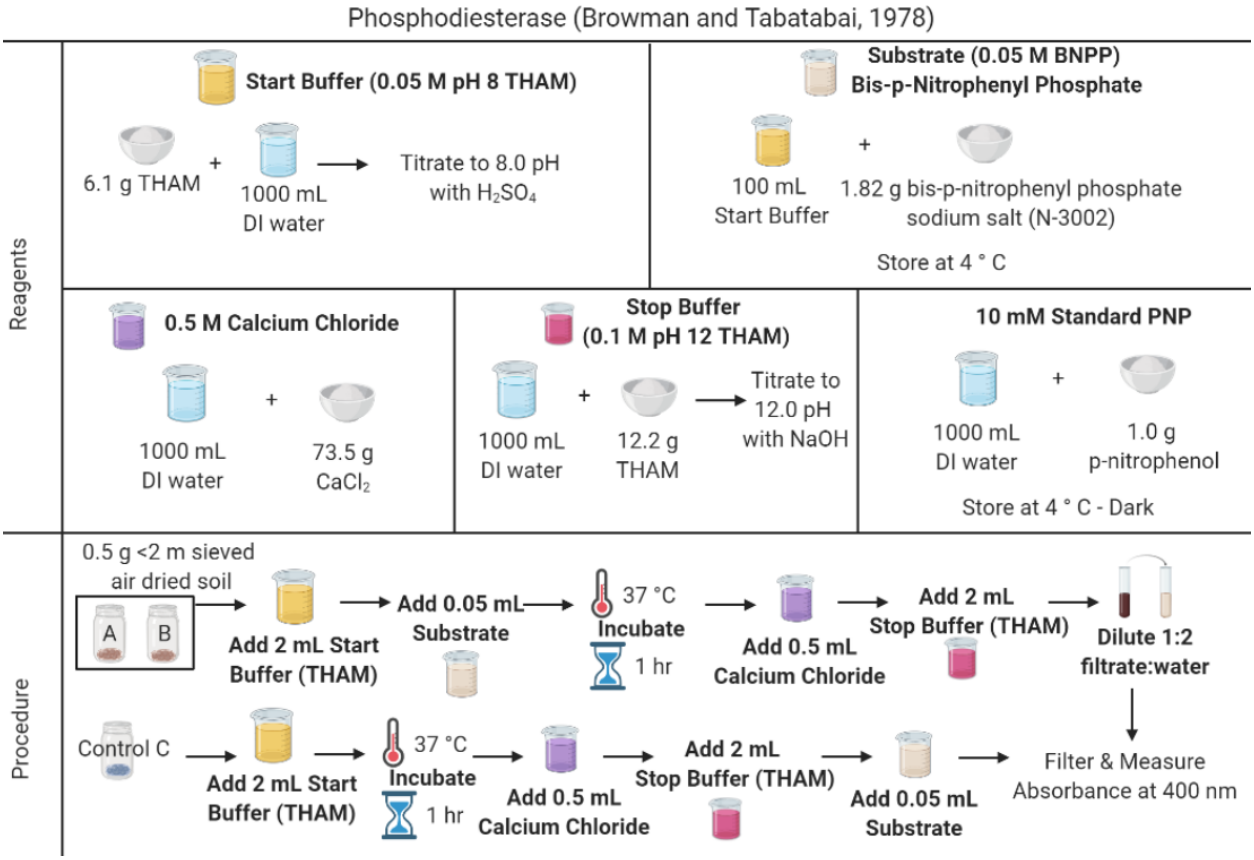

Figure 3.11. Phosphodiesterase modified version from Browman and Tabatabai (1978).

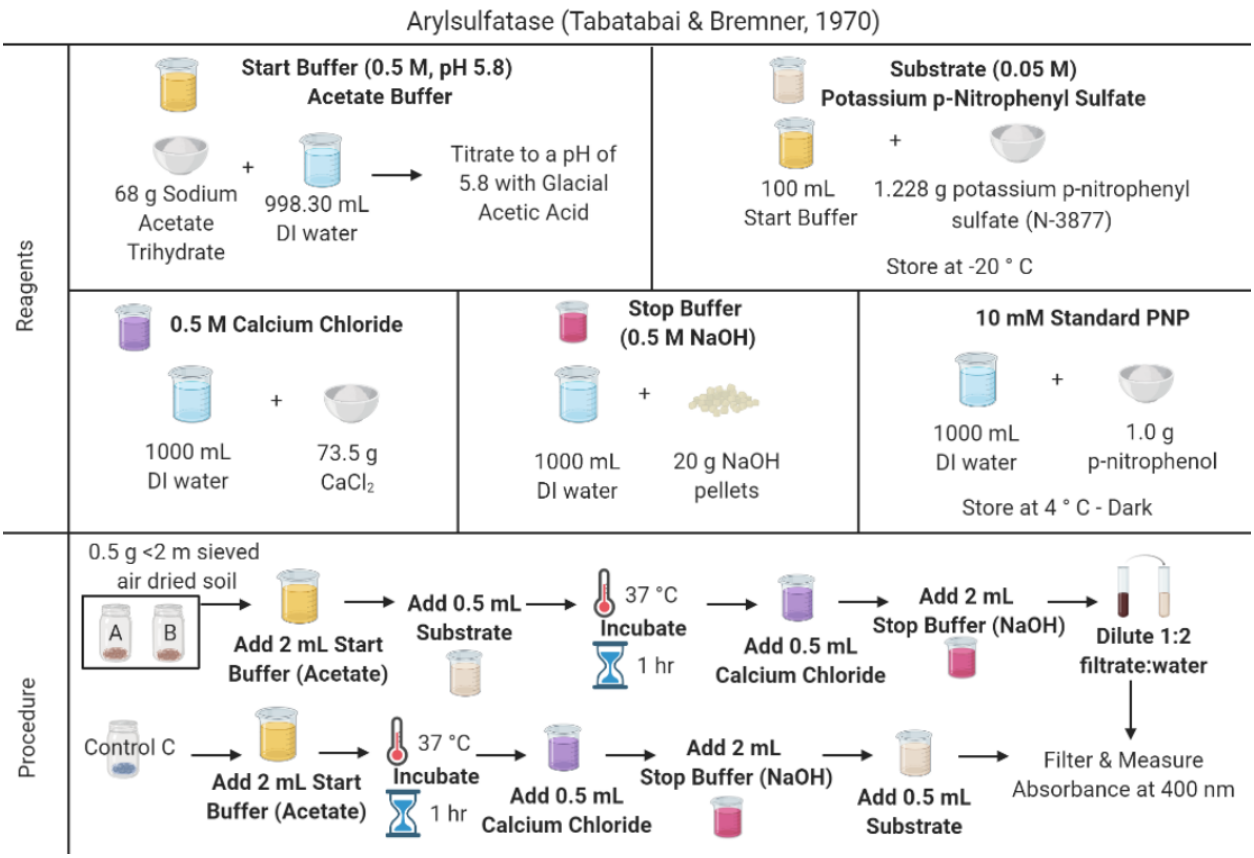

Figure 3.12. Arylsulfatase modified version from Tabatabai and Bremner (1970).

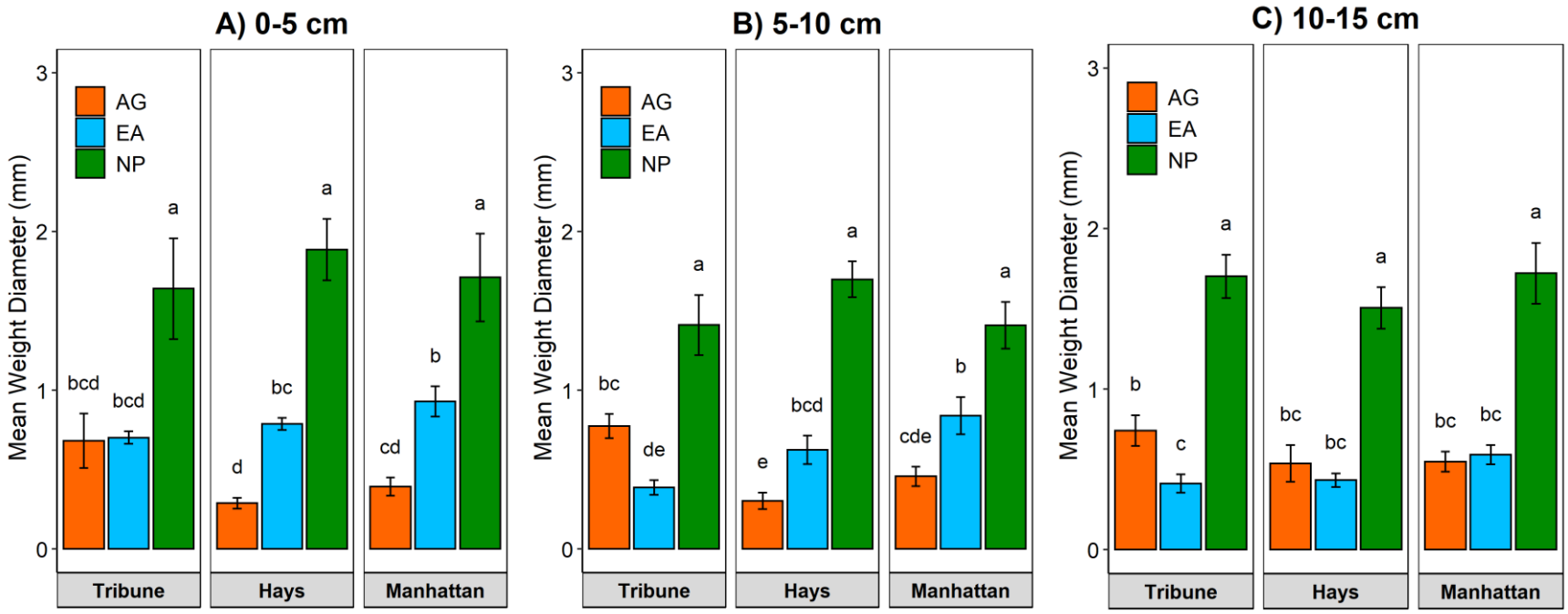

Figure 3.13. Mean weight diameter by land use and precipitation in top 15 cm soil. Land use effect in 0-5 cm (A), land use and precipitation interaction in 5-10 cm (B), and land use effect in 10-15 cm (C). ANOVA with letters representing significant differences ($p<0.05$).

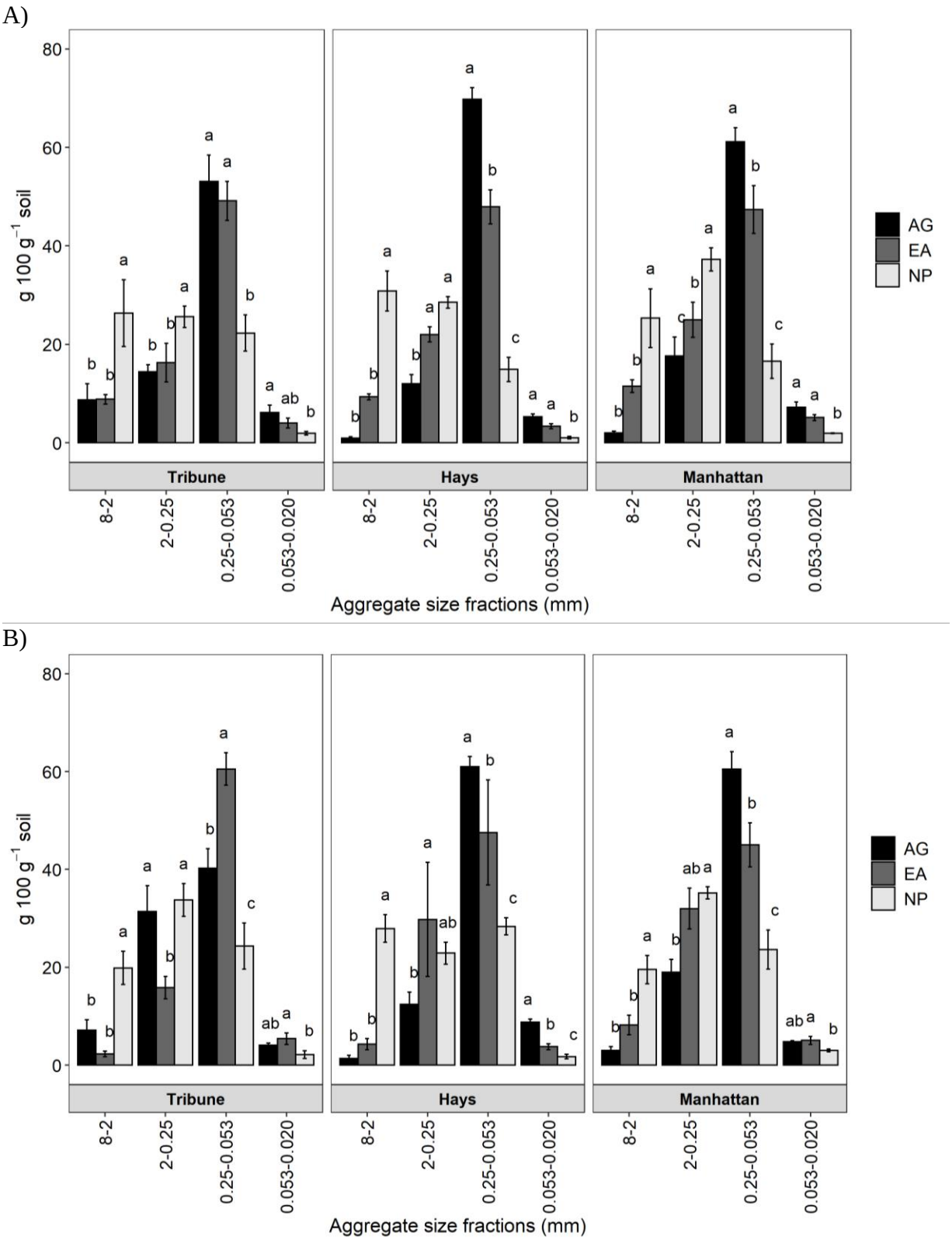

Figure 3.14. Aggregate fraction distribution by land use and precipitation in top 15 cm soil. ANOVA with letters representing significant differences ($p<0.05$).

C)

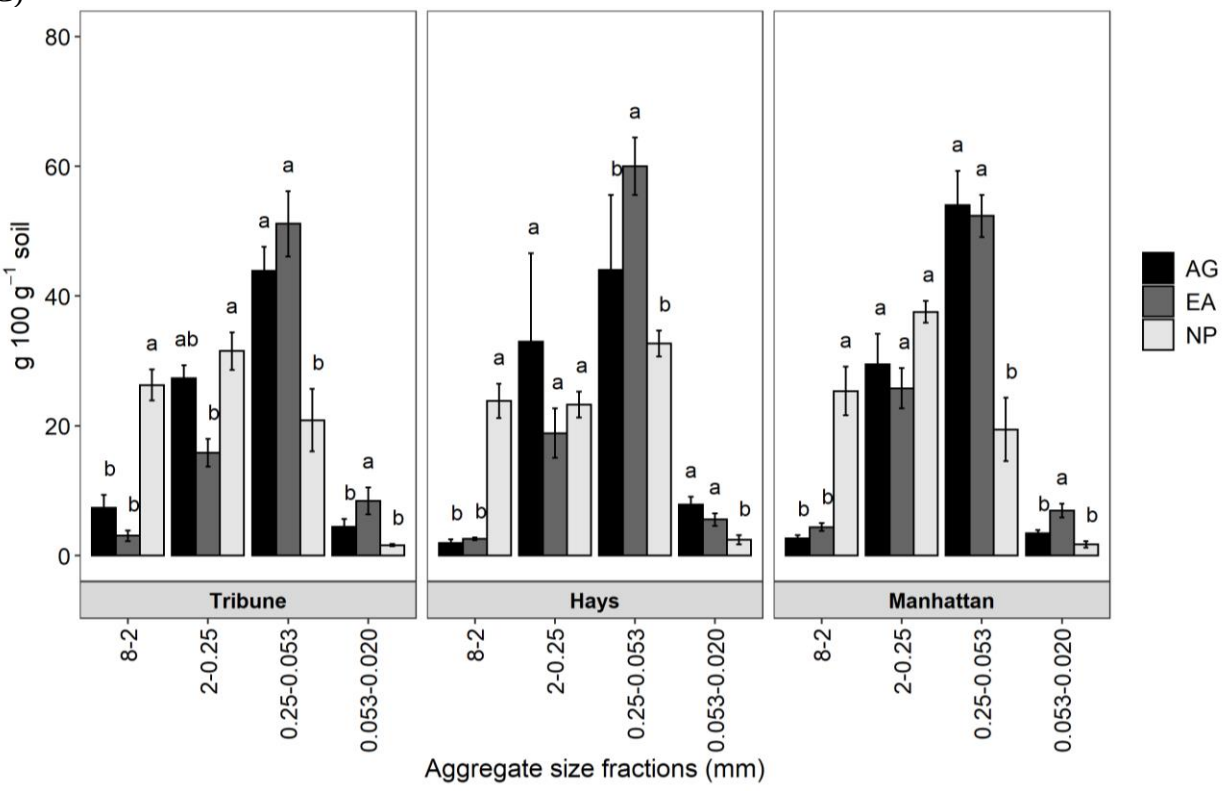

Figure 3.14. Continued.

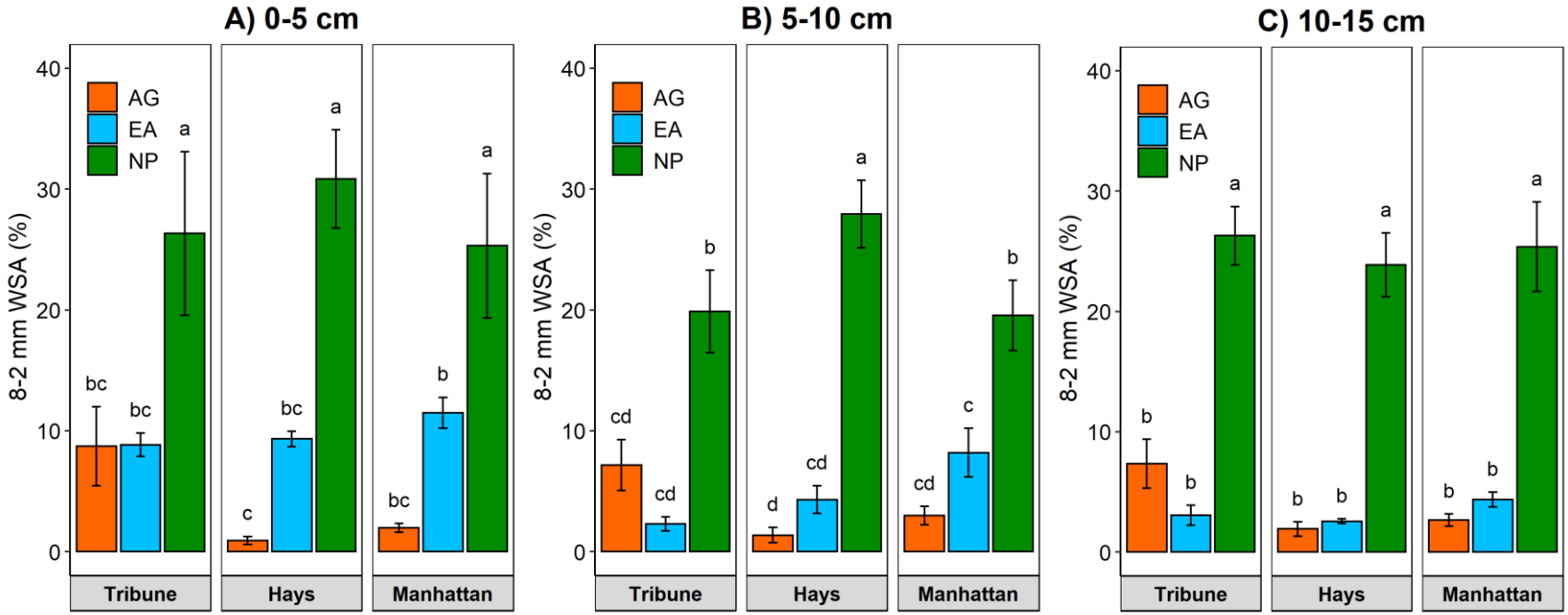

Figure 3.15. Water stable aggregate fractions in the 8-2 mm size class by land use and precipitation in top 15 cm soil. Land use effect in 0-5 cm (A), land use and precipitation interaction in 5-10 cm (B), and land use effect in 10-15 cm (C). ANOVA with letters representing significant differences ($p<0.05$).

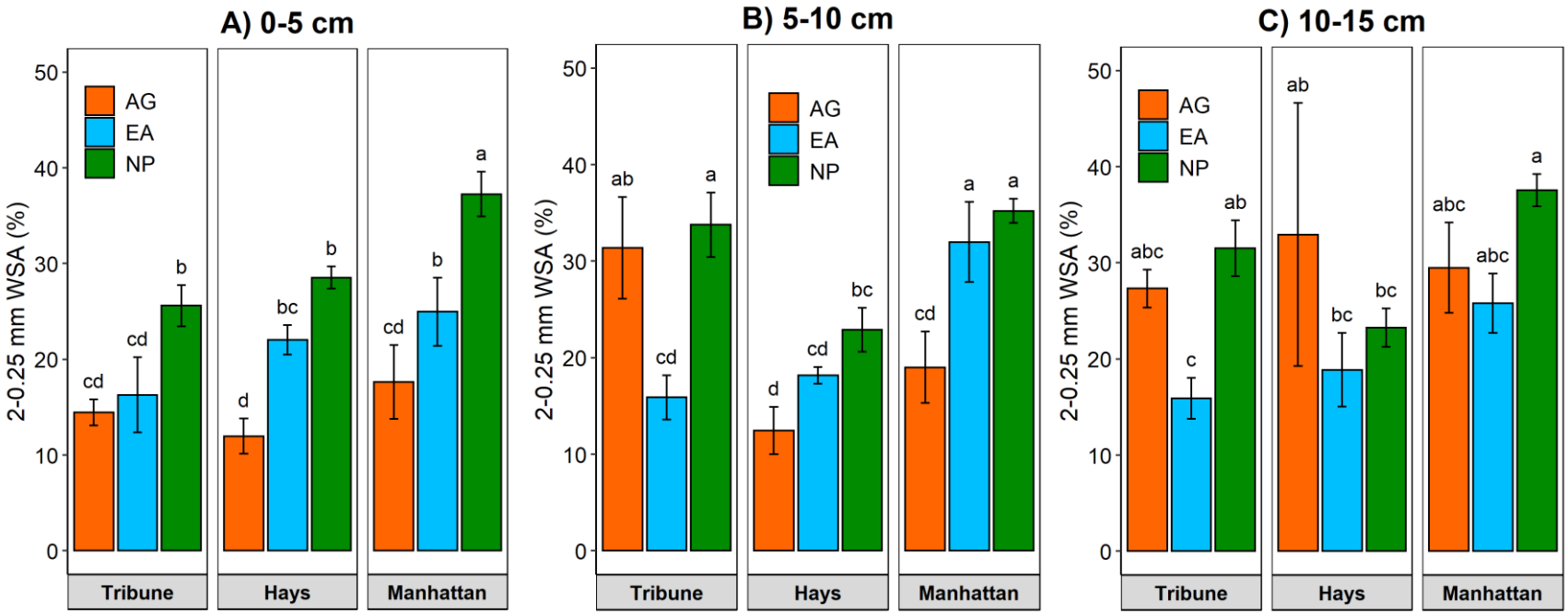

Figure 3.16. Water stable aggregate fractions in the 2-0.25 mm size class by land use and precipitation in top 15 cm soil. Land use and precipitation effect in 0-5 cm (A), land use and precipitation interaction in 5-10 cm (B), and land use effect in 10-15 cm (C). ANOVA with letters representing significant differences ($p<0.05$).

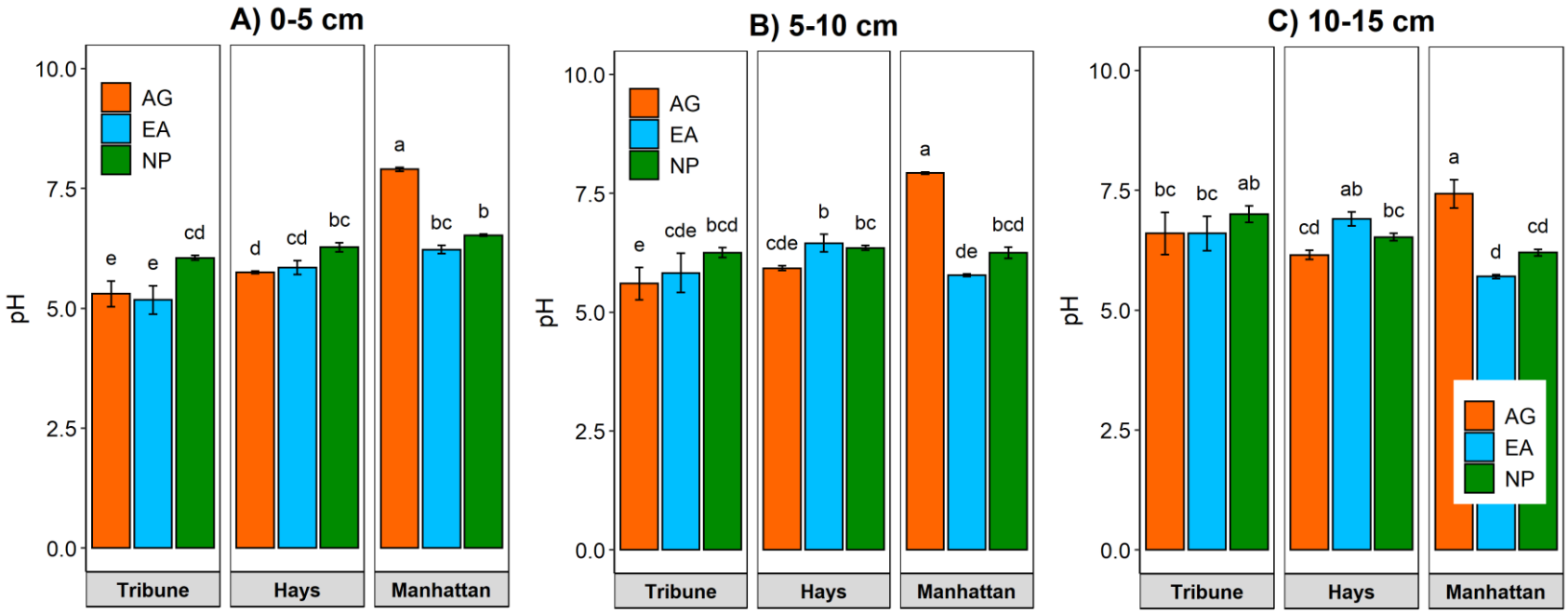

Figure 3.17. Soil pH by land use and precipitation in top 15 cm soil. Land use and precipitation interaction in 0-5 cm (A), 5-10 cm (B), and 10-15 cm (C). ANOVA with letters representing significant differences ($p<0.05$).

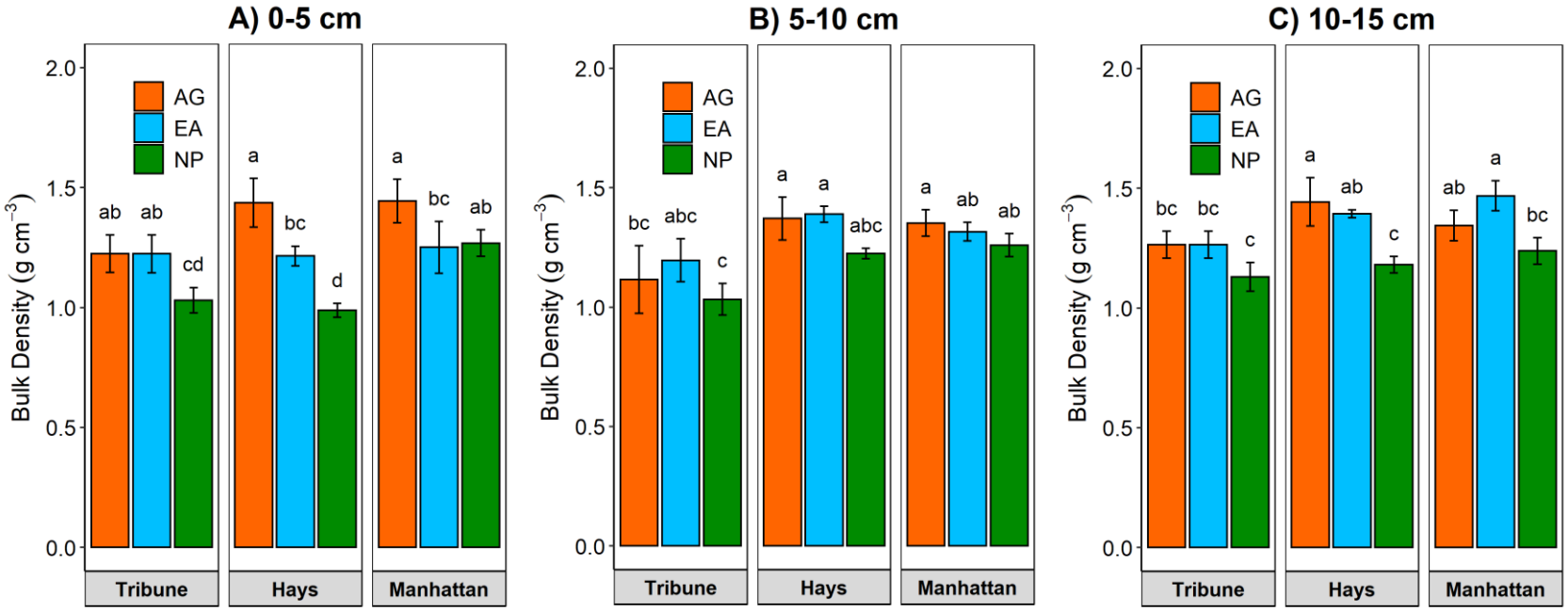

Figure 3.18. Bulk density by land use and precipitation in top 15 cm soil. Land use effect in 0-5 cm (A), precipitation effect in 5-10 cm (B), and land use effect in 10-15 cm (C). ANOVA with letters representing significant differences ($p<0.05$).

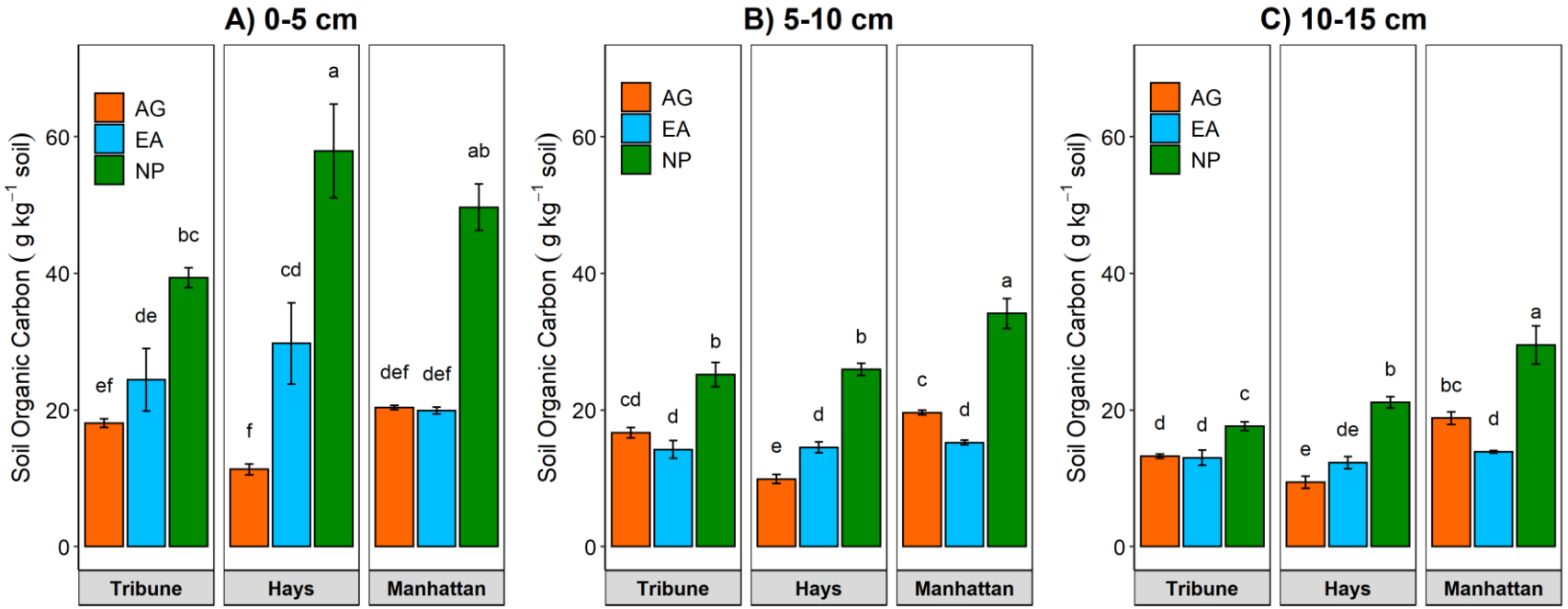

Figure 3.19. Soil organic carbon by land use and precipitation in top 15 cm soil. Land use and precipitation interaction in 0-5 cm (A), 5-10 cm (B), and 10-15 cm (C). ANOVA with letters representing significant differences ($p<0.05$).

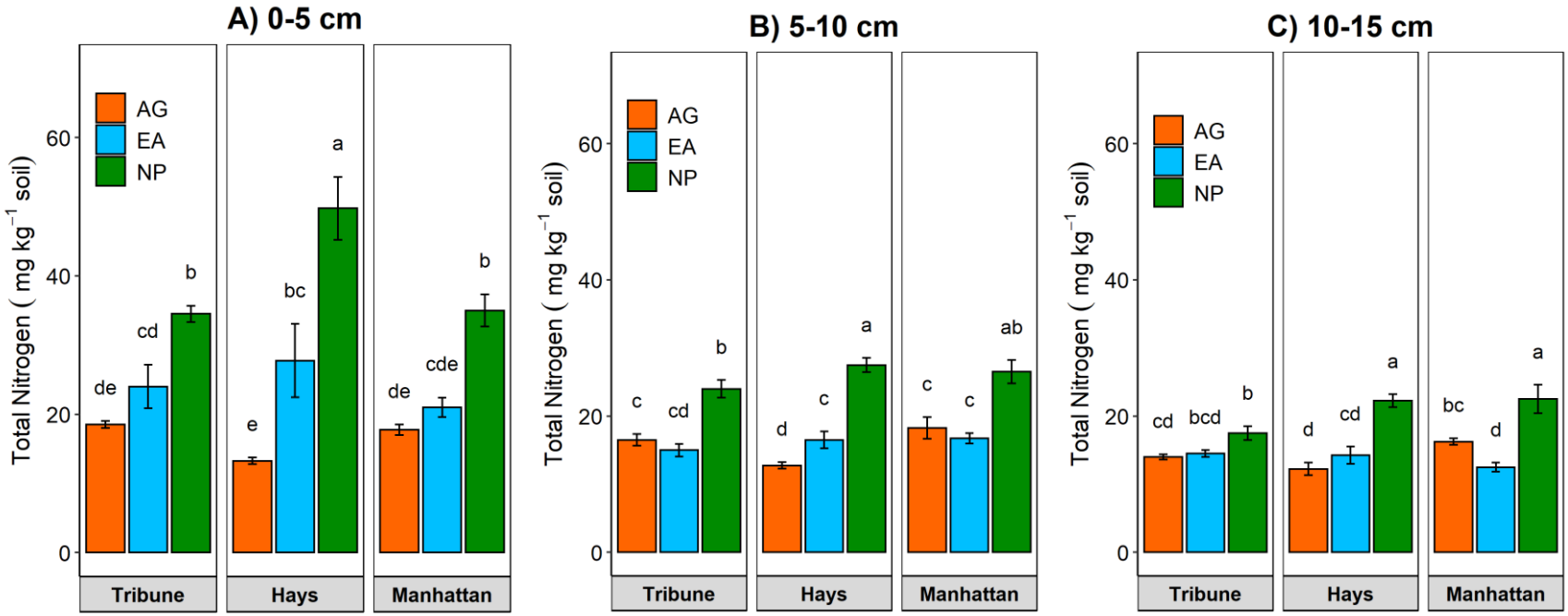

Figure 3.20. Total nitrogen by land use and precipitation in top 15 cm soil. Land use and precipitation interaction in 0-5 cm (A), 5-10 cm (B), and 10-15 cm (C). ANOVA with letters representing significant differences ($p<0.05$).

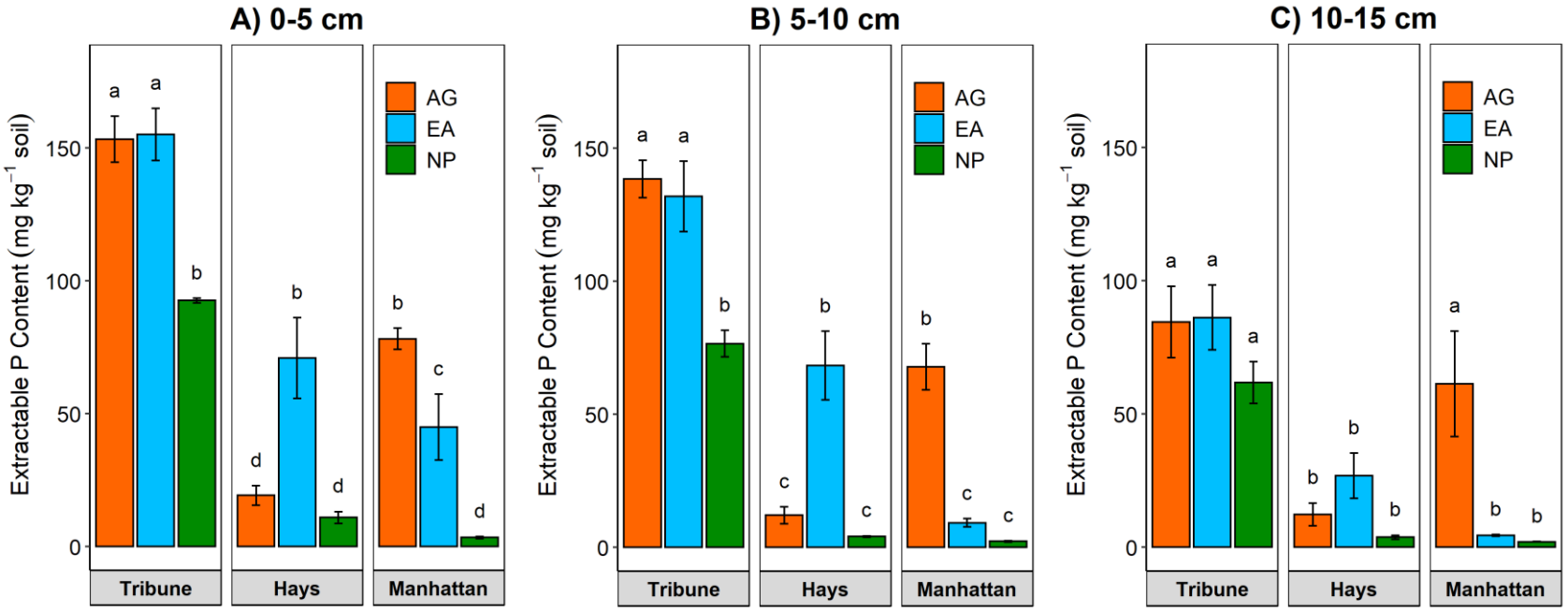

Figure 3.21. Extractable phosphorus content by land use and precipitation in top 15 cm soil. Land use and precipitation interaction in 0-5 cm (A), 5-10 cm (B), and 10-15 cm (C). ANOVA with letters representing significant differences ($p<0.05$).

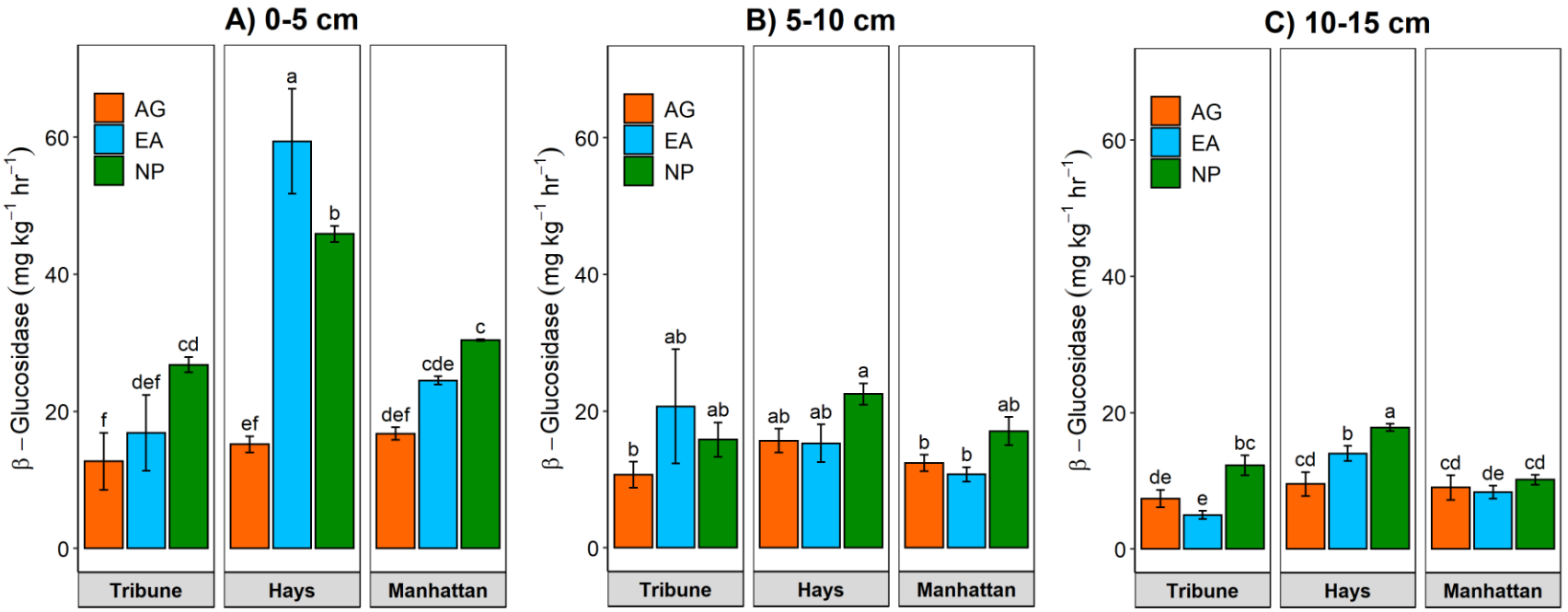

Figure 3.22. β-glucosidase by land use and precipitation in top 15 cm soil. Land use and precipitation interaction in 0-5 cm (A), no effect in 5-10 cm (B), and land use and precipitation interaction in 10-15 cm (C). ANOVA with letters representing significant differences ($p<0.05$).

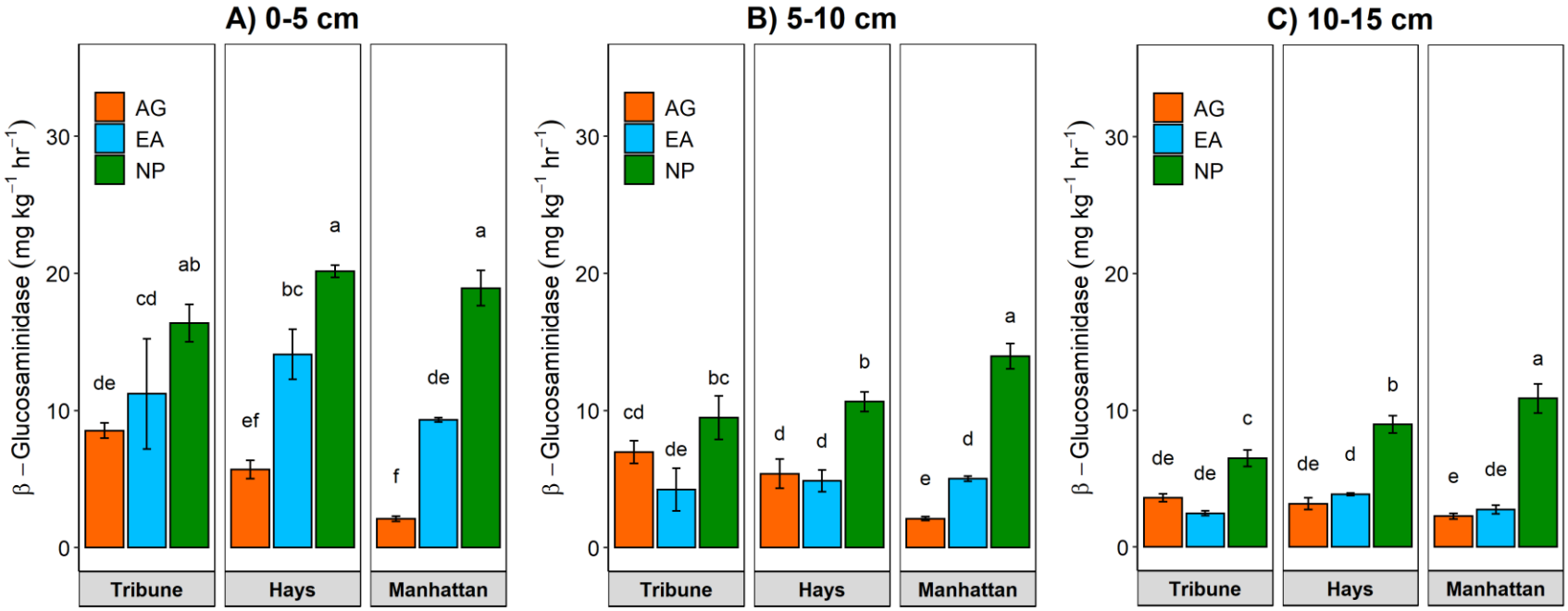

Figure 3.23. N-acetyl-b-D-glucosaminidase by land use and precipitation in top 15 cm soil. Land use effect in 0-5 cm (A), land use and precipitation interaction in 5-10 cm (B), and land use and precipitation interaction in 10-15 cm (C). ANOVA with letters representing significant differences ($p<0.05$).

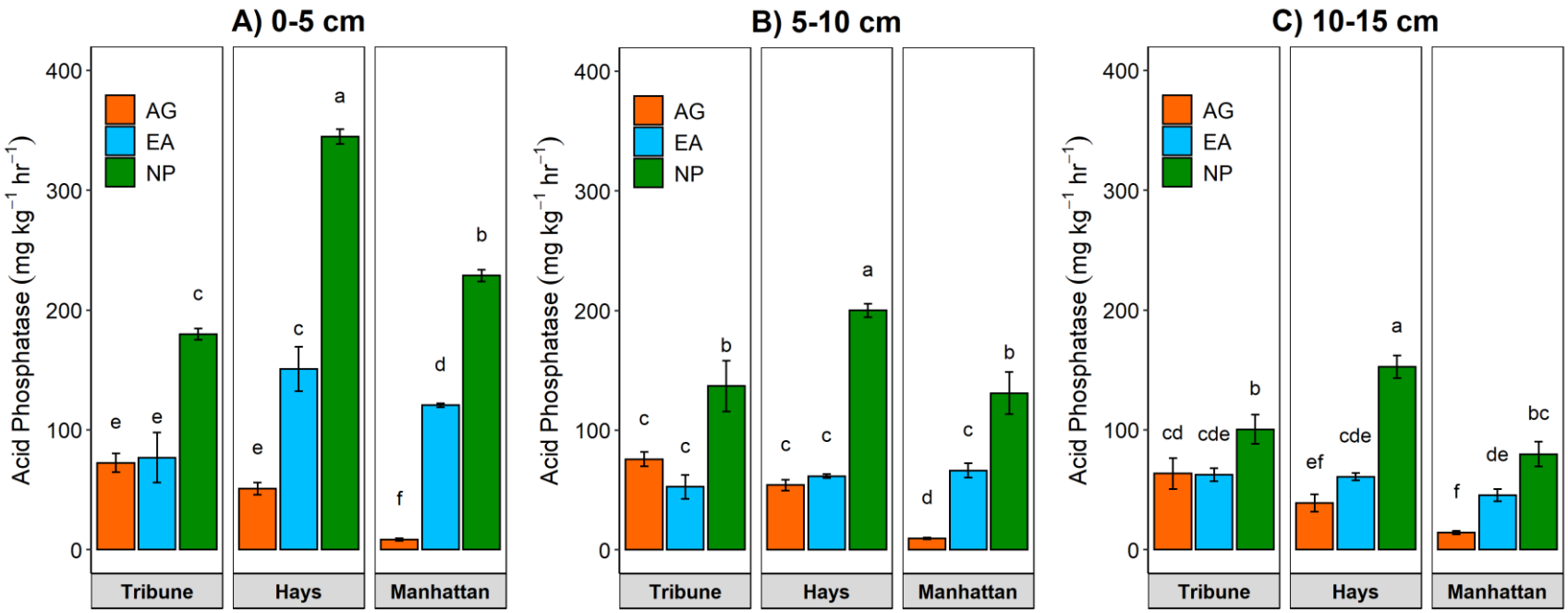

Figure 3.24. Acid phosphatase by land use and precipitation in top 15 cm soil. Land use and precipitation interaction in 0-5 cm (A), 5-10 cm (B), and 10-15 cm (C). ANOVA with letters representing significant differences ($p<0.05$).

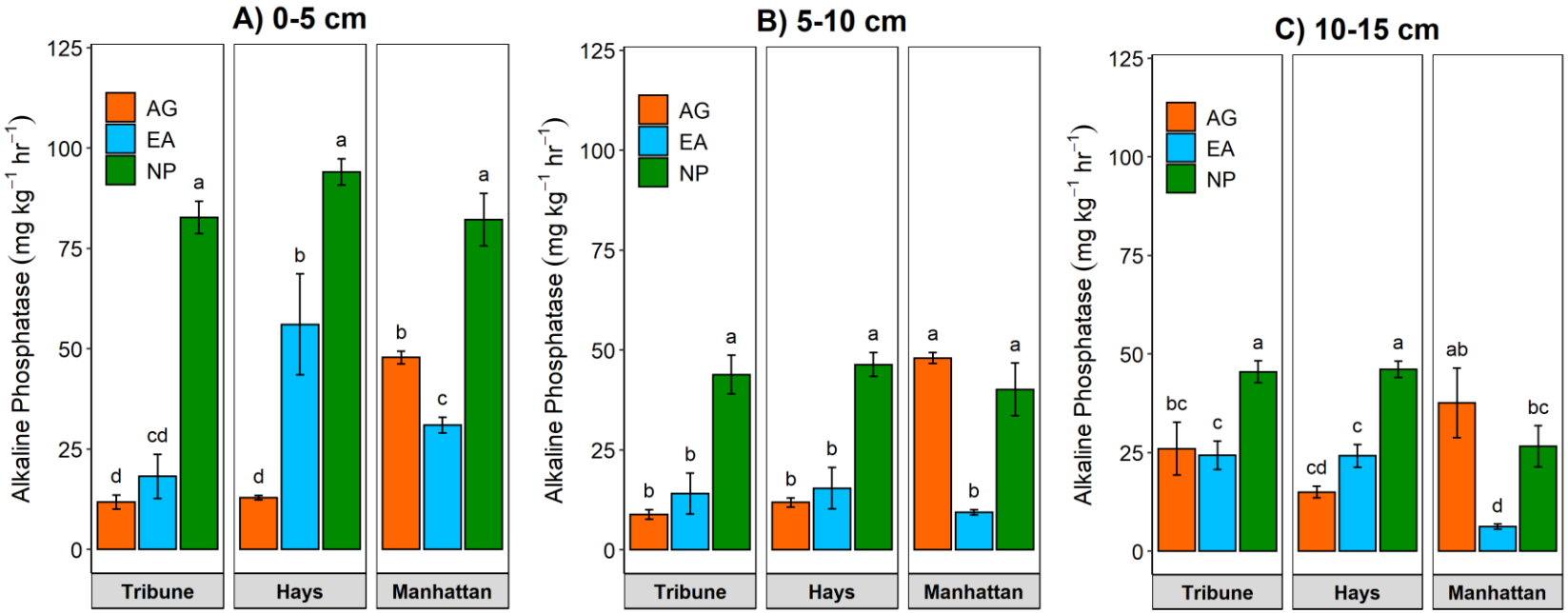

Figure 3.25. Alkaline phosphatase by land use and precipitation in top 15 cm soil. Land use and precipitation interaction in 0-5 cm (A), 5-10 cm (B), and 10-15 cm (C). ANOVA with letters representing significant differences ($p<0.05$).

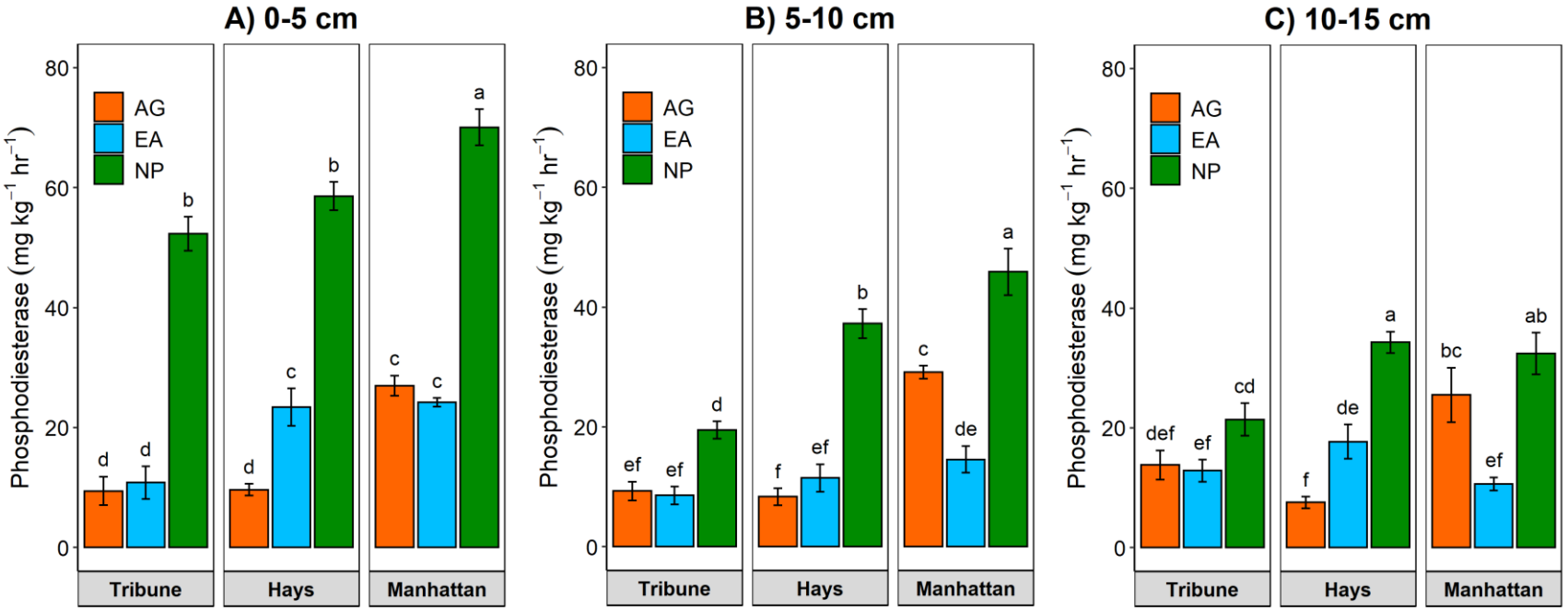

Figure 3.26. Phosphodiesterase by land use and precipitation in top 15 cm soil. Land use and precipitation interaction in 0-5 cm (A), 5-10 cm (B), and 10-15 cm (C). ANOVA with letters representing significant differences ($p<0.05$).

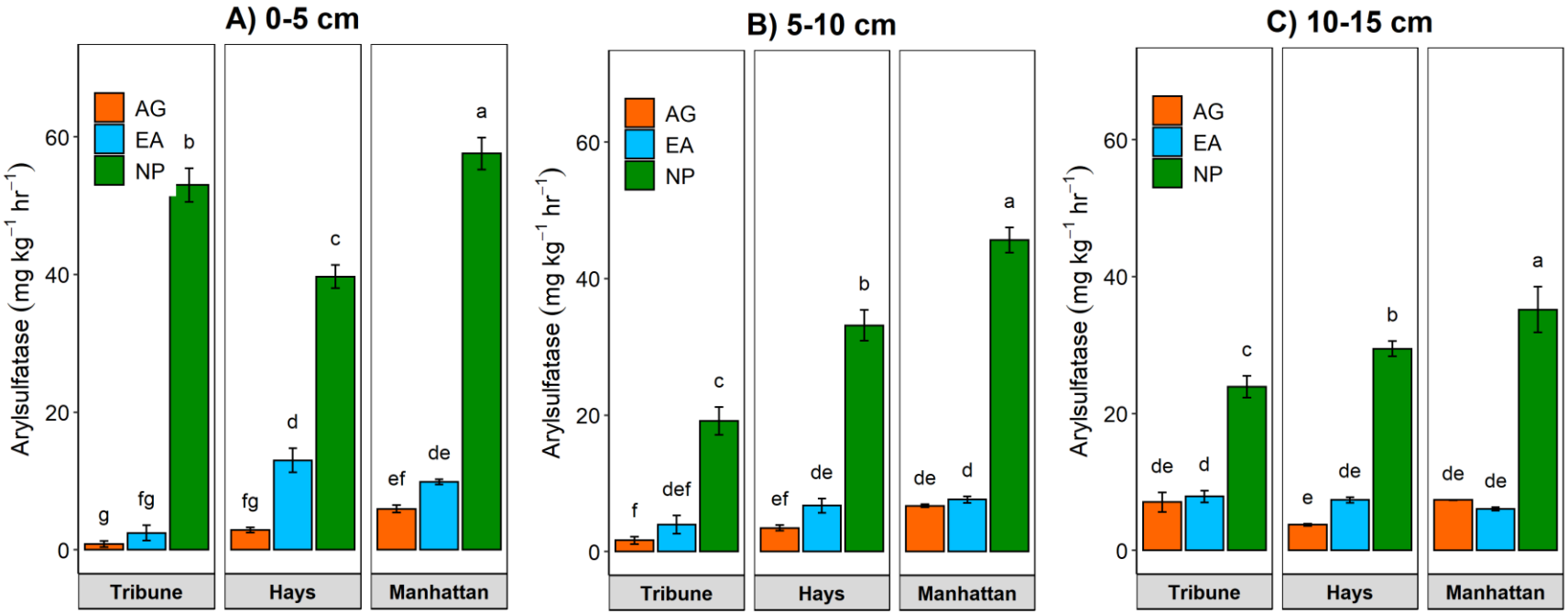

Figure 3.27. Arylsulfatase by land use and precipitation in top 15 cm soil. Land use and precipitation interaction in 0-5 cm (A), 5-10 cm (B), and 10-15 cm (C). ANOVA with letters representing significant differences ($p<0.05$).

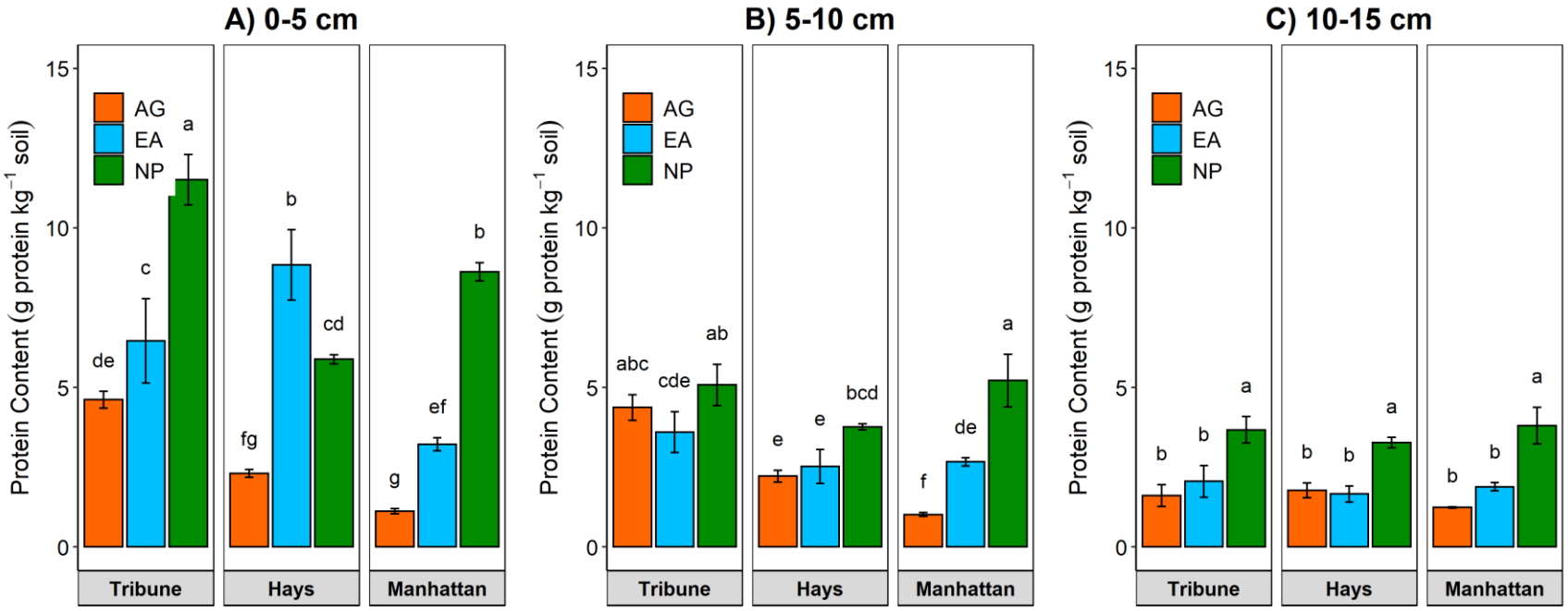

Figure 3.28. Autoclaved citrate extractable protein content by land use and precipitation in top 15 cm soil. Land use and precipitation interaction in 0-5 cm (A), land use and precipitation interaction in 5-10 cm (B), and land use effect in 10-15 cm (C). ANOVA with letters representing significant differences ($p<0.05$).

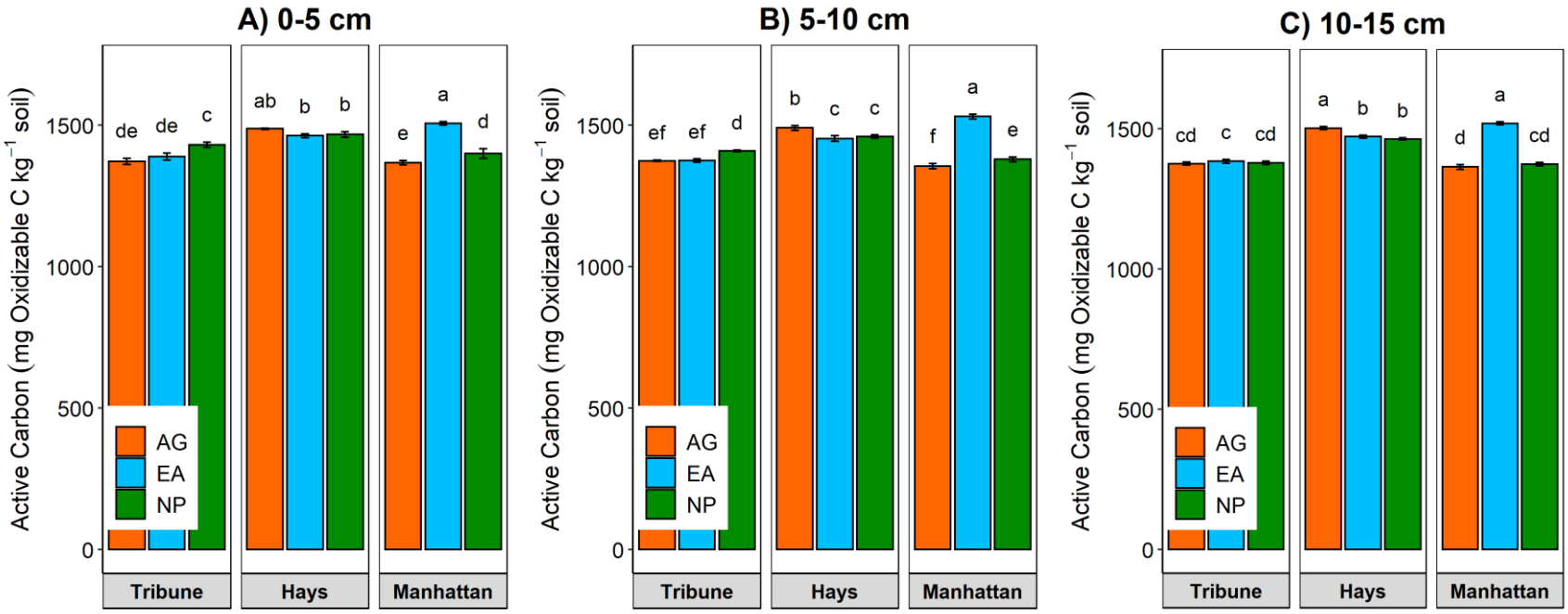

Figure 3.29. Permanganate oxidizable carbon (active carbon) by land use and precipitation in top 15 cm soil. Land use and precipitation interaction in 0-5 cm (A), 5-10 cm (B), and 10-15 cm (C). ANOVA with letters representing significant differences ($p<0.05$).

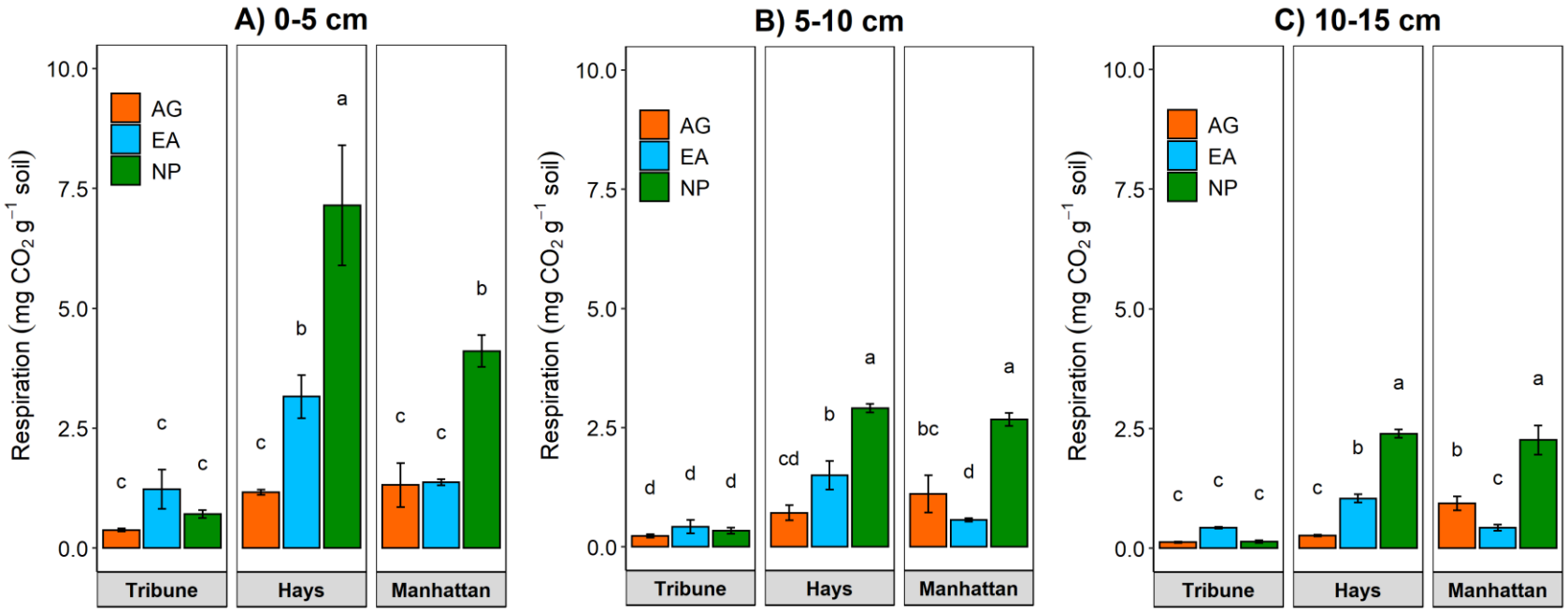

Figure 3.30. Soil respiration by land use and precipitation in top 15 cm soil. Land use and precipitation interaction in 0-5 cm (A), 5-10 cm (B), and 10-15 cm (C). ANOVA with letters representing significant differences ($p<0.05$).

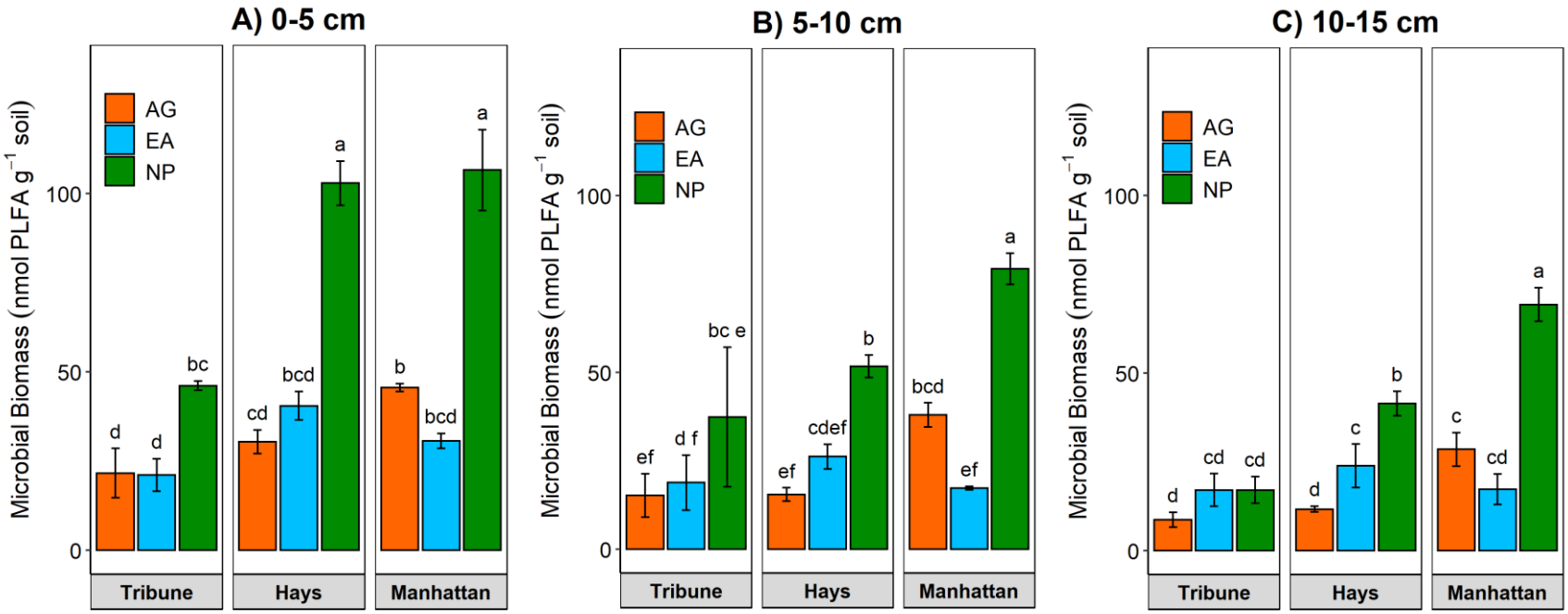

Figure 3.31. Microbial biomass by land use and precipitation in top 15 cm soil. Land use and precipitation interaction in 0-5 cm (A), 5-10 cm (B), and 10-15 cm (C). ANOVA with letters representing significant differences ($p<0.05$).

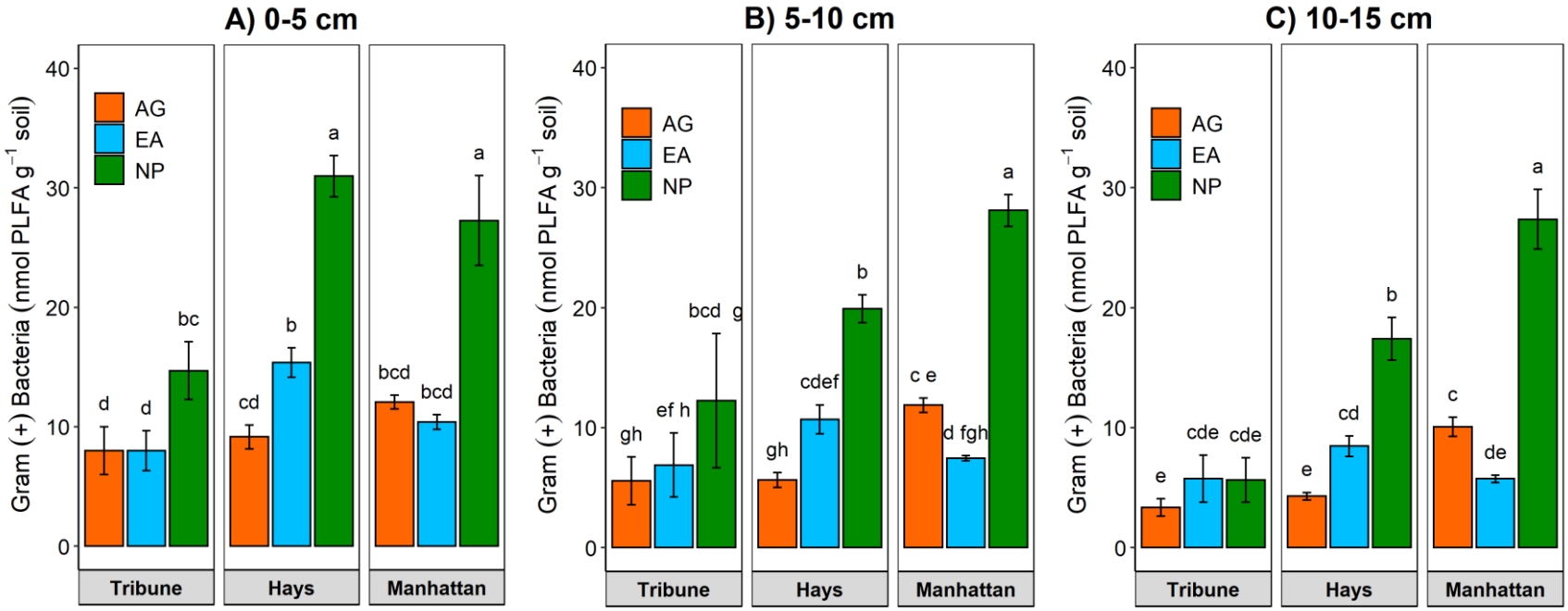

Figure 3.32. Gram positive bacteria by land use and precipitation in top 15 cm soil. Land use and precipitation interaction in 0-5 cm (A), 5-10 cm (B), and 10-15 cm (C). ANOVA with letters representing significant differences ($p<0.05$).

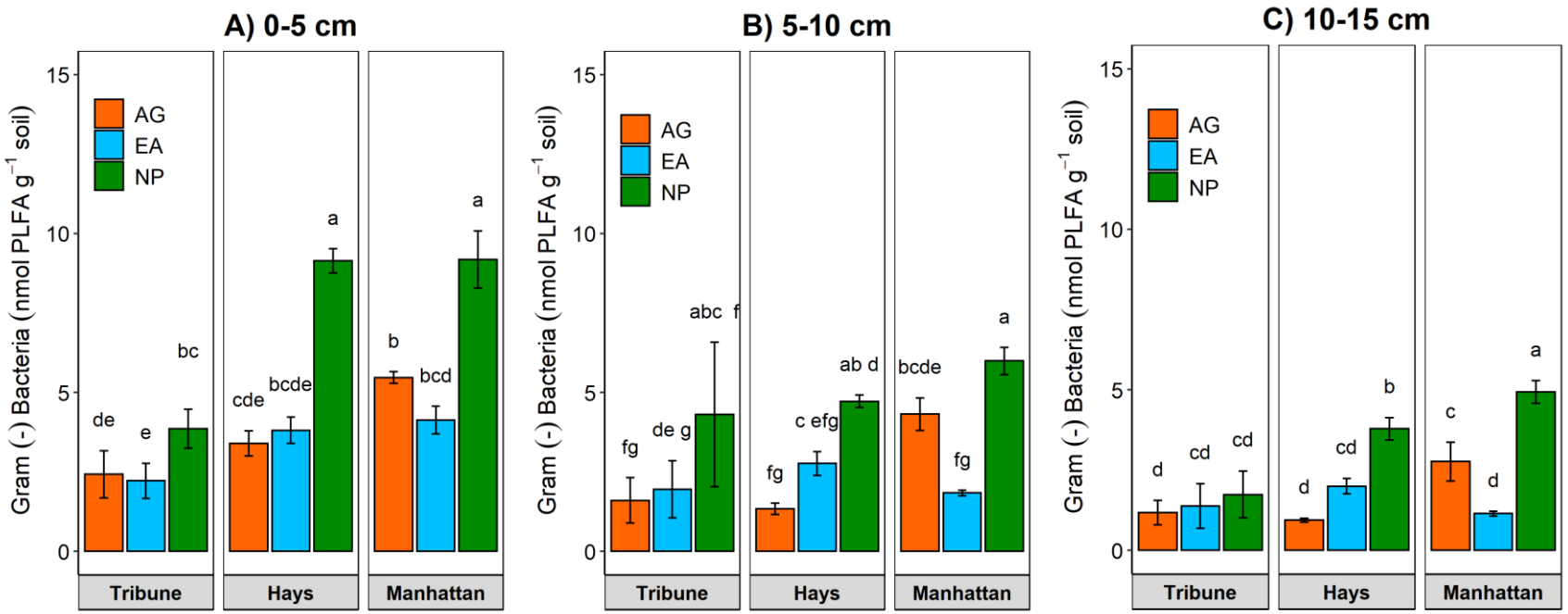

Figure 3.33. Gram negative bacteria by land use and precipitation in top 15 cm soil. Land use and precipitation interaction in 0-5 cm (A), 5-10 cm (B), and 10-15 cm (C). ANOVA with letters representing significant differences ($p<0.05$).

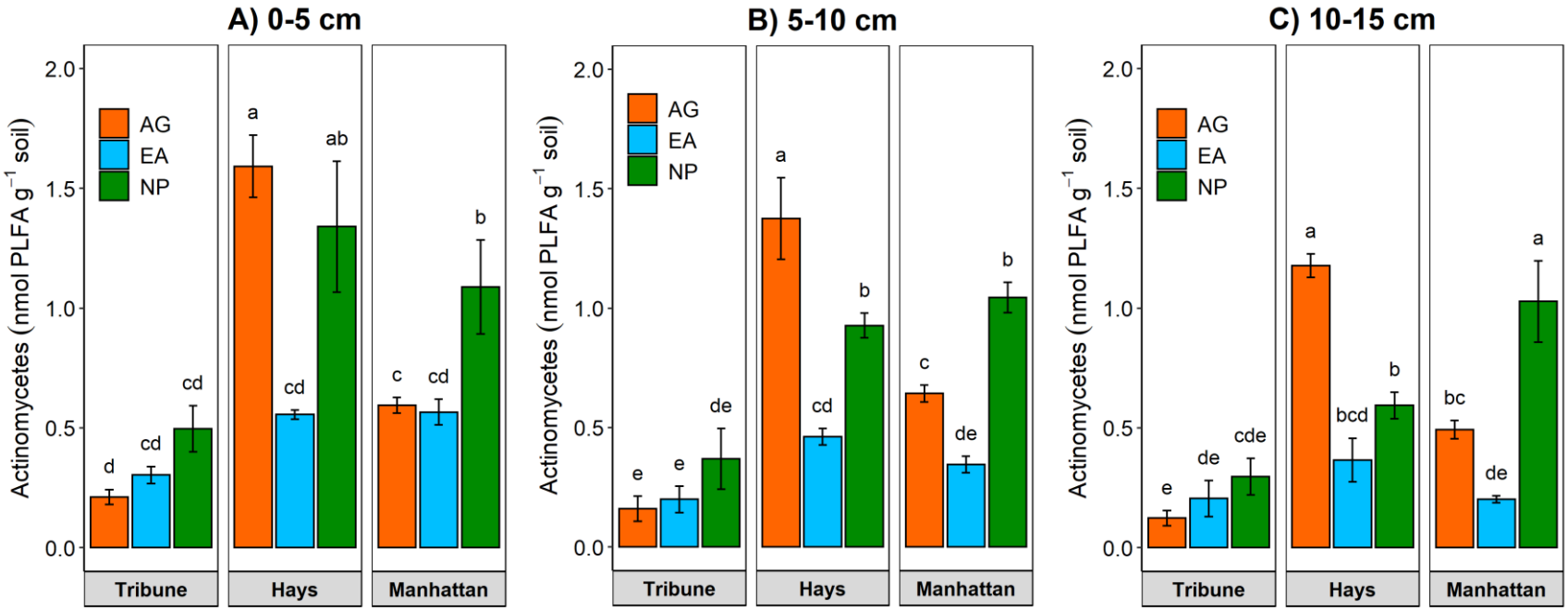

Figure 3.34. Actinomycetes by land use and precipitation in top 15 cm soil. Land use and precipitation interaction in 0-5 cm (A), 5-10 cm (B), and 10-15 cm (C). ANOVA with letters representing significant differences ($p<0.05$).

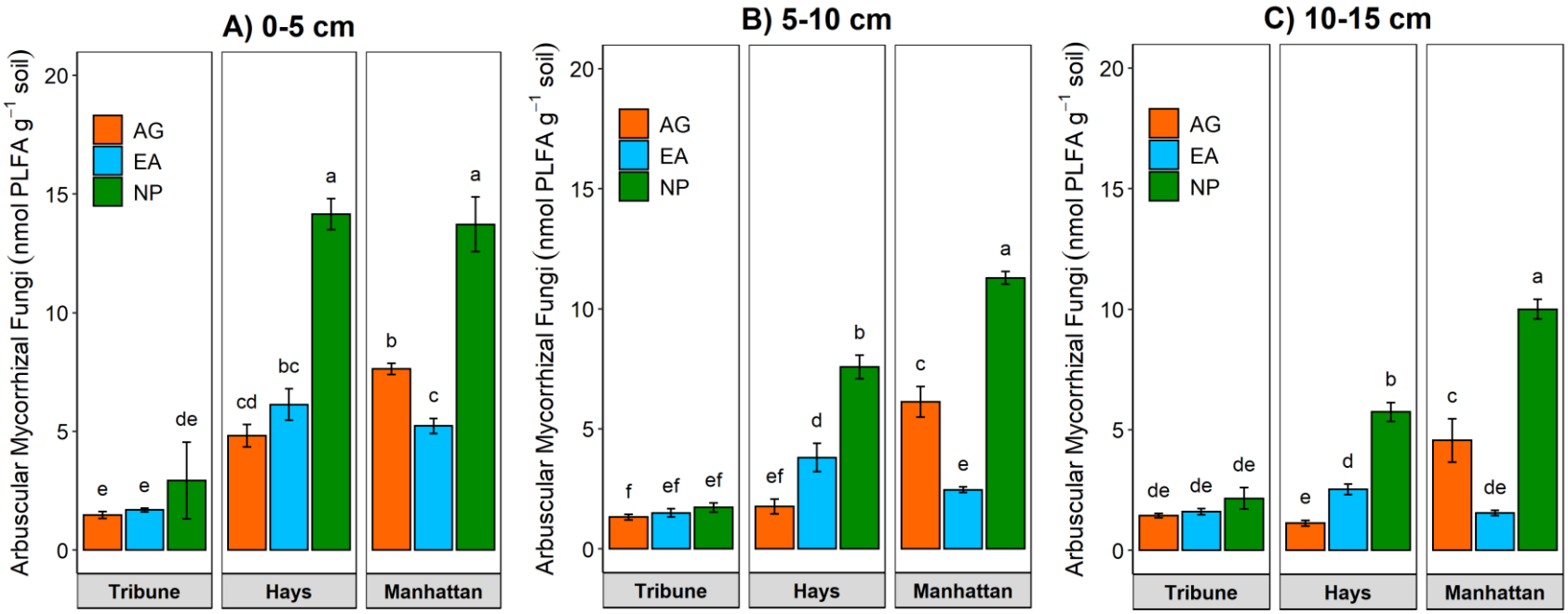

Figure 3.35. Arbuscular mycorrhizal fungi by land use and precipitation in top 15 cm soil. Land use and precipitation interaction in 0-5 cm (A), 5-10 cm (B), and 10-15 cm (C). ANOVA with letters representing significant differences ($p<0.05$).

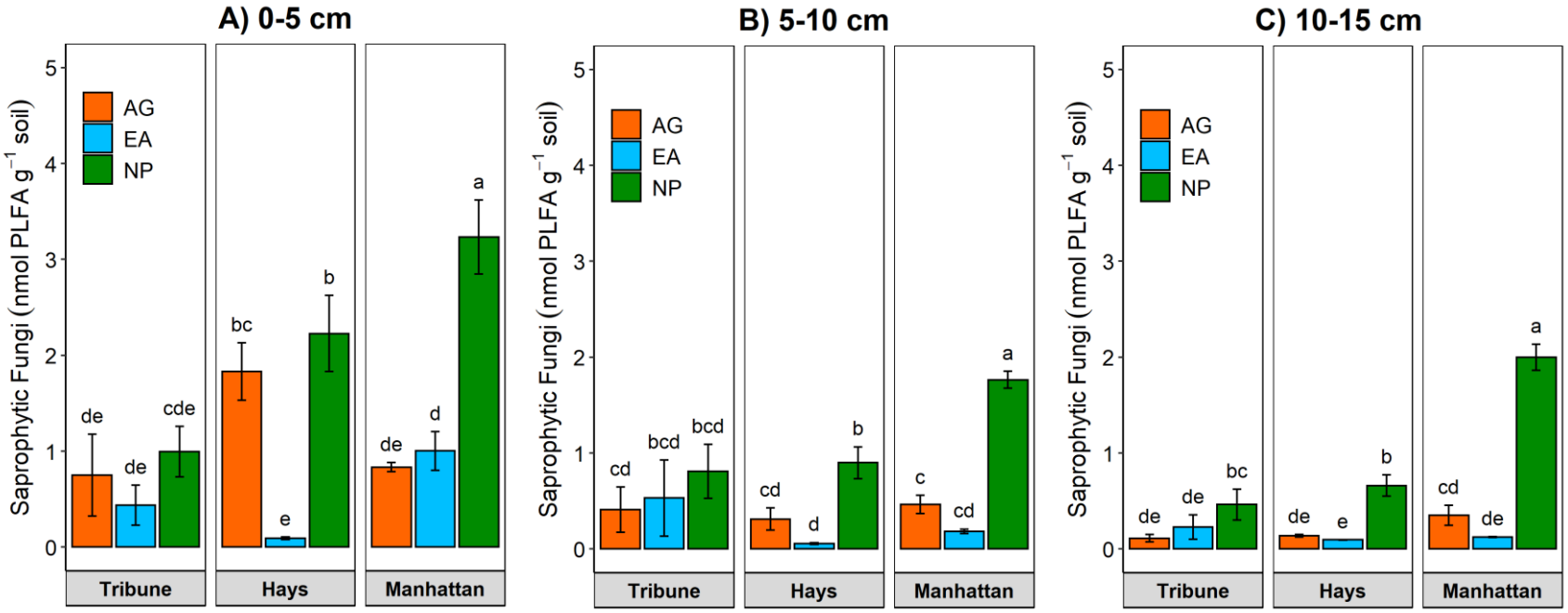

Figure 3.36. Saprophytic fungi by land use and precipitation in top 15 cm soil. Land use and precipitation interaction in 0-5 cm (A), 5-10 cm (B), and 10-15 cm (C). ANOVA with letters representing significant differences ($p<0.05$).

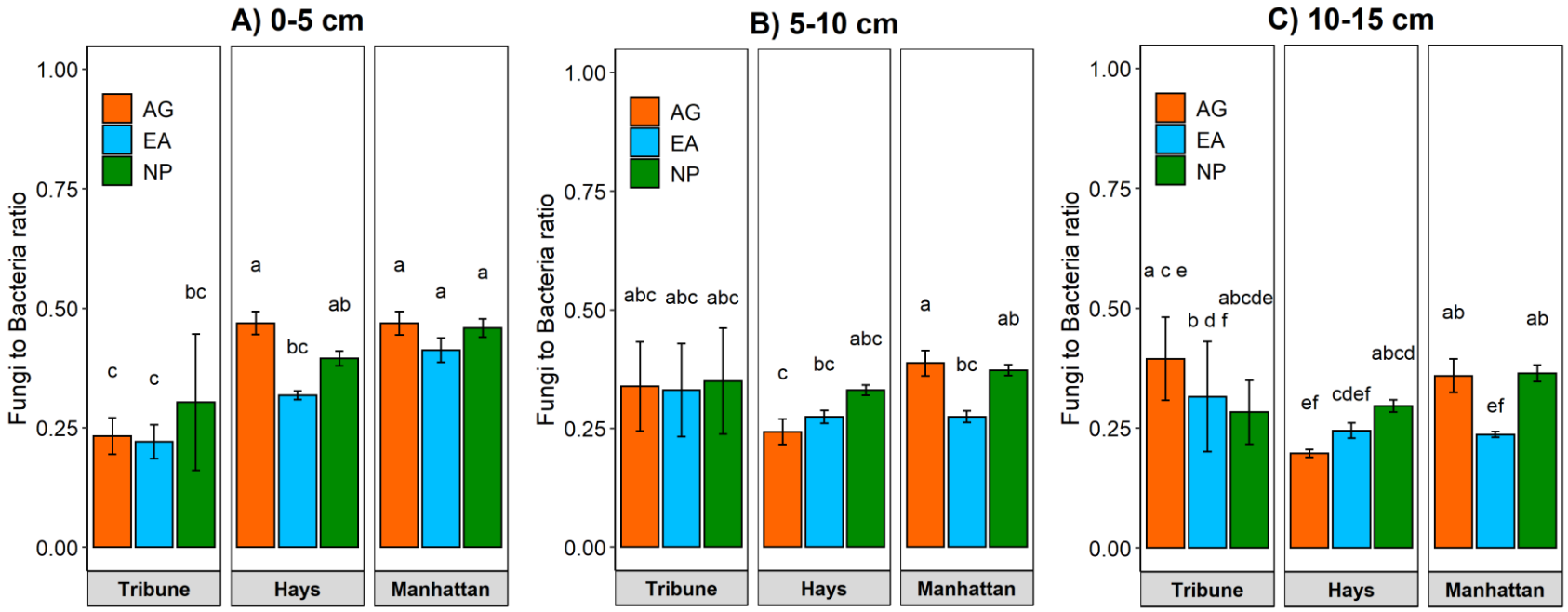

Figure 3.37. Differences in fungal to bacteria ratios by land use and precipitation in top 15 cm soil. Land use and precipitation effect in 0-5 cm (A), no effect in 5-10 cm (B), and land use effect in 10-15 cm (C). ANOVA with letters representing significant differences ($p<0.05$).

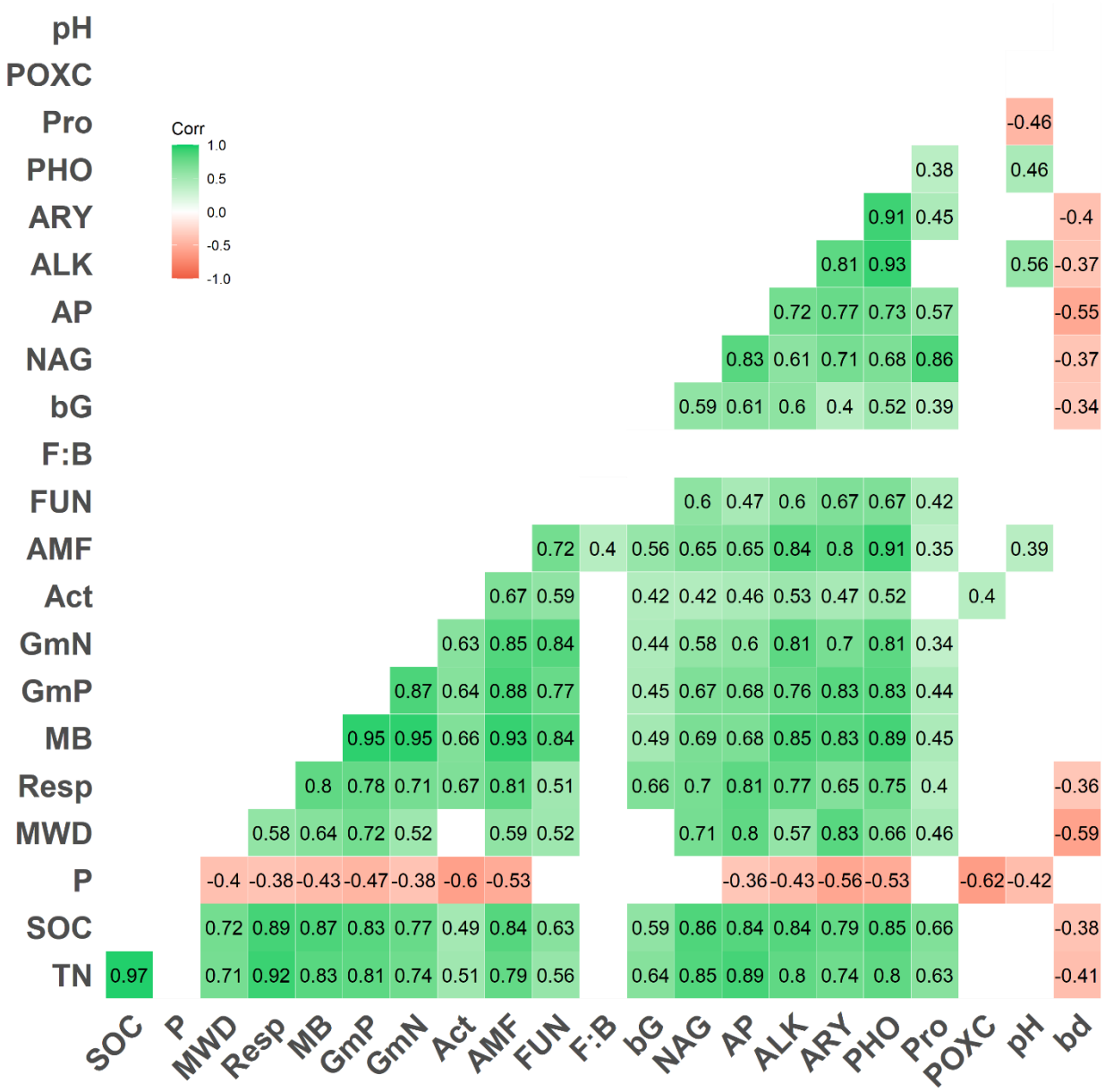

Figure 3.38. Correlation matrix of soil health properties using Spearman correlation coefficient given inside squares ($p<0.05$) for top 15 cm soils. MWD: mean weight diameter (mm); bd: bulk density (g cm^{-3}); SOC: soil organic carbon (%); TN: total nitrogen (%); P: phosphorus (mg kg^{-1}); pH; bG: β-glucosidase (mg $kg^{-1}hr^{-1}$); NAG: N-acetyl glucosaminidase (mg $kg^{-1}hr^{-1}$); AP: acid phosphatase (mg $kg^{-1}hr^{-1}$); ALK: alkaline phosphatase (mg $kg^{-1}hr^{-1}$); PHO: phosphodiesterase (mg $kg^{-1}hr^{-1}$); ARY: arylsulfatase (mg $kg^{-1}hr^{-1}$); Resp: soil respiration (mg CO2 g-1); POXC: permanganate-oxidizable carbon (mg kg^{-1}) ; Pro: protein content (g protein kg^{-1}); autoclavable MB: PLFA microbial biomass (nmol PLFA g^{-1}); GmP: Gram-positive bacteria (nmol PLFA g^{-1}); GmN: Gram-negative bacteria (nmol PLFA g^{-1}); Act: actinomycete (nmol PLFA g^{-1}); AMF: arbuscular mycorrhizal fungi (nmol PLFA g^{-1}); Fun: fungi (nmol PLFA g^{-1}); FB: fungi to bacteria ratio.

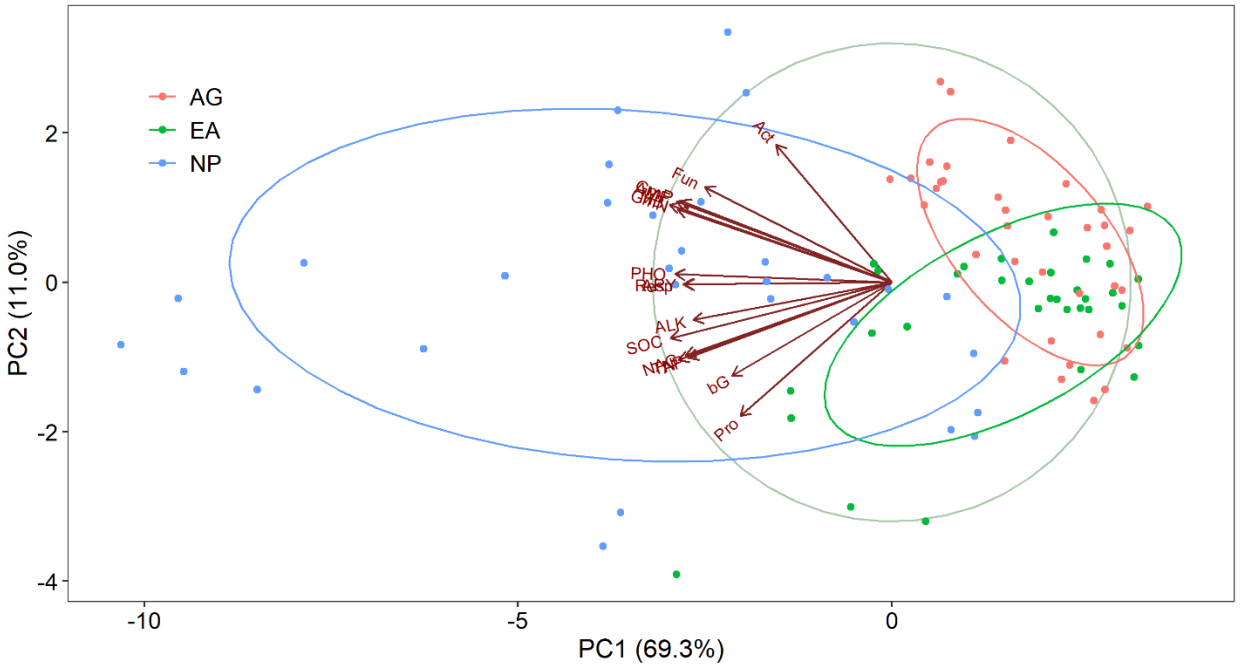

Figure 3.39. Principal component analysis biplot of soil organic carbon, total nitrogen, soil microbial community composition and enzyme activity grouped by land use in the top 15 cm soil.

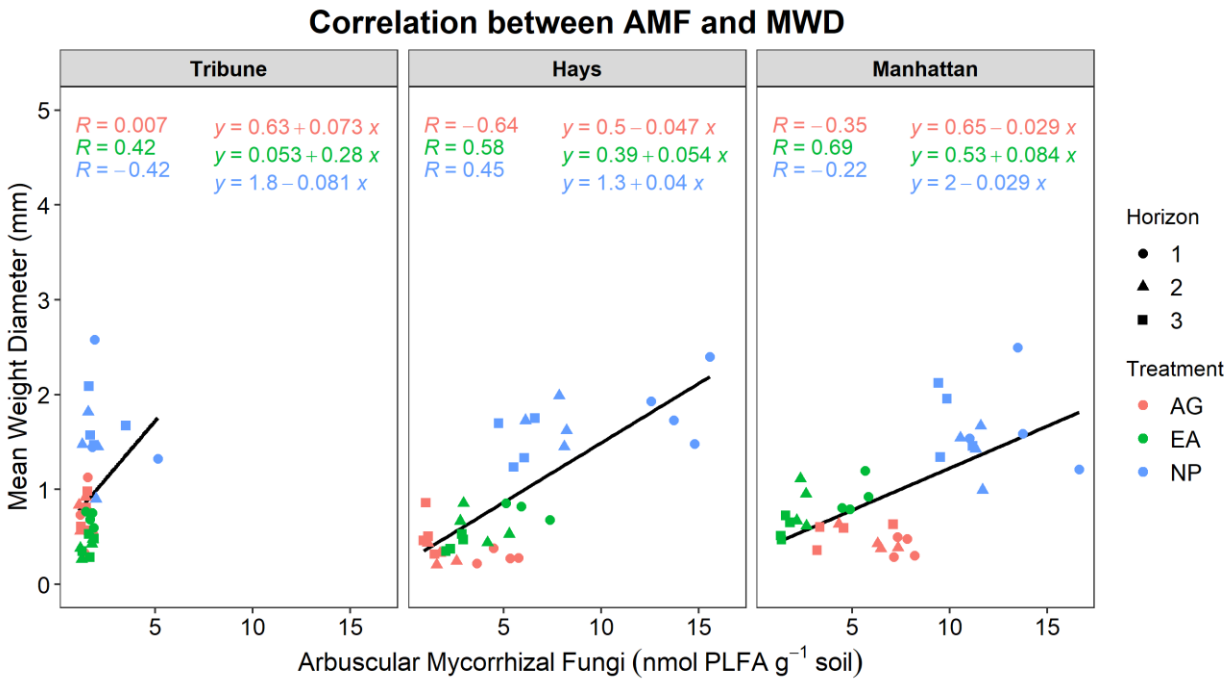

Figure 3.40. Simple linear regression for arbuscular mycorrhizae fungi and mean weight diameter subset by land use, location, and top 0-15 cm. Correlation (R) and linear regression fitted by location and land use. Horizon 1, 2, 3 are 0-5, 5-10, and 10-15 cm, respectively. Land use is labeled as conventional tillage (AG), no-till (EA), and native prairie (NP).

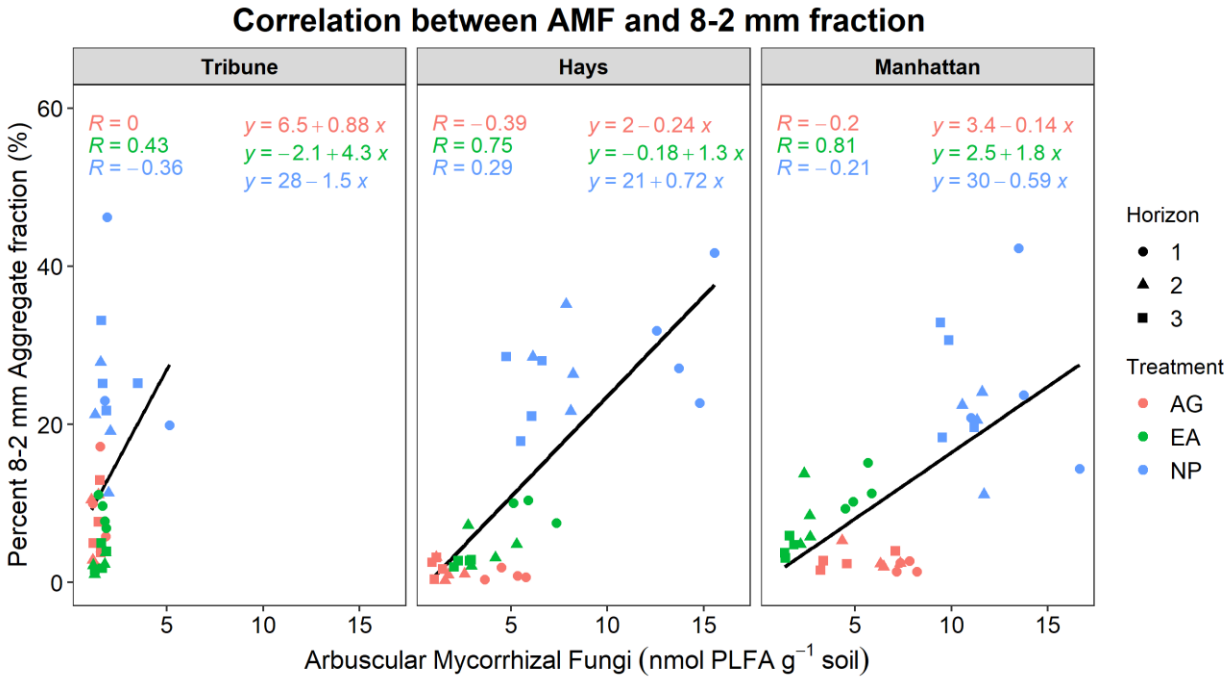

Figure 3.41. Simple linear regression for arbuscular mycorrhizae fungi and 8-2 mm size fraction subset by land use, location, and top 0-15 cm. Correlation (R) and linear regression fitted by location and land use. Horizon 1, 2, 3 are 0-5, 5-10, and 10-15 cm, respectively. Land use is labeled as conventional tillage (AG), no-till (EA), and native prairie (NP).

Chapter 4 - Soil Health to a 100 cm Depth

Abstract

This study evaluated a set of soil health (SH) metrics from a precipitation gradient across Kansas to 1-m depth. The three different mean annual precipitation regimes, Tribune (483 mm/yr), Hays (579 mm/yr), and Manhattan (850 mm/yr), KS. Each location had three land uses; native prairie, conventional tillage agriculture, and no-till agriculture. Soil health metrics included aggregate stability, soil organic carbon (SOC), total nitrogen (TN), SOC and TN stocks, soil cations and metals, soil respiration, permanganate-oxidizable carbon, autoclaved citrate extractable protein, six enzyme assays, and phospholipid fatty acid analysis. Several soil health metrics were distinguish differences among land use along the precipitation gradient to a 1 m soil depth. Greater differences occurred at the wetter site, Manhattan. Soil health properties decreased logarithmically with depth. Native prairie typically had higher SH metrics than cropping systems. A PCA biplot explained positive correlations among different biological properties, SOC, and TN. At the drier site, Tribune exhibited similar soil health metrics for chemical and physical properties for all land uses. Hays and Manhattan cropping system had contrasting variations between EA and AG due to different management histories, making interpretation more challenging. A more effective measurement of soil health would track temporal changes in soil health within a site. Overall, the set of SH metrics can differentiate among agronomic management systems in Kansas soils across a precipitation gradient under different soil types to 1 m.

Introduction

Soil properties are different in subsoils than in surface soils due to different responses in nutrient content, moisture, soil texture, microbial activity, vegetation type, and environmental conditions (Celestina et al., 2019; Hsiao et al., 2008; Preusser et al., 2019; Jobbágy and Jackson, 2000). Subsurface soils are distinguished by impacts from compaction, water regime, mineralogy, vegetation type, rooting depth, and particle-size distribution (Weil and Brady, 2019; Jobbágy and Jackson, 2000; Wardle et al., 2004). A great majority of global microbial biomass or soil organic matter is located in the first 1 m (Fierer et al., 2009; Batjes, 1996; Rumpel and Kögel-Knabner, 2011). Organic matter (OM) in subsurface horizons is highly processed and comprised of microbial-derived C compounds converted from plant biomass (Rumpel and Kögel-Knabner, 2011).

Several studies found land use and management to impact subsurface C stocks (Guo and Gifford 2002; Wright et al. 2007; Strahm et al. 2009; Follett et al. 2009). Land conversion from forest to pasture or agriculture has decreased translocation of C, specifically plant roots, root exudates, dissolved organic matter, and bioturbation (Rumpel and Kögel-Knabner, 2011; Guo and Gifford 2002). Temperate grasses have a shallower rooting depth than temperate coniferous forests and shrubs, which impact C allocation above- and below-ground (Jackson et al. 1996). Soil texture also affects SOM stabilization due to more clay with greater surface areas for absorption and protection (Paul, 1984, Baldock and Skjemstad, 2000).

The vertical distribution of soil C is driven by land use, age, root distribution, microbial activity, parent material, climate, and vegetation (Xu et al., 2019). Changes in land use, such as native grassland or forest systems to agricultural activities, directly change organic matter (OM) pools and mechanisms of soil stabilization (Lal, 2003). In addition, input rates of C and N are

considerably different between surface and subsurface soils based on shoot vs. root-derived material (Rasse, 2005). Kuzyakov and Domanski (2000) found that cultivated soils and pasture soils had similar translocation of soil C. Cultivated soils have lower rates of organic C input due to shorter vegetation period, crop removal, and detrimental management practices (fallow and/or tillage) (Kuzyakov and Domanski, 2000; Lorenz and Lal, 2005). However, improved practices (nutrient amendments, selective crop breeding, and intensive crop productivity per area) could increase C inputs (Kuzyakov and Domanski, 2000; Lorenz and Lal, 2005). In addition, crop production can be managed with conservation practices that promote C sequestration through reduced tillage, leguminous cover crops, selection of higher root-to-shoot plants, higher lignin content plants, and longer vegetative period (Sollins et al., 1996; Six et al., 2002; Gregorich et al., 2001; Nicoloso and Rice, 2021). Research on soil profile C and N storage, and below-ground biomass can provide insight into changes caused by land use (Lorenz and Lal, 2005).

The type of crop grown influences soil metrics through the soil profile (Guo and Gifford 2002; Strahm et al. 2009). Annual monoculture crops generally have shallower roots allocated in the top 0.3 m of soil, compared to perennial plants with root development to >2 m (Glover et al., 2007; Jackson et al. 1996). The impact of management practices on biological, chemical, and physical soil properties may also vary in sensitivity with depth (Blume et al., 2002). The objectives of this study were 1) to determine the loss in SOC and TN from native prairie to agricultural land use, 2) assess the differences in soil health metrics across a precipitation gradient with three land uses (native prairie, conventional tillage, enhanced agriculture), and 3) to assess soil health metrics to a 1m depth. We hypothesized that wetter, more disturbed sites would have a greater degree of changes in soil health metrics than drier sites.

Materials and Methods

Site descriptions

This study was conducted across a precipitation gradient, Tribune (483 mm/yr), Hays (579 mm/yr), and Manhattan (850 mm/yr), KS. At each location three land uses (native prairie-NP, enhanced agriculture-EA, and conventional tillage-AG). Land use at each location had similar soil map units, while soil mapping units varied between locations. Tribune also included a no-till irrigation (IR) land use.

Soil sampling

Six soil cores were collected for each replication (n=4) using a Giddings probe (Giddings Machine Company, Windsor, CO, USA) with a 6.35 cm dia. metal tube and a 6-cm dia. plastic soil liner to a depth of 90 cm. One set of soil cores determined soil bulk density. The remainder of the samples were divided into 0-5, 5-10, and 10-15 cm and then by soil genetic horizons and homogenized per replication, with 4 replications per site. For the Tribune irrigated site, a 2 m soil pit was dug and sampled from the face of the pit wall. The top 15 cm was sampled by shovel to collect natural fabric samples for aggregation. The homogenized moist samples were separated into two groups, 25 g for PLFA analysis and 500 g for other soil tests. Soil samples were stored at 4°C until analysis except for PLFA soils. Samples for PLFA were stored at -4°C until analysis.

Manhattan, KS

Native prairie and AG were sampled on 13 September 2019, at the Konza Prairie Biological Station (KPBS) (Table 1). Soil cores were separated by 0-5, 5-10, 10-15, 15-29, 29-59, 59-90 cm in NP, while AG and EA soil cores were separated by 0-5, 5-10, 10-15, 15-26, 26-47, 47-71, 71-90 cm. Native prairie area was dominated by perennial C4 grasses (big bluestem

(*Andropogon gerardi*), Indiangrass (*Sorghastrum nutans*), and switch grass (*Panicum virgatum*)) and C3 herbaceous forb species (Heisler-White et al., 2009; Freeman, 1998). Conventional tillage was cultivated since the 1960s with soybean (*Glycine max*), wheat (*Triticum aestivum*), and grain sorghum (*Sorghum bicolor*) with tillage and local fertilizer and pesticide application practices (Kamlesh et al., 2010). Soybean was the current crop. The soil for both NP and AG was a Reading silt loam (Fine-silty, mixed, superactive, mesic Pachic Argiudoll). Enhanced agriculture was sampled on 21 October 2021 after corn harvest at a private farm with no-till corn-soybean rotation. The soil cores were separated by 0-5, 5-10, 10-15, 15-25, 25-50, 50-75, 75-90 cm. The soil was a Tully silt clay loam (Fine, mixed, superactive, mesic Pachic Argiustolls).

Hays, KS

Native prairie and EA were sampled on 20 September 2019 near Hays Agricultural Research Center. Sample cores were separated by 0-5, 5-10, 10-15, 15-40, 40-60, 60-90 cm in NP, while cores were separated by 0-5, 5-10, 10-15, 15-45, 45-65, 75-90 cm in EA. Native prairie consisted of mixed grass prairie, including buffalo grass (*Buchloe dactyloides*), western wheatgrass (*Agropyron smithii*), blue grama (*Bouteloua gracilis*); side- oats grama (*Bouteloua curtipendula*), little bluestem (*Andropogon scoparius*), and big bluestem (*Andropogon gerardi*) (Jones, 1960). Conventional agriculture was sampled on 15 October 2021 at Hays Agricultural Research Center. The soil cores were separated by 0-5, 5-10, 10-15, 15-45, 45-65, 65-75, and 75-90 cm. The AG was sampled after sorghum harvest in a wheat-sorghum-fallow rotation. The soil for all land uses was a Harney silt loam soil (Fine, smectitic, mesic Typic Argiustolls).

Tribune, KS

Native prairie, AG, and EA were sampled on 19-20 August 2019 at the Southwest Research Center- Tribune Unit. Samples were separated by 0-5, 5-10, 10-15, 15-40, 40-75, 75-90 cm. Soils from Tribune were sampled in a randomized strip block design, excluding the irrigation treatment. Native prairie vegetation type consisted of C3 and C4 grasses with the dominant species being buffalo grass (*Buchloe dactyloides*). Conventional agriculture and EA was sampled after wheat harvest in a wheat-grain sorghum-fallow rotation with tillage and no-till for AG and EA, respectively. The irrigation treatment was sampled on 4 November 2019. Technicians dug a 2 m pit. Soil samples were separated by 0-5, 5-10, 10-15, 15-30, 30-50, 50-85, 85-100 cm. Soil at Tribune were classified as Richfield silt loam (fine-smectitc, mesic Aridic Argiustolls). Excluding irrigation, the experiment was started in 1989 with treatments imposed in native prairie (Blanco-Canqui et al., 2011).

Laboratory assessments

Physical soil properties

Bulk density

Plastic soil core liners with freshly collected soils were sectioned by the appropriate depths. Moist soil was oven-dried at 105°C for 1 week. The oven-dry soil mass was divided by the volume of the soil core segment to calculate soil bulk density.

Water stable aggregates

The fresh soil samples were separated along natural breaks, air-dried for at least 24 h, and sieved through an 8-mm diameter sieve while removing large stones and organic matter for aggregate analysis. Soil (100g) was weighed and placed in a Yoder wet-sieving apparatus modified for recovery of all particle fractions as described by Kemper and Rosenau (1986) modified by Mikha and Rice (2004). Each soil sample was separated into four aggregate size

classes (8-2 mm, 0.250-2 mm, 0.053-0.25 mm, and 0.02-0.053 mm diameter). The air-dried soil was placed on the top sieve >2 mm, above the 0.25-2 mm, and 1 liter of distilled (DI) water was added to submerge the soil in water for 10 min. The oscillation time was at 10 min, stroke length at 4 cm, and frequency 30 cycles min^{-1}. After the soil was wet-sieved, the sieves were poured into tins and the oscillation container was poured into the finer sieves of 0.053- and 0.02-mm diameter, then poured into tins. Floating organic matter was removed in the >2 mm fraction sieve. The individual particle fractions were dried at 70°C for 24 h until the water completely evaporated. Each dried fraction was then weighed to determine the percent aggregate size fraction. Aggregates from each tillage treatment were fractionated into macroaggregate (>2 and 0.25–2 mm) and microaggregate (0.053–0.25 and 0.020–0.053 mm) size classes. Mean weight diameter (MWD) was calculated by the sum of the aggregate mass retained on each sieve multiplied by the mean aperture of adjacent sieves, expressed in mm. The equation below represents the MWD based on the four soil fractions used:

$$MWD\ (mm) = [(8 - 2\ mm\ WSA * 5) + (2 - 0.25\ mm\ WSA * 1.125) + (0.25 - 0.053\ mm\ WSA * 0.1515) + (0.053 - 0.02\ WSA * 0.0365)]/100$$

For reference, 8-2 mm WSA was the wet stable aggregate fraction in percent retained after wet sieving for soil aggregates greater than 2 mm diameter and less than 8 mm diameter. The mean aperture of the 8- and 2-mm diameter sieves was 5 mm.

Chemical soil properties

Soil nutrients

The soil samples from each depth and treatment were homogenized, air dried, roots removed, passed through 2 mm sieves, and then sent to the Kansas State University Soil Testing Laboratory for soil pH and chemical analysis on plant-available micro-and macro-nutrients in soils. Mehlich-3 extractable phosphorus was extracted with glacial acetic acid, ammonium

nitrate, ammonium fluoride, and nitric acid and then, analyzed using Lachat Quickchem 8000 colorimetric analysis (Frank et al., 1998). The exchangeable cations, calcium, potassium, magnesium, and sodium were analyzed by Inductively Coupled Plasma (ICP) Spectrometer (Model 720-ES ICP Optical Emission Spectrometer, manufactured by Varian Australia Pty Ltd, Mulgrave, Vic Australia) after extraction with ammonium acetate (1 M, pH 7.0) and filtered through low-sodium filter paper (Warncke and Brown, 1998).

Soil organic carbon and total nitrogen

Soil organic carbon (SOC) and total nitrogen (TN) was determined by a LECO TruSpec Carbon/Nitrogen combustion analyzer (LECO Corporation, St. Joseph, MI, 2005). Total C was considered soil organic carbon for soils with pH <7.2, while soils with pH >7.2 were pretreated for carbonates using a second LECO combustion sample with dilute Phosphoric Acid. Carbonates were released as CO_2 from calcium and magnesium carbonates in calcareous soils, leaving only the soil organic carbon.

Soil pH

Soil pH was determined with a 1:1 slurry method of 10 g <2 mm sieved air-dry soil and 10 ml of DI water (Watson and Brown, 1998). All pH measurements were made with a Skalar SP50 Robotic Analyzer (Skalar Inc., Buford, Georgia).

Soil metals

Soil metals for iron, zinc, copper, and manganese were diethylenetriaminepentaacetic acid (DTPA) extracted using an Inductively Coupled Plasma (ICP) Spectrometer (Model 720-ES ICP Optical Emission Spectrometer, manufactured by Varian Australia Pty Ltd, Mulgrave, Vic Australia) as described by (Whitney, 1998).

Biological soil properties

Microbial phospholipid analysis

The total lipids were extracted from freeze-dried soil using a modification of the Bligh and Dyer lipid extraction method (Bligh and Dyer, 1959; White and Ringelberg, 1998; White and Rice, 2009). Briefly, phospholipid fatty acids (PLFA) were separated from the total lipid extract using silicic acid chromatography. The fatty acids were cleaved from the glycerol backbone using KOH saponification, and the harvested fatty acids were methylated to form fatty acid methyl esters (FAME). The resulting FAMEs were analyzed using a Thermo Scientific Trace GC-ISQ mass spectrometer (Thermo Fisher Scientific, Waltham, Massachusetts, USA) equipped with a DB5 MS column (30m x 250 µm i.d. x 0.25 µm film thickness, Agilent Technologies, Santa Clara, California, USA). The FAME peaks were identified by comparison with a total of 32 biomarkers, 26 biomarkers from a bacterial acid methyl esters mix (BAME; Matreya 1114; Matreya LLC, Pleasant Gap, Pennsylvania, USA) and six additional FAMEs were custom made for 10Me16:0 (Cayman Chemical 24823; Cayman Chemical Company; Ann Arbor, Mississippi, USA), 10Me18:0 (Larodan 21-1810; Larodan AB; Solna, Sweden), a17:0 (Matreya 1614; Matreya LLC, Pleasant Gap, Pennsylvania, USA), C16:1:11 (Matreya custom synthesis; Matreya LLC, Pleasant Gap, Pennsylvania, USA), C18:1:11:cis (MilliporeSigma 17264; MilliporeSigma; Burlington, St. Louis, Missouri, USA), and C20:0 (MilliporeSigma 10941; MilliporeSigma; Burlington, St. Louis, Missouri, USA). Peak concentration was quantified using the internal standard methyl nonadecanoate (19:0 FAME) (MilliporeSigma N5377; MilliporeSigma; Burlington, St. Louis, Missouri, USA). Fatty acids were grouped into Gram-positive (+) bacteria (i15:0, a15:0, i16:0, i17:0, and a17:0), Gram-negative (-) bacteria (19:0:delta9,10; C18:1:11:cis; 17:0:delta9,10; C10:0:2-OH, C12:0:2-OH, C12:0:3-OH, C14:0:2-OH, C14:0:3-OH, C16:1:0:cis, C16:0:2-OH), actinomycetes (10Me16:0 and 10Me18:0),

arbuscular mycorrhizal fungi (AMF) (C16:1:11), and fungi (C18:2:9,12) (White and Rice, 2009). Phospholipid fatty acid abundance was reported as nmol per gram of dry soil. Total microbial biomass was estimated using the sum of all PLFA biomarkers and the common biomarkers in microbes with FAMEs for C11:0; C12:0; C13:0; C14:0; C15:0; C16:0; C17:0; C18:0; and C20:0. The fungal to bacterial ratio was calculated by dividing the sum of AMF and saprophytic fungi by the sum of Gram (+), Gram (-), and actinomycetes. Percent composition of microbial community was determined for relative abundance as specific microbial groups divided by the sum of all the groups included. The equation below details the process:

$$Percent\ relative\ abundance = \left(\frac{Concentration\ of\ microbial\ group}{(Concentration\ of\ Gram\ (+) + Gram\ (-) + Actinomycetes + AMF + saprophytic\ fungi)}\right) \times 100$$

Soil respiration

Soil respiration was based on a modified version of Schindelbeck et al. (2016). Twenty (±0.05) g of 8-mm-sieved air-dried soil was placed in a perforated aluminum weigh boat then placed in a 1000 mL wide-mouth Ball Mason jar with 2 Whatman No. 42 filter paper place on the bottom. The soil was rewet from the bottom by pipetting 7.5 mL of DI water onto the filter paper and incubated for 4-days at 25 ℃. Jars were sealed with a modified flat screw-top ring with a rubber septum and Dow Corning high vacuum grease. After incubation, two 10 mL gas samples were taken per incubation jar. A 0.5 mL sample of each gas sample was analyzed for CO_2 on a Shimadzu Gas Chromatograph-8A (Shimadzu Scientific Instruments Inc., Columbia, MD). The gas chromatograph was equipped with a thermal conductivity detector and a 2-m Porapak Q column (0.318 id). The column temperature was 75 ℃ with an injection temperature

of 75 ℃. Helium (14-mL min^{-1}) was used as the carrier gas. An incubation with no soil was used to correct for CO_2 present before soil incubation. The equation below details the process:

$$\frac{\text{mg CO2}}{\text{g of soil}} = \left((\mu\text{g } CO_2 \text{ sample} - \mu\text{g } CO_2 \text{ control}) * \left(1000 \text{ mL} \frac{\text{volume}}{0.5} \text{mL gas sample} \right) \right.$$

$$\left. * \left(\frac{1}{20} \text{g soil} \right) * \left(\frac{1}{1} + \text{ soil moisture} \right) * \left(\frac{1\ mg}{1000\ \mu g} \right) \right)$$

Autoclavable extractable protein content

Autoclaved citrate extractable (ACE) protein content was measured following Schindelbeck et al. (2016) based on Wright and Upadhyaya (1996) with modifications by Hurisso et al. (2018). Air-dried soil (3 g) was combined with 24 mL 20 mM sodium citrate at a pH of 7.0 in a 50 mL centrifuge tube, shaken for 5 min at 180 OSC/min and then autoclaved for 30 min at 120 °C at 15 psi. Following autoclaving, soils were shaken for 3 min, the solution clarified by transferring 1 mL to a microcentrifuge and centrifuged at 10,000 RPM for 3 min. Following centrifugation, 10 µL was transferred to a 96-well plate with 200 µL of pre-made protein assay reagent of bovine serum albumin standard pre-diluted set (23208, Thermo Fisher Scientific, Waltham, Massachusetts, USA). The 96-well plates were sealed and incubated for 1 hr at 61.5 ℃. A pre-diluted set of protein assay standards, bovine serum albumin were used to generate a standard curve. Varioskan LUX Multimode Microplate Reader (3020, Thermo Fisher Scientific, Waltham, Massachusetts, USA) was used to measure the absorbance of each well in the 96-well plate at 562 nm.

Permanganate-oxidizable carbon

Permanganate-oxidizable carbon (POXC) was based on a modified version of Weil et al. (2003) by Kellogg Soil Survey Staff (2014). POXC was determined from 2.5 g soil (< 2 mm) combined with 10 mL 0.02 M $KMnO_4$ into 50 mL plastic screw top centrifuge tubes (06-443-20,

Thermo Fisher Scientific, Waltham, Massachusetts, USA). Each tube was vortexed and left to settle for 10 min before centrifuging for 10 min at 2000 rpm. A 0.5 mL sample of the supernatant was transferred to another centrifuge with 49.5 mL of DI water for dilution. The absorbance of the solution was determined on a Genesys 20 Visible Spectrophotometer (Thermo Fisher Scientific, Waltham, Massachusetts, USA) at 550 nm. The reactive soil organic carbon was reported as mg of oxidizable C kg^{-1} of soil. The equation below is the calculation for POXC:

$$\text{mg reactive C } kg^{-1} \text{ of soil} = \left(\left(0.02 \frac{\text{mol}}{\text{L}} \text{KMn}O_4\right) - (\text{a} + \text{b} * \text{ABS})\right) * \left(\frac{9000 \text{ mg C}}{\text{mol KMn}O_4}\right) * \left(\frac{0.02 \text{ L solution}}{0.0025 \text{ kg}}\right) * \left(\frac{\text{AD}}{\text{OD}}\right)$$

Enzyme assay

Six soil enzymes were assayed using p-nitrophenyl linked substrates and analyzed colorimetrically (Kellogg Soil Survey Staff, 2014; Acosta-Martínez and Tabatabai, 2011). β-glucosidase (Eivazi and Tabatabai, 1988), N-acetyl-β-glucosaminidase (Parham and Deng, 2000), acid phosphatase, alkaline phosphatase (Tabatabai and Bremner, 1969; Eivazi and Tabatabai, 1977), phosphodiesterase (Browman and Tabatabai, 1978), and arylsulfatase (Tabatabai and Bremner, 1970) are extracellular enzymes related to C, N, P, and S cycling, respectively. Three sets of 0.5 g air-dried 2-mm-sieved soil were placed in 20-mL glass screw-top vials with 2 mL of buffer. Two vials had 0.5 mL of p-nitrophenyl linked substrate added, and one vial served as a control with no reagent. Flasks were capped and incubated for 1 h at 37 ºC. Following incubation, 0.5 mL of 0.5 M $CaCl_2$ and 2 mL of stop buffer were added to each flask. The control had 0.5 mL of p-nitrophenyl linked substrate added after all the reagents. Samples

were filtered using Whatman 2V 9.0-cm diameter filter paper and absorbance measured using a Genesys 20 Visible Spectrophotometer (Thermo Fisher Scientific, Waltham, Massachusetts, USA) at 400 nm. Sample solutions with absorbances over 1.5 Au were diluted with nanopore water at a 3 to 5-fold dilution.

For the standard curve, the p-nitrophenol (PNP) standard solution was prepared with 1 g of PNP in 100 L of water, then 1 mL of the PNP standard solution was diluted with 99 mL of DI water. A calibration curve with 0, 2, 4, 6, 8, and 10 µg PNP was produced by adding 0, 1, 2, 3, 4, and 5 mL the diluted PNP standard solution to a 50 mL volumetric flask with water and then 0.5 mL of 0.5 M $CaCl_2$ and 2 mL of stop buffer were added to terminate the reaction. The solutions were filtered and measured using a spectrophotometer at a wavelength of 400 nm.

Oven-dried air-dried soil content

Soil metrics (soil respiration and POXC) that require moisture correction for using air-dried samples had oven-dried air-dried measurements calculated using the equation:

$$Oven\ dried\ air\ dry\ soil = \frac{Air\ Dry\ Soil\ Sample\ (g) -\ Oven\ Dry\ Soil\ (g)}{Oven\ Dry\ Soil\ (g)} * 100$$

Soil organic carbon and total nitrogen stocks

The SOC and TN stocks for each land use at each location was calculated as follows:

$$SOCS_i = SOC_i \text{ x } BD_i \text{ x } t_i \text{ (cm) x } 0.1$$

$$TNS_i = TN_i \text{ x } BD_i \text{ x } t_i \text{ (cm) x } 0.1$$

where $SOCS_i$ is the soil organic carbon stock (Mg C ha^{-1}) of depth increment i, SOC_i is the soil organic carbon content (g C kg^{-1}) of depth increment i, where TNS_i is the total nitrogen stock (Mg N ha^{-1}) of depth increment i, TN_i is the total nitrogen content (g N kg^{-1}) of depth increment i, BD_i is the dry soil mass per volume of soil (g cm^{-3}) in depth increment i, t_i is the depth

thickness (cm) at increment i, and 0.1 is the conversion factor to Mg SOC ha^{-1} and Mg TN ha^{-1} (Xu et al., 2019; Harrison et al., 2011).

SOC and TN stock losses in the cropping system were determined by the difference between NP and cropping system at each location. Soil stock was determined at the second to last horizon due to bedrock at Manhattan NP.

Data Analysis

Custom-written scripts in R version 4.0.3 (R core Team 2020) were used for graphing soil health parameters by depth, land use, and location. Error bars are standard errors of the mean (n=4). Standard deviation is a poor estimate of dispersion for a small number of observations, so outliers were determined based on a 90% confidence range using Dixon's Q test (Dean and Dixon, 1951). The Q test is determined by the difference between a doubtful observation from its nearest neighbor, divided by the range of values (Dean and Dixon, 1951). Correlation between measured soil health parameters was determined with Spearman Correlation at a $p<0.05$ significant level for the whole soil profile. A biplot was constructed with a principal component analysis (PCA) plot based on positive correlations in the correlation matrix for soil microbial composition and enzyme activity clustered by land use to show variation in datasets with loadings (arrows) and scores (data points) (Gabriel, 1971).

Results and Discussion

Physical soil properties

Mean weight diameter (MWD) was higher in the NP than AG and EA throughout the soil profile (Fig. 4.1). Higher MWD in NP was due to less soil disturbance and greater soil structure from perennial root development. The cropping systems had soil disturbance from tillage, plant

biomass removal, annual crops with shallower roots, and reduced microbial activity (Glover et al., 2007; Culman et al., 2010). As precipitation increased, soil aggregation for EA increased in the surface. This indicates aggregation was rebuilding in the surface with no-till and at a faster rate with increased precipitation. Lower MWD occurred in AG and EA relative to NP even to 100 cm depth. Thus, the change to annual plants and tillage translated to a loss of aggregation throughout the soil profile. There was some improvement in aggregation near the surface with EA, but this had not translated to deeper depths. The Tribune site was unique in that this site was converted to cultivated agriculture in 1989, so we know the loss of aggregation occurred in the last 30 years. Irrigation at the Tribune site had not improved aggregation. Blanco-Canqui et al. (2011) did not find significantly higher MWD in NT than CT at Hays and Tribune. In this study, Hays NT had a higher MWD than CT for the top 10 cm and then similar MWD below 15 cm.

Chemical soil properties

Soil organic carbon (Fig. 4.2) was greater in NP than AG and EA near the surface. Soil profile organic C is higher in the grassland than most cropland (Dodds et al., 1996). Only Hays had higher SOC in the EA than AG, indicating discrepancies in land use with location for different management systems. Soil organic carbon stocks (Fig. 4.3 and 4.4) were higher in NP than the cropping systems at all depths for Hays and Tribune. In Manhattan, the land uses had similar SOC with depth. Soil C in the topsoil was mainly associated with macroaggregates as a mineralizable resource, and vegetation and root exudates strongly influence soil organic carbon (SOC) stability. Conversely, below 30 cm, soil C absorbed by clay or other minerals is protected from mineralization (Singh et al., 2018). Yang and Wander (1999) found no-till soils (>10 yr) with greater SOC in the top 30 cm compared to moldboard plowed soils. Soil texture was similar

between Manhattan and Hays, while Tribune had slightly less clay content (25-35%) which would reduce stabilized SOC.

Total nitrogen followed the patterns of SOC (Fig. 4.5). The TN content was higher in NP than the cropping system and TN decreased with depth. Total nitrogen stocks were higher in NP than the cropping systems in Tribune and Hays (Fig. 4.6 and 4.7). At Manhattan, TN stocks were higher at deeper depths in AG than NP, similar to SOC stocks. Total N stocks for the profile were similar between Ag and NP, 16 and 17 Mg N ha-1 soil, respectively. The increase in C and N stocks down to 50 cm in Manhattan cropping system is due to C translocation as higher precipitation and higher pH dissolves OM and deposits C and N into subsoils (Zhang et al., 2012; Nicoloso et al., 2018). In addition, tillage promotes release of OM and annual cropping systems had less water uptake, allowing for dissolved OM to translocate deeper in the soil. Dissolved OM are mobile OM (<0.45 μm) that is ubiquidous in nature, made up leaf litter, stems, root exudates, roots, and decomposition of OM (Thurman, 2012; Bolan et al., 2011). Overall, carbon and nitrogen flux are altered by cultivation (Dodds et al., 1996).

Conversion of native prairie to agricultural use leads to a decline in SOC and TN, but the rate and amount of decline in stocks vary due to soil properties, climate, time, land use, and plant productivity (Sanderman et al., 2017). Changes in SOC and TN stocks were found for both cropping systems compared to NP at all locations. The SOC and TN stocks generally decrease from Tribune to Hays and then increase from Hays to Manhattan. In the semi-arid regions of Kansas, EA of Tribune and Hays had higher stocks than AG, while Manhattan EA and AG were relatively similar in stocks. The soil C and N stock loss at each location was relatively greater in AG vs. EA (Table 4.1). The loss was due to greater mineralization rates as a result of tillage. Tribune AG lost 25% SOC and 15% TN, whereas Tribune EA lost 20% SOC and 15% TN. Hays

AG lost 40% SOC and 33% TN , while Hays EA lost 26% SOC and 7% TN . Manhattan AG and EA both lost 20% SOC, while TN loss was 6% for AG and 18% for EA. The EA also retained greater SOC (Tribune and Hays) and TN (Hays) than AG for the whole soil profile. In the same Hays and Tribune site, Blanco-Canqui et al. (2011) found no-till did not store more SOC than conventional tillage. In addition, SOC and TN did not significantly differ between cropping systems for the whole soil profile (0-100 cm) (Blanco-Canqui et al., 2011).

Whole profile estimation of C and N stocks are important for measuring C and N contributions of various land uses to supporting ecosystem services, sequester SOM, and contributing to earth's sustainability (Kravchenko and Robertson, 2011). In this study, more than 40 years of intensive cultivation reduced soil C levels as high as 40% in Hay and as low as 20% in Manhattan compared to native prairie (Table 4.1). Cultivation of native soils generally results in 50-60% reduction in OM content in the first ~50 years, followed by a new equilibrium (Paul et al., 1997; Sotomayor and Rice, 1999). Thus, the C reductions to depth are possibly near equilibrium in the cropping systems.

Available P was generally low in NP except for Tribune (Fig. 4.8). Available P was generally higher in cropping systems than NP, especially in the surface layers. The higher P was likely due to the addition of P from fertilization. The differences between AG and EA for the Hays and Manhattan sites are likely due to differences in the management of land managers. Tribune AG and EA had similar P content, which was managed the same as far as P fertilization. Interestingly, the IR site had much lower P levels which may be due to management.

Soil pH increased with increasing depth in NP (Fig. 4.10). Soil pH was higher in the Manhattan Ag, presumably due to liming. Tribune IR had higher soil pH levels than other land uses (AG, EA, and NP) due to irrigated water with Ca content that raised the soil pH.

Manhattan Ag soil pH was relatively basic with soil depth most likely due to calcium carbonates and limestone bedrock.

Calcium content generally increased with increasing soil depth since Ca leaches out of the top horizon and is more abundant in deep soil horizons due to limestone bedrock (Fig. 4.9) (Wehmueller, 1996). This is much more evident in Tribune and Hays, while Manhattan has more variable Ca due to differences in land management, fertilizer application, and soil. Tribune IR had significantly higher Ca levels in the deeper horizons due to irrigation waters having high Ca content.

Biological soil properties

Soil microbial biomass was generally higher in surface soils than subsoils (Fig. 4.20). Higher soil nutrients and optimal soil conditions promote greater microbial biomass in NP at all locations than cropping systems. Microbial biomass decreased exponentially with depth was also found in numerous studies (Hsiao et al., 2018; Stone et al., 2014; Wardle et al., 2004). For cropping systems, microbial biomass was, unexpectedly, higher in the surface of Manhattan AG than EA, while Hays EA had higher microbial biomass than Hays AG. This unexpected difference between Manhattan AG and EA is likely due to management.. Microorganisms in subsurface soils are exposed to SOM inputs from deep roots, dissolved organic carbon, and decaying microbial cells (Pett-Ridge et al., 2018). Other factors that regulate microbial composition in subsoils include moisture, physical soil properties (texture, aggregation), chemical properties (pH, oxygen availability, mineral reactivity), and other soil biota (Pett-Ridge et al., 2018). Precipitation can shift microbial biomass, composition, and activity (Castro et al., 2010). Overall, cropping systems had significantly less microbial biomass than NP with depth in Manhattan and Hays which supports other findings that intensive agriculture reduces the

microbial biomass (Sander mand et al., 2017). Native prairies at all locations had higher microbial biomass than cropping systems due to perennial plants with deep rooting systems that increase organic C and N into the deeper soil horizons (Beniston et al., 2014; Jackson et al., 1996). Improved soil management and shifts towards perennial crops could sequester C fixed by plants while simultaneously improving soil health, water holding capacity, nutrients, reducing erosion and buffering the impacts of climate change (Smith 2012; Paustian et al. 2016; Pett-Ridge et al., 2018).

Plants provide the substrate and nutrients for soil decomposers and symbionts (microbes, nematodes, mites, earthworms. Plant species differ in quantity and quality of resources returned to soil (de Vries et al., 2012). Bacterial groups are responsive to the presence of particular plants, although patterns are generally complex and unpredictable due to the diversity of biota (Porazinska et al., 2003; Bradford et al., 2002). Gram (+) bacteria followed the same trend as total microbial biomass (Fig. 4.21). Native prairie had the highest Gram (+) bacteria at all locations through the soil profile. For native prairie, Gram (-) bacteria was generally higher at all locations with depth (Fig. 4.22). Hays and Tribune cropping systems had similar levels of Gram (-) bacteria. Actinomycetes (Fig. 4.23) are Gram (+) bacteria with varying levels of inhibitory activity against fungal pathogens (Olanrewaju and Babalola, 2019; El-Tarabily et al., 2000; Zaitlin et al., 2004). NP tended to have greater actinomycetes than the cropping systems except for Hays EA. Actinomycetes generally declined with depth with a greater decrease with increasing precipitation. Mathew et al. (2012) found actinobacteria to be consistently higher in no-till surface soils. Our findings were contrary to Mathew et al. (2012) since no-till did not have higher actinomycetes at any location.

Arbuscular mycorrhizal fungi (Fig. 4.24) were more abundant in NP than both cropping systems at Manhattan and Hays, while Tribune NP was similar in abundance with EA and AG. Saprophytic fungi (Fig. 4.25) were more prevalent in NP and decline with depth. The differences between land uses were greater with increasing precipitation.

Soil bacteria and fungi respond differently to moisture conditions. Drought conditions destabilize bacterial networks more than fungi (de Vries et al., 2018). The fungal to bacterial ratio (Fig. 4.26) varied with location and land use. The F:B ratio varies due to substrate availability and type of carbon sources (Preusser et al., 2019; Rumpel et al. 2002). The increase in the F:B ratio in the lower depths indicates a shift in fungal domination. Tribune has a relatively higher response of fungi in subsoils, likely because fungi are known to be less moisture dependent than bacteria (Drenovsky et al., 2004). The F:B ratio in the surface soils for all land uses were similar, except Hays EA. Less variation in the F:B ratio at Manhattan could be due to fewer climate limiting conditions (Ettema and Wardle, 2002).

Shifts in microbial communities may indicate ability or adaptation to withstand stress. Cultivated soils usually have greater microbial diversity due to increases in stress, but have lower microbial populations (Kennedy and Smith, 1995). The relative abundance indicates shift in microbial community (Fig. 4.27, 4.28, 4.29, 4.30, and 4.31). In general, Gram (+) bacteria was most abundant among all land use and locations between 40-60% (Fig. 4.27), followed by Gram (-) bacteria within 20% (Fig. 4.28), AMF within 15-25% (Fig. 4.30), saprophytic fungi within 5% (Fig. 4.31), and actinomycetes with <5% (Fig. 4.29). Actinomycetes did not respond to location, depth and land use except in Hays AG. Saprophytic fungi decreased with disturbance and declined with depth. This was due to higher substrate availability for decomposition in native prairie and surface soils compared with cropping system and less plant inputs in subsoils

(Sanaullah et al., 2016). Arbuscular mycorrhizal fungi abundance generally decreased with depth for all land uses. The relative abundance of AMF was higher in NP than AG with soil depth. Gram (+) bacteria and Gram (-) bacteria had contrasting relative abundances where Gram (+) bacteria was lower if Gram (-) bacteria was higher and vice versa. For example, Hays AG decreased with Gram (+) bacteria with depth, while Gram (-) bacteria increased with depth. At Manhattan EA, Gram (+) bacteria decreased and then increased, while Gram (-) bacteria followed a reverse pattern. In conjunction with PLFA, our study found greater enzyme activity in the top 15 cm than subsurface soils. Sanaullah et al. (2016) also found enzyme activities to be much higher at the top 30 cm than lower depths due to greater SOM and better soil environmental conditions.

In prairies, greater microbial biomass and soil organic matter indicates greater nutrient cycling and C turnover (Franzluebber et al., 1999). β-glucosidase activity decreased with depth in all land use and locations (Fig. 4.11). This is due to a more active microbial community in the topsoil from greater C inputs and more optimal growing conditions. Hays EA had the highest bG activity than any other location and land use. This was likely due to cover crop release of bG for C cycling. These results were expected as organic C is higher and requires enzymes for mineralization. Tribune IR had the highest bG activity due to higher soil moisture, greater crop growth resulting in higher microbial activity. The differences between land use were less apparent than with SOC. Fungal communities are indicative of β-glucosidase potential to degrade cellulose and lignocellulose (Osono and Takeda, 2006; Sanualla et al., 2016).

N-acetyl-b-D-glucosaminidase activity generally decreased with depth (Fig. 4.12). Native prairie had higher NAG activity followed by EA and then AG at all locations. This was due to more substrate for microbial activity in NP followed by EA than AG. Tribune IR has the lowest

NAG activity compared to the other Tribune land uses due to higher available inorganic N. For AG, NAG activity was lowest because of N fertilizer application that inhibits microbial N cycling (Burns et al., 2013).

Acid phosphatase activity decreased with depth (Fig. 4.13). Native prairie had higher AP at all locations due to more P needed for microbial and plant growth. Alkaline phosphatase activity was generally higher near the soil surface, but did not follow the trend as AP with precipitation (Fig. 4.14). Manhattan topsoil had greater ALP activity in order of NP>AG>EA, while at lower depths ALP activity shifted towards the order of AG>NP>EA. This was likely due to a shift in soil pH and microbial activity that induces ALP production. Hays's topsoil had ALP activity in order of NP>EA>AG, while deeper soil had NP>AG=EA trends. Hays and Tribune both increased in ALP activity with depth likely due to more basic soil pH. Tribune IR decreased in ALP activity with depth even with a high soil pH, due to high levels of inorganic P.

In general, phosphodiesterase activity was highest in NP at all locations and decreased with depth (Fig. 4.15). The variations in PHO was similar to ALP since hydrolysis of phosphodiester is by phosphodiesterase to produce phosphomonoester that will then be hydrolyzed by phosphomonoesterase (phosphatase) (Hou et al., 2015; Nannipieri et al., 2011). Arylsulfatase activity was highest in NP and declined with depth (Fig. 4.16). There were no differences between EA and AG and did not vary with depth.

Protein content responded to land management, precipitation, and depth (Fig. 4.17). Native prairie had higher protein content than cropping systems for Tribune and Manhattan, while Hays EA had higher protein content in the surface likely due to cover cropping. Protein content decreased with depth at all sites due to a decrease in organic N. Autoclaved citrate extractable protein content to total nitrogen ratio (Fig. 4.27) was greater in NP than cropping

systems at Manhattan, while EA had a greater protein:TN ratio than AG with depth. Tribune AG, EA, and NP had similar protein:TN ratio in the surface but decreased at a faster rate in the cropping systems than NP. Hays had unexpected higher protein:TN ratio. In particular, the ratio in the topsoil was ordered EA>AG>NP where NP had the least.

Permanganate-oxidizable carbon did not respond to depth and precipitation and did not follow the pattern as SOC (Fig. 4.18). Pulleman et al. (2021) determined POXC was not a good measure of active carbon. Soil respiration was more responsive than POXC to land use and depth (Fig. 4.19). Native prairie at Manhattan and Hays had greater respiration than both cropping systems. Respiration decreased with depth for all land uses. Respiration at Hays EA was higher than Hays AG due to greater microbial activity. Tribune land uses followed the order of IR>EA>NP>AG.

Soil respiration to soil organic carbon ratio (Fig. 4.28) was similar at Manhattan surface soil but NP increased in respiration:SOC ratio with depth. At Hays, respiration:SOC ratio was similar in surface soils, but NP and EA increased in ratio with depth compared to AG. Tribune IR had higher respiration:SOC, followed by EA>NP=AG in the surface soils.

The NP and cultivated soils were different in a majority of all metrics assays. The biogeological properties such as microbial biomass, OM substrate cycling, microbial activity, and OM levels were higher in NP than cropping systems similar to other studies comparing prairie and cultivated lands (Kennedy and Smith, 1995).

Correlation and principal component analysis

The sensitivity of different indicators in distinguishing field types varied by land use and soil type. Correlation and principal component analysis (PCA) are best suited for normalizing and weighting the entire data set (Rinot et al., 2019; Mukherjee and Lal, 2014). The correlation

matrix (Fig. 4.34) and PCA biplot (Fig. 4.35) indicated high correlations between soil microbial composition biological variables, respiration, protein, soil microbial community composition, and enzyme activity (Fig. 4.34 and 4.35). A PCA biplot of the biological soil properties describes 77.3% of the variance. The loadings of the variables had highly positive correlations between the biological variables, specifically enzyme activity with respiration and protein content, and soil microbial community composition among each variable. The correlation between microbial composition and enzyme indicators was likely due to soil microorganisms devoting energy to extracellular enzyme production (Hsiao et al., 2018; Burns et al., 2013; Stone et al., 2014). The land use groupings indicated greater variability in NP followed by EA and then AG. This is likely due to greater diversity in plant species in NP with more biological diversity compared to cropping systems.

Acid phosphatase, alkaline phosphatases, and phosphodiesterase were not correlated with extractable P content. This was due to available P being negatively associated with the release of phosphatase and phosphodiesterase which release cycle P from organic P (Margalef et al., 2017). In addition, alkaline phosphatase and phosphodiesterase followed similar trends in SOC and TN since P cycling enzymes are highly related to the C and N availability (Margalef et al., 2017).

Mean weight diameter was correlated with SOC, TN, and biological soil properties. Soil microbial communities contribute to C and N stabilization due to biochemical recalcitrance from microbial products and hyphae, while aggregation of organic matter offers physical protection (Six et al., 2006; Wright and Upadhyaya, 1998). Research between bacterial and fungal communities across pH gradients has indicated pH having a greater influence on soil bacteria than fungal composition most likely due to narrower pH range for bacterial growth (Rousk et al., 2010; Lauber et al., 2008).

Conclusions

Soil health metrics was useful in understanding precipitation and land use. Evidence of land use change occurs in a heterogeneous way (Vitousek, 1994). Several soil health metrics were able to distinguish differences among long-term land management in a multi-site analysis along a Kansas precipitation gradient to a 1 m soil depth. Variability between surface and subsurface soils captured more differences in the wetter sites. Soil organic carbon and TN stocks were higher in NP than cropping systems. Soil microbial community composition was generally higher in NP than cropping systems with precipitation. For the drier site, Tribune exhibited similar soil health measurements in chemical and physical properties between land uses except IR. In contrast, enzyme activity, soil respiration, and soil microbial community composition were much less than wetter sites of Kansas. The PCA biplot explained positive correlations among different biological properties.

The set of soil health metrics to assess soil health was able to detect surface and subsurface changes with different soil types.. Several soil properties have high correlations, such as ALK and PHO. A single sampling time may not properly demonstrate changes for the more dynamic soil health properties. Thus, the best approach to capturing soil health may be to eliminate highly correlated measures, replace measures that need more consideration, and investigate variations in soil sampling times with select soil health metrics. The use of the permanganate-oxidizable carbon method may also need further investigation related to interpretability across different soils (Gruver, 2015).

In conclusion, NP across precipitation had consistently higher soil health metrics, while variations in management histories for the cropping systems make interpreting the soil health status more challenging. A more effective measurement of soil health would be monitoring soil

health change over time. Overall, there is value in assessing changes in soil health to understand complex patterns.

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Tables

Table 4.1. Percent of soil organic carbon and total nitrogen stock losses in cropping systems based on native prairie stocks.

		SOC Stock	TN Stock
		% loss	
Tribune	AG	25.18	15.38
	EA	20.14	15.38
Hays	AG	40.30	33.33
	EA	26.12	6.67
Manhattan	AG	19.89	5.88
	EA	19.89	17.65

Figures

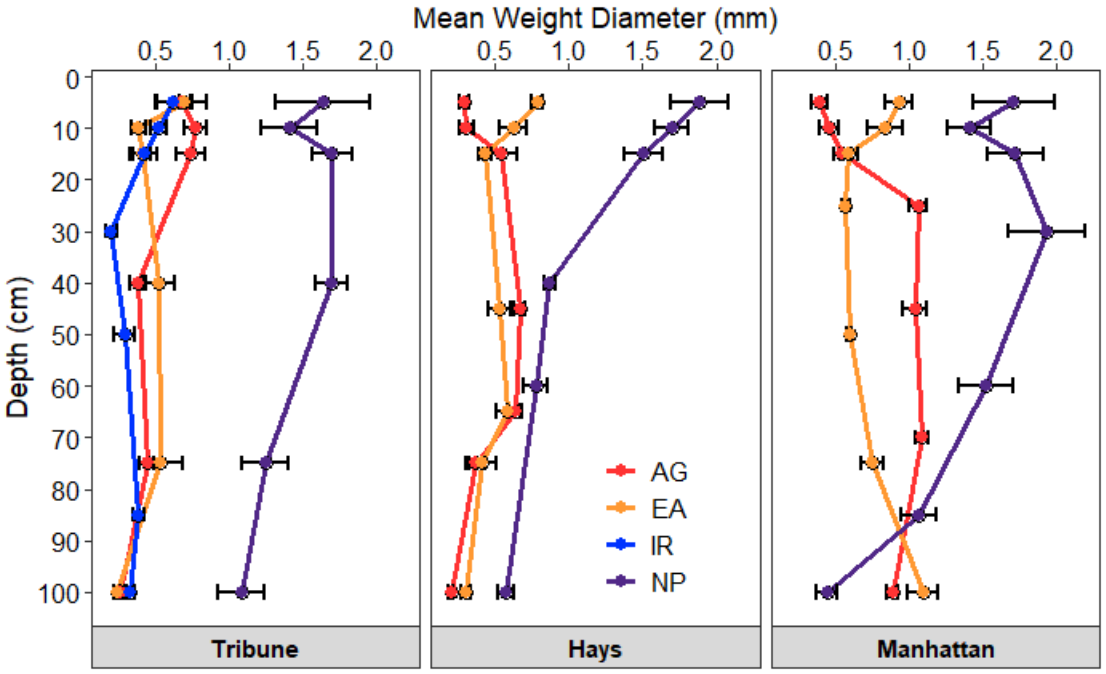

Figure 4.1. Mean weight diameter by depth for different land uses and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

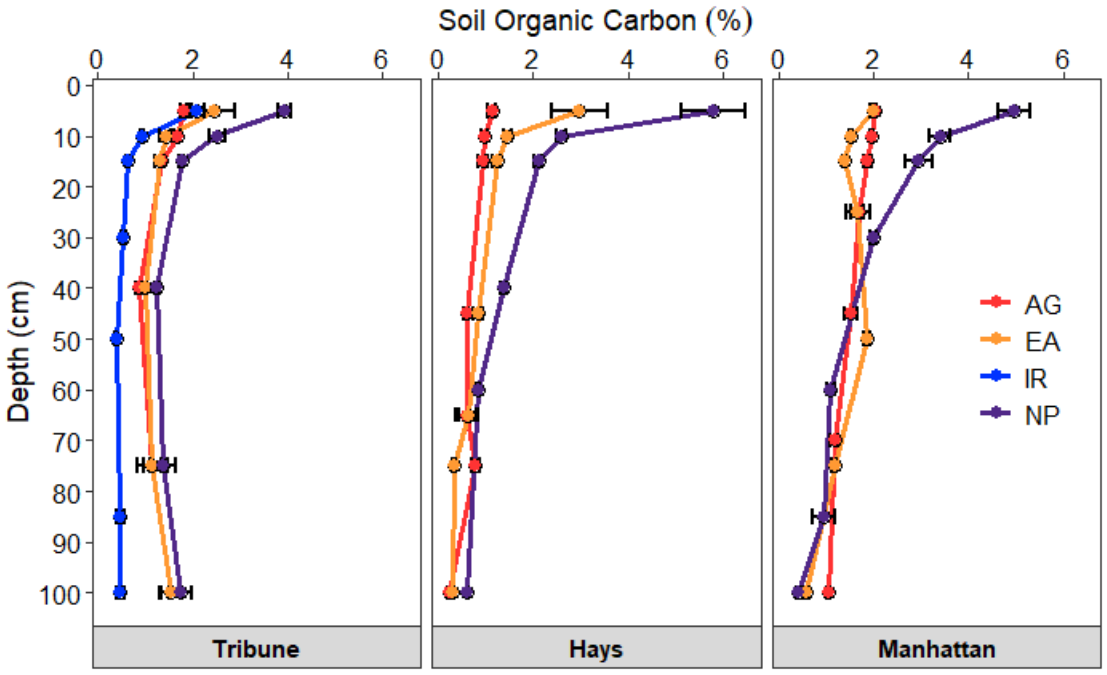

Figure 4.2. Soil organic carbon by depth for different land uses and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

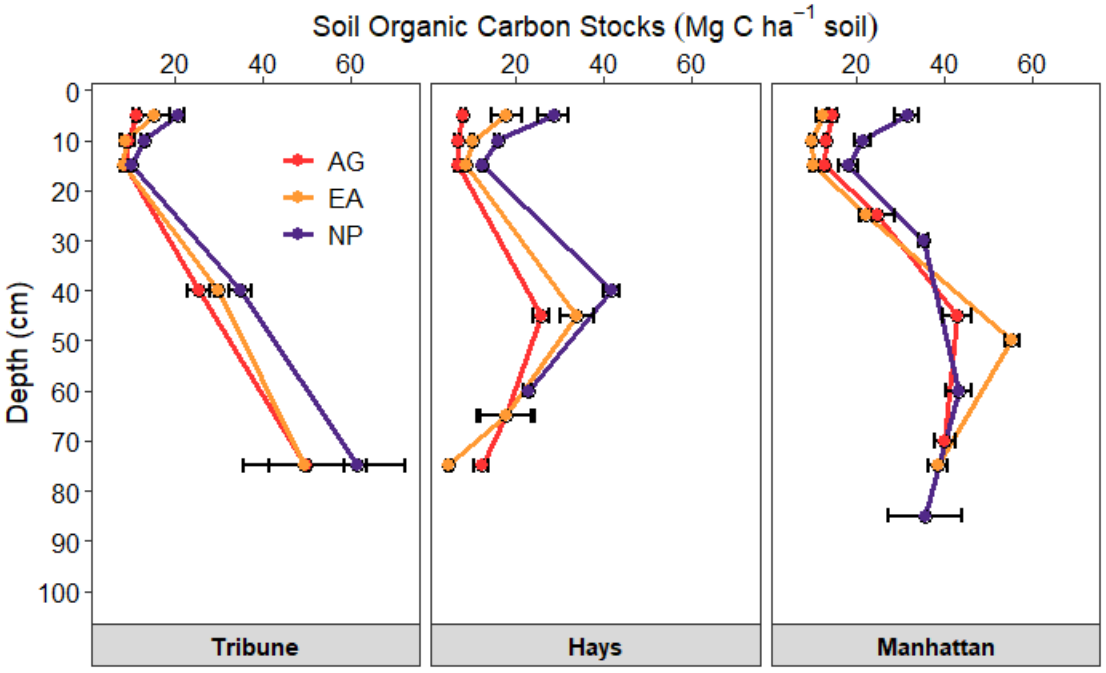

Figure 4.3. Soil organic carbon stocks by depth for different land uses and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), and native prairie (NP).

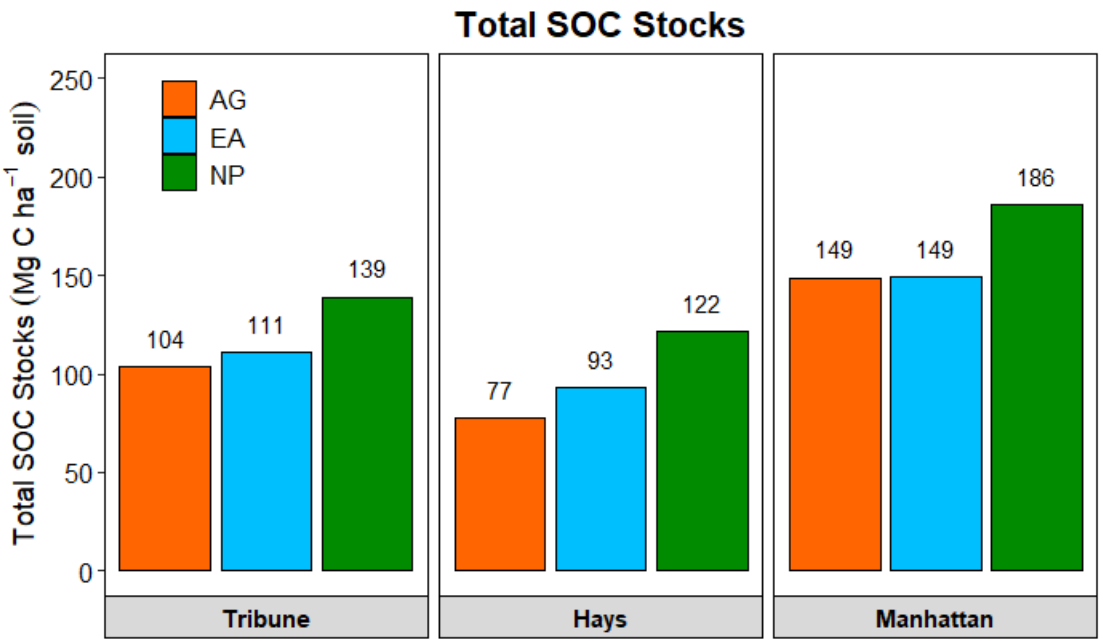

Figure 4.4. Soil organic carbon stocks summed for different land uses and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), and native prairie (NP).

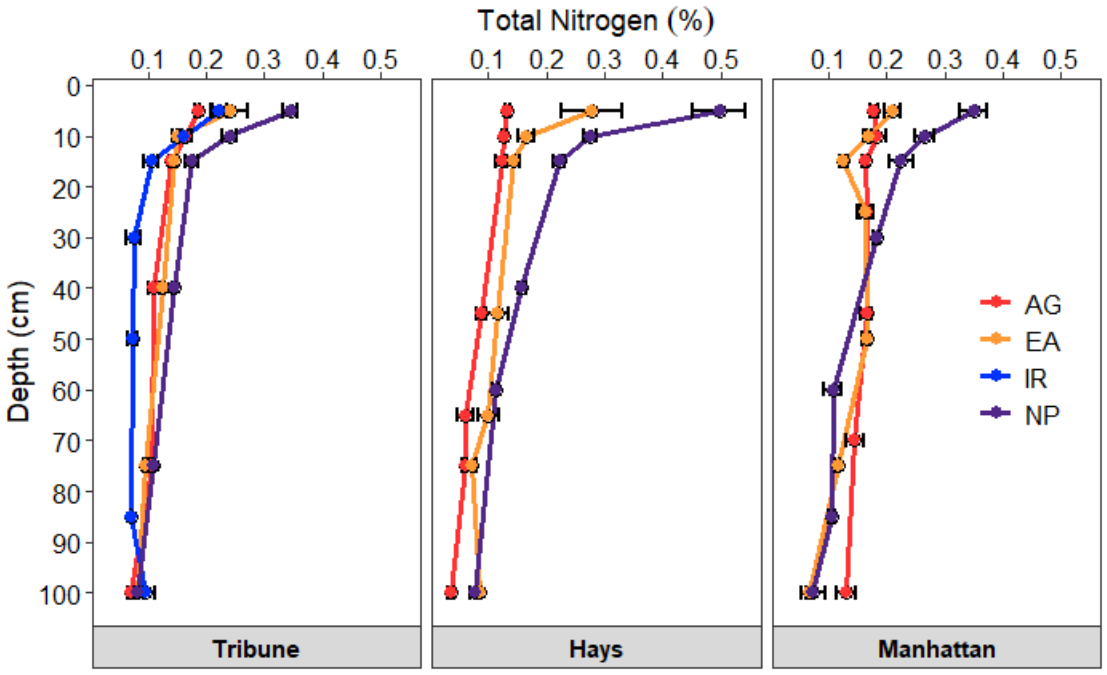

Figure 4.5. Total nitrogen by depth for different land uses and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

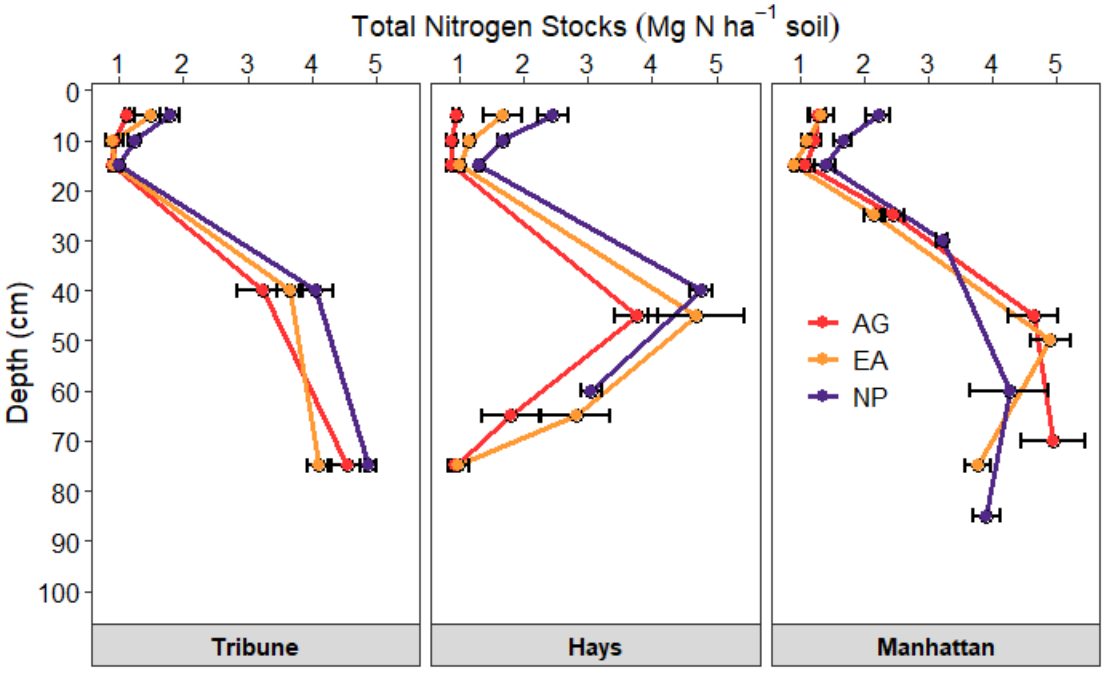

Figure 4.6. Total nitrogen stocks by depth for different land uses and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), and native prairie (NP).

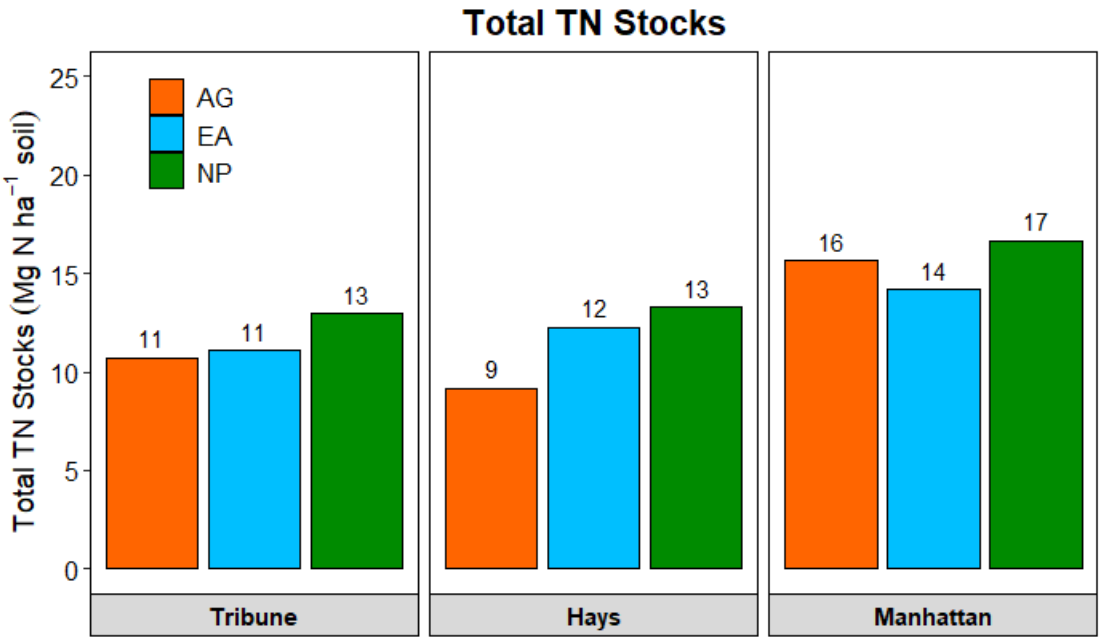

Figure 4.7. Total nitrogen stocks summed for different land uses and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), and native prairie (NP).

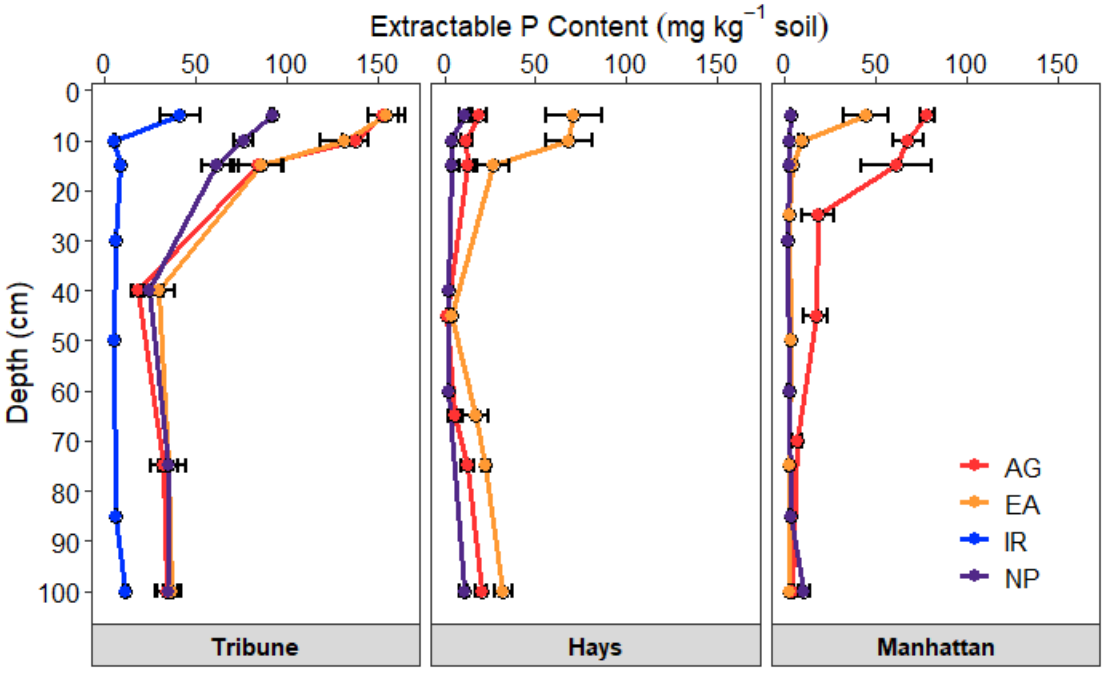

Figure 4.8. Extractable P by depth for different land uses and locations to a100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

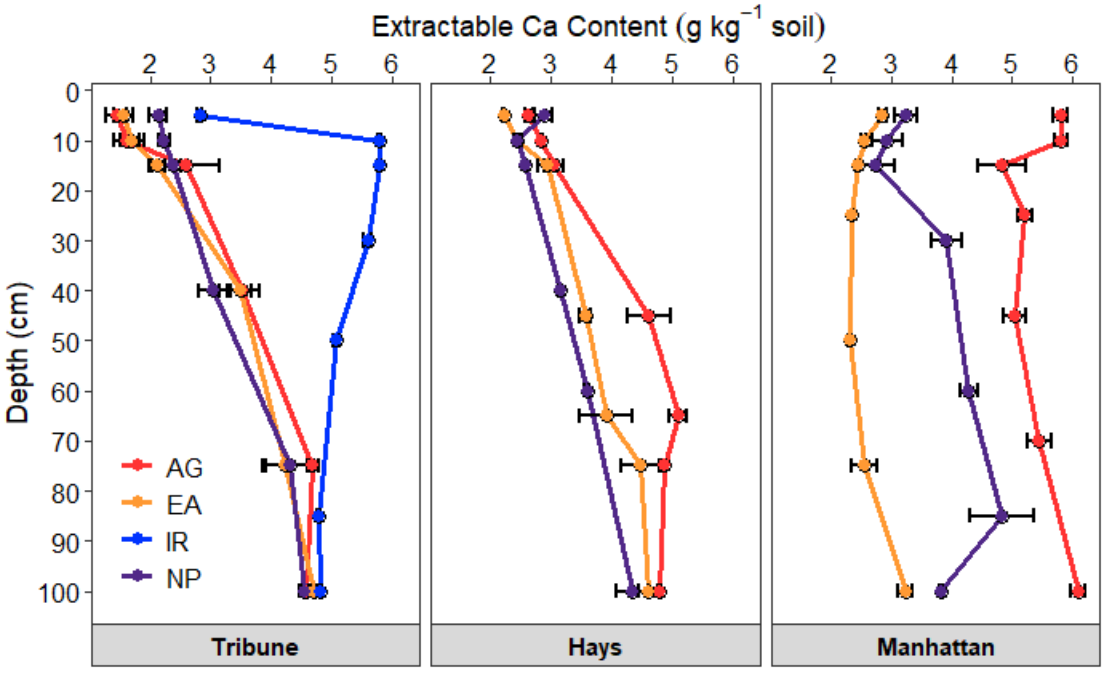

Figure 4.9. Exchangeable Ca profile for different land uses and locations to 100 cm. Land use was labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

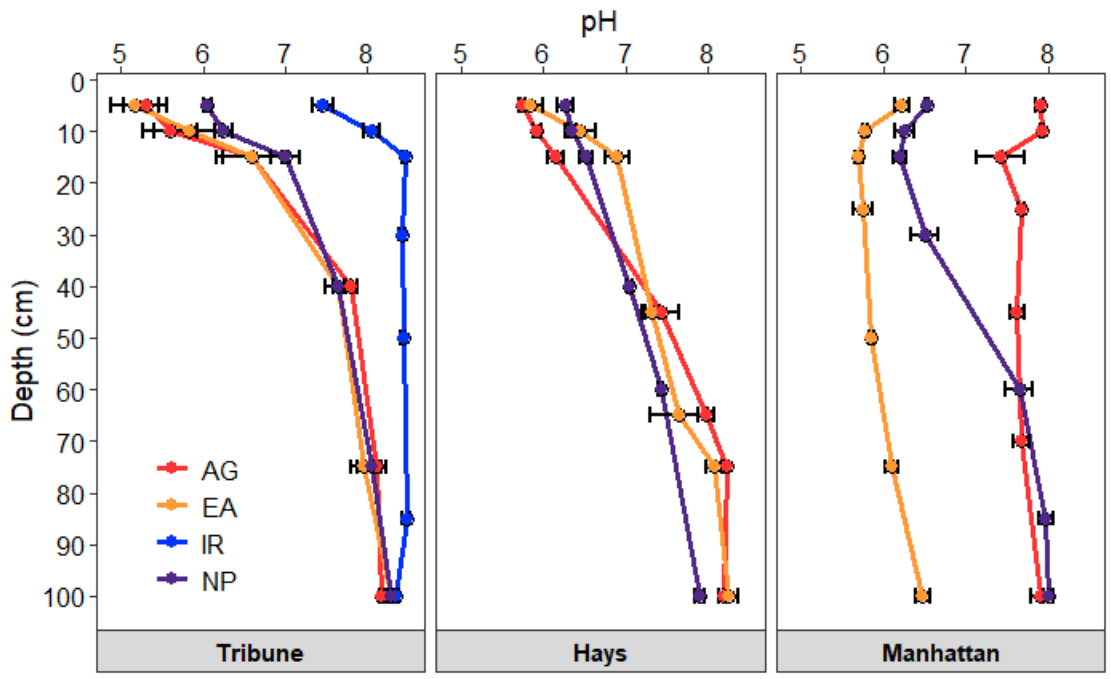

Figure 4.10. Soil pH by depth for different land uses and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

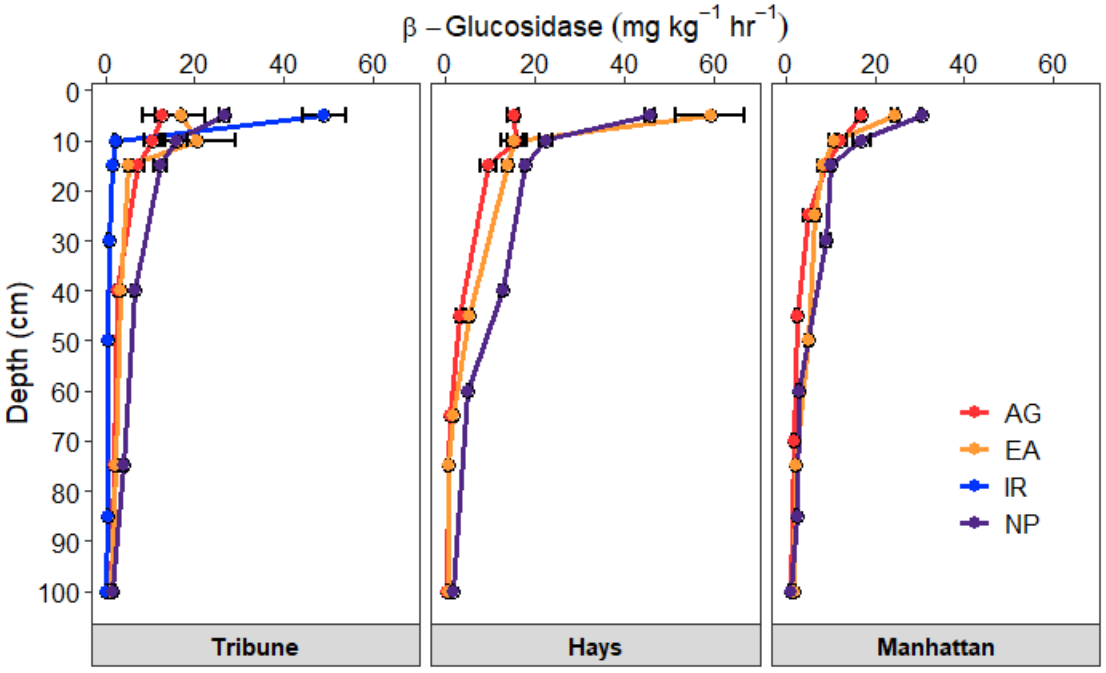

Figure 4.11. β-glucosidase for different land uses and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

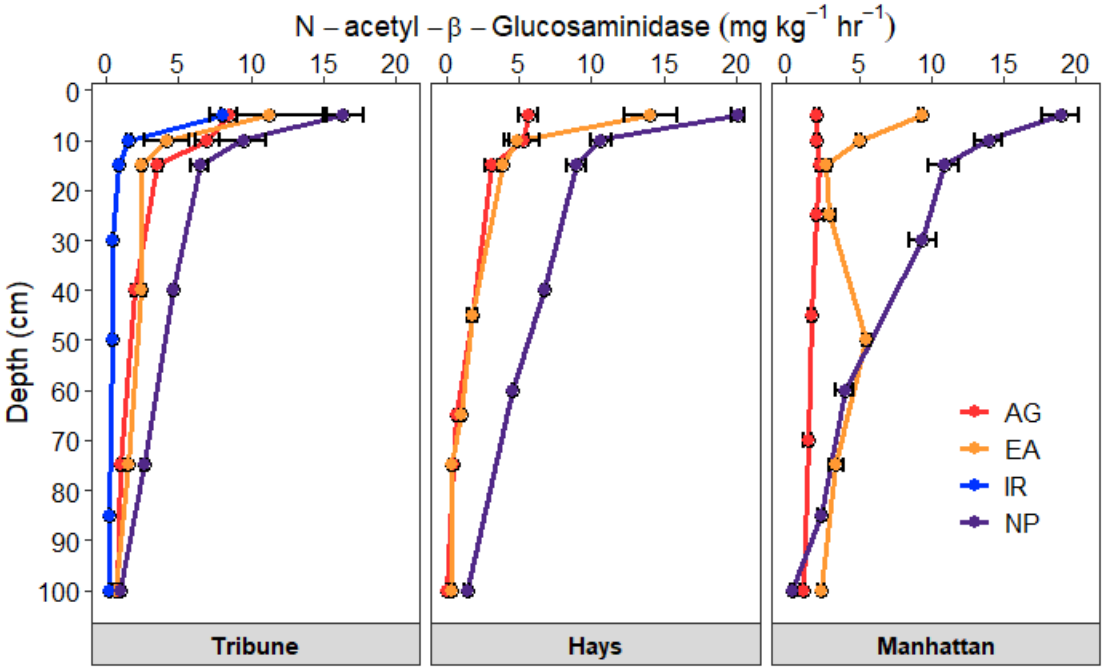

Figure 4.12. N-acetyl-b-D-glucosaminidase by depth for different land uses and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

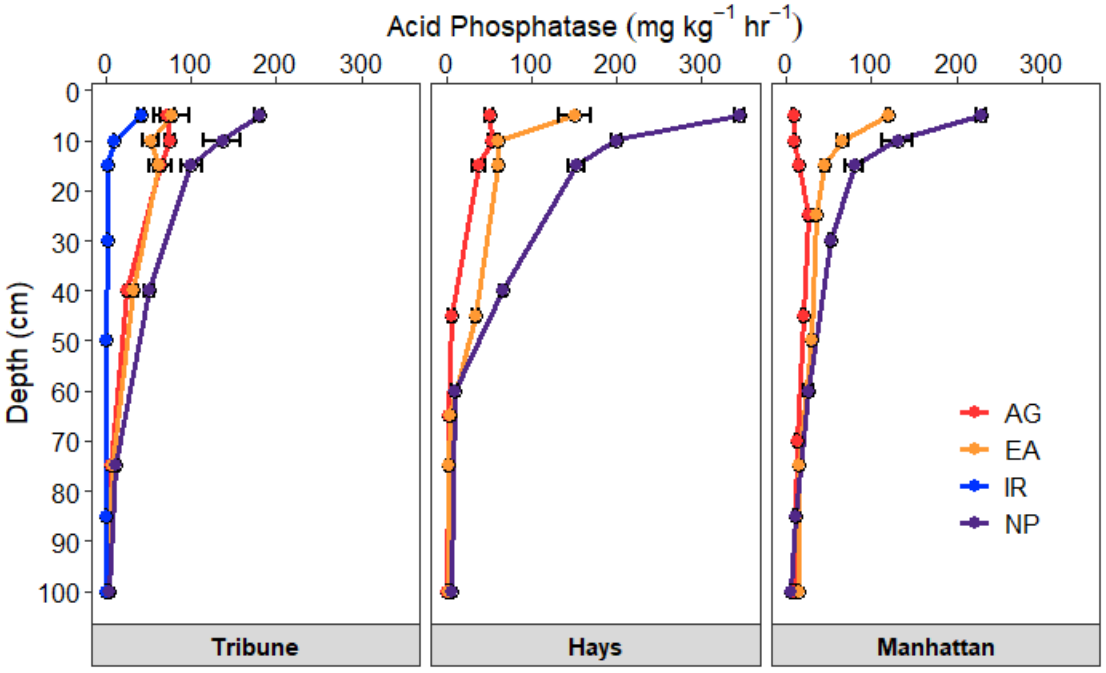

Figure 4.13. Acid phosphatase by depth for different land uses and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

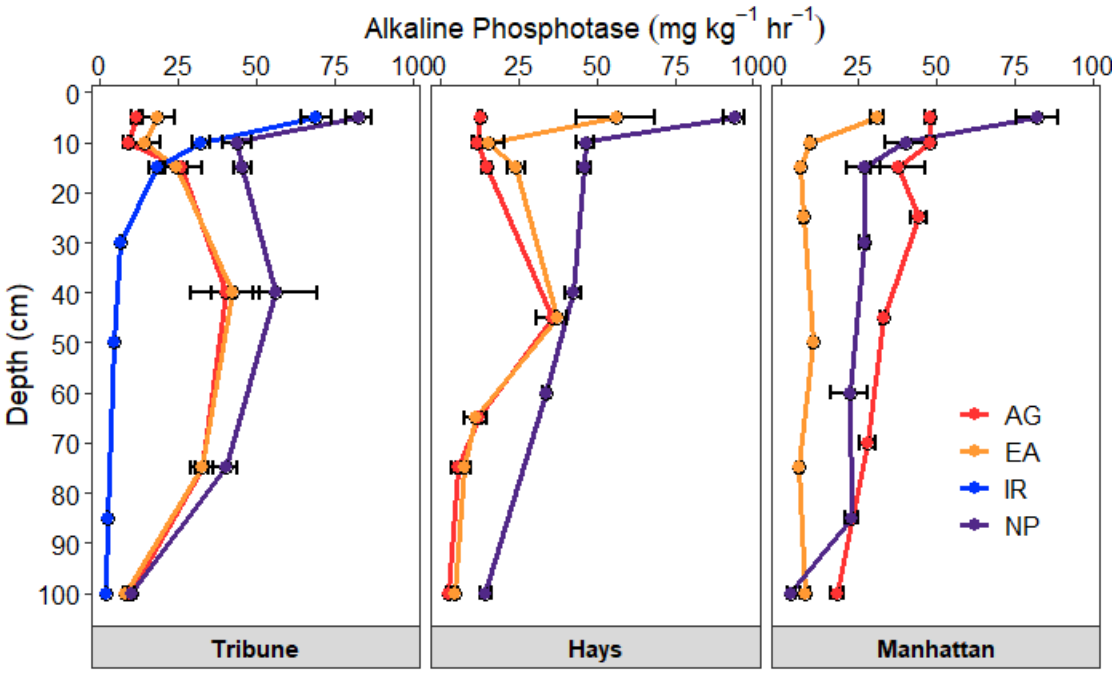

Figure 4.14. Alkaline phosphatase by depth for different land uses and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

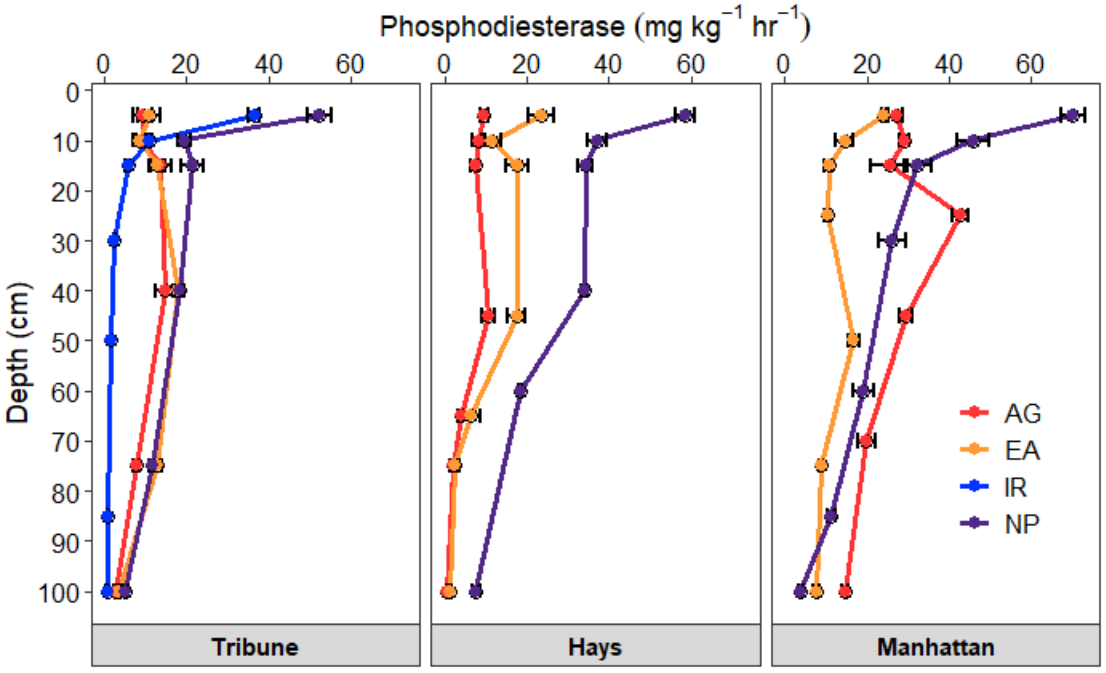

Figure 4.15. Phosphodiesterase by depth for different land uses and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

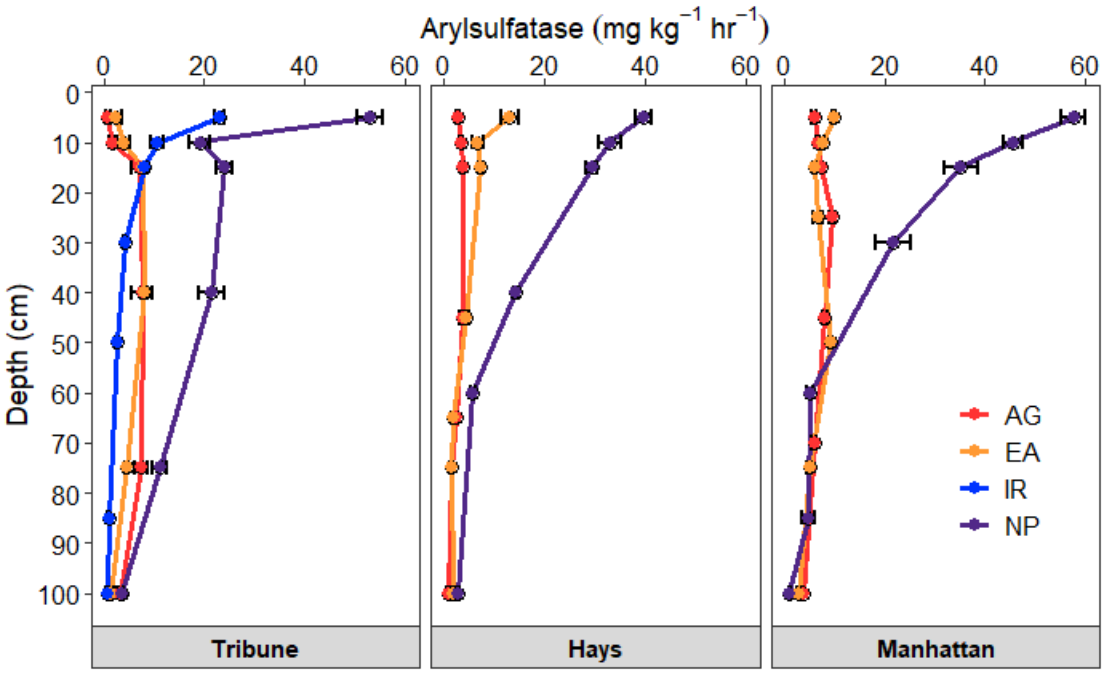

Figure 4.16. Arylsulfatase by depth for different land uses and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

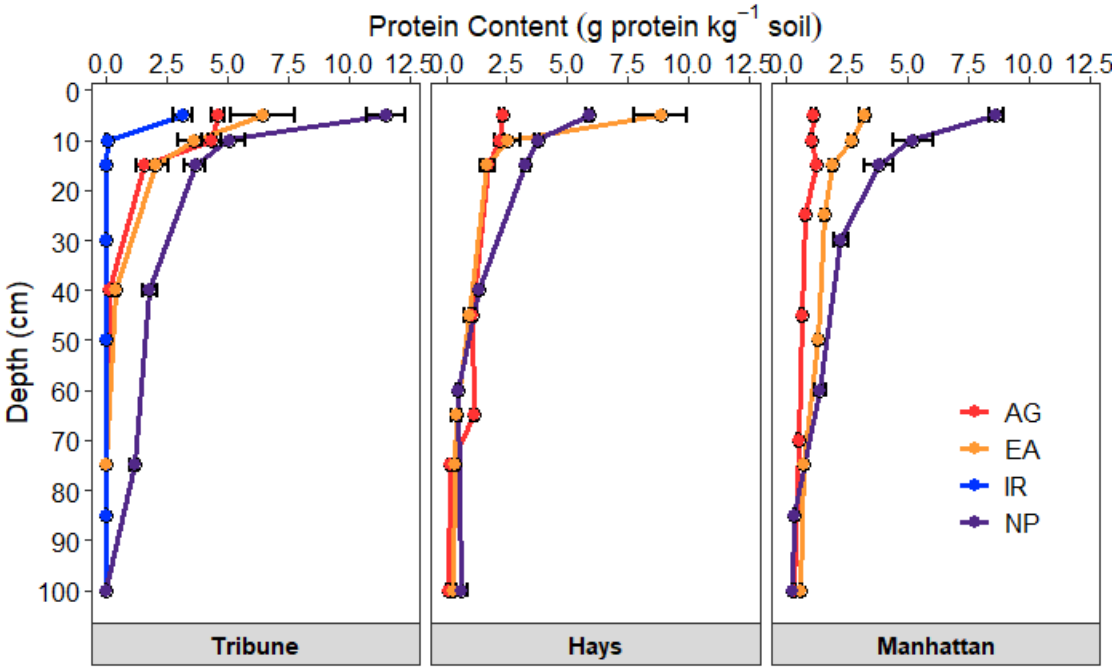

Figure 4.17. Protein content by depth for different land uses and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

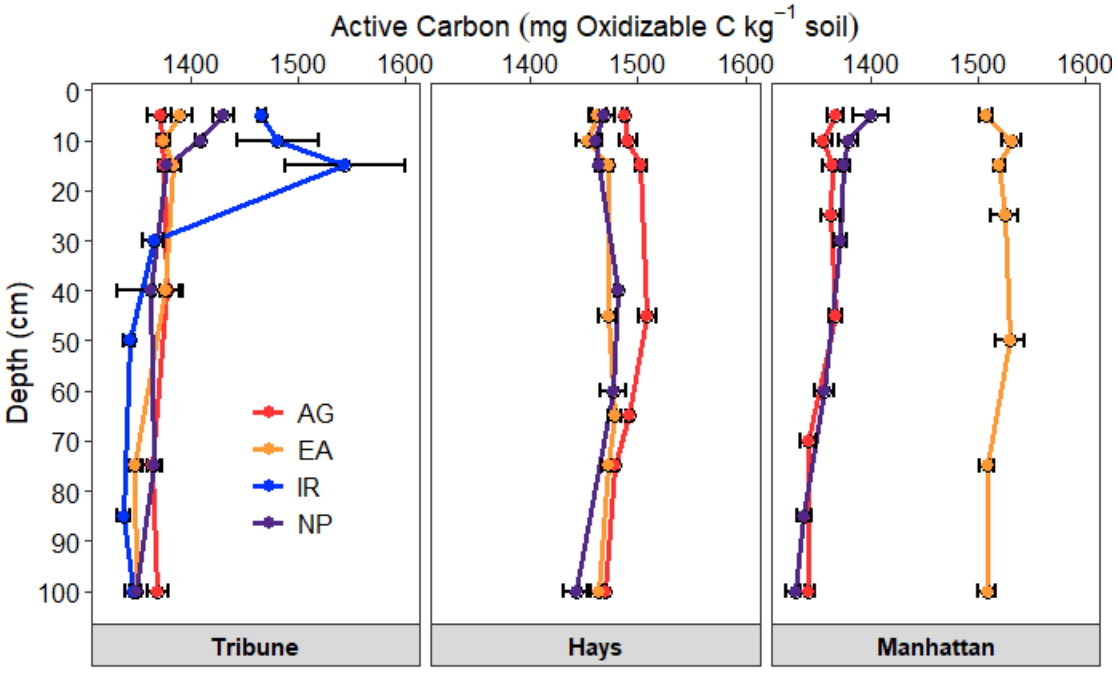

Figure 4.18. Permanganate-oxidizable carbon (active carbon) by depth for different land uses and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

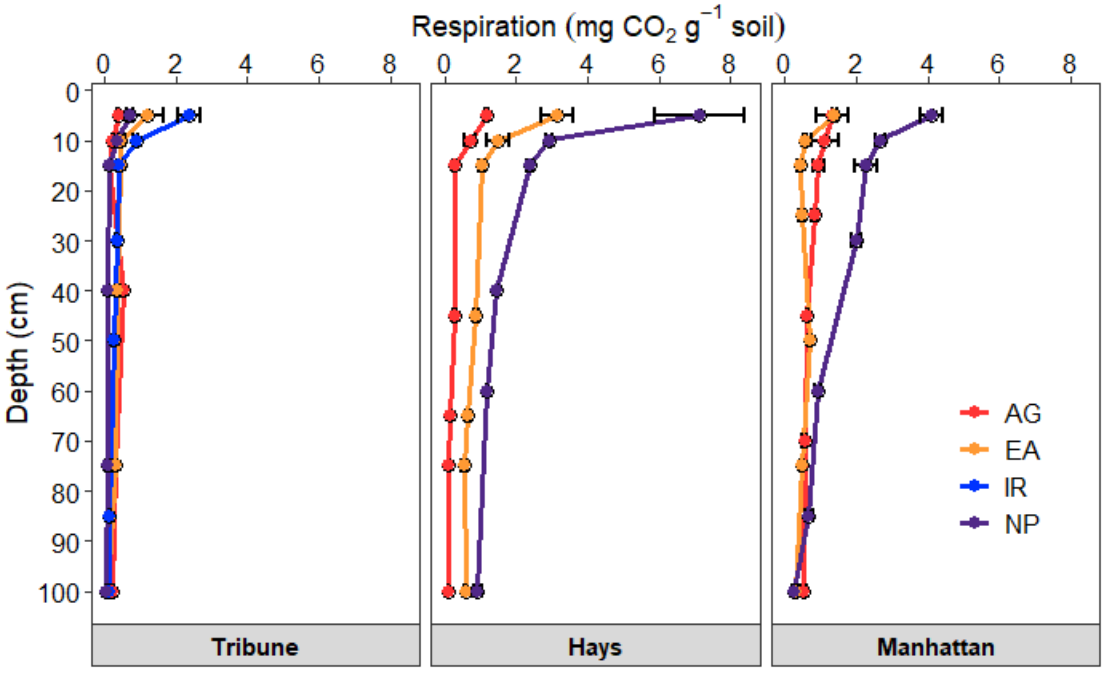

Figure 4.19. Soil respiration by depth for different land uses and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

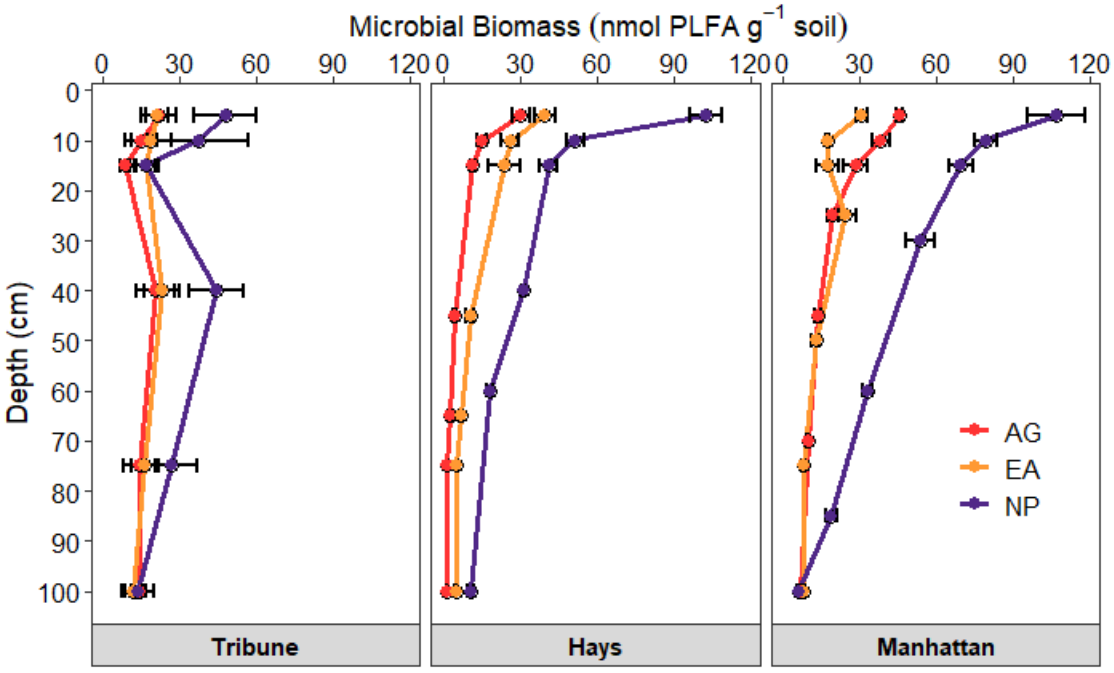

Figure 4.20. Microbial biomass by land use and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

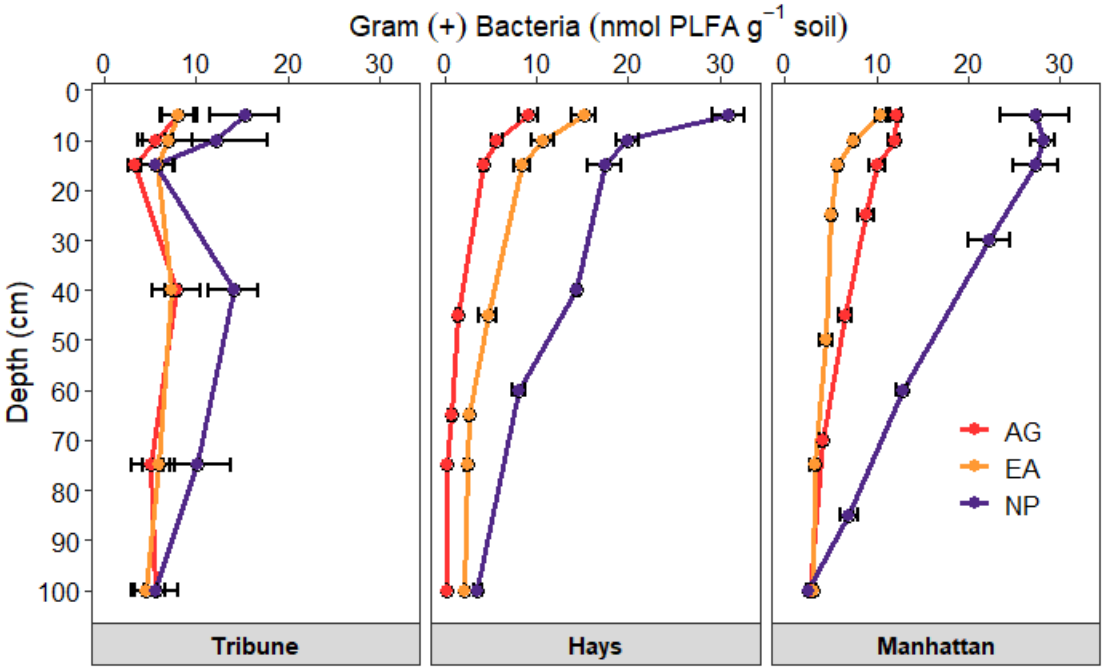

Figure 4.21. Gram positive bacteria by land use and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

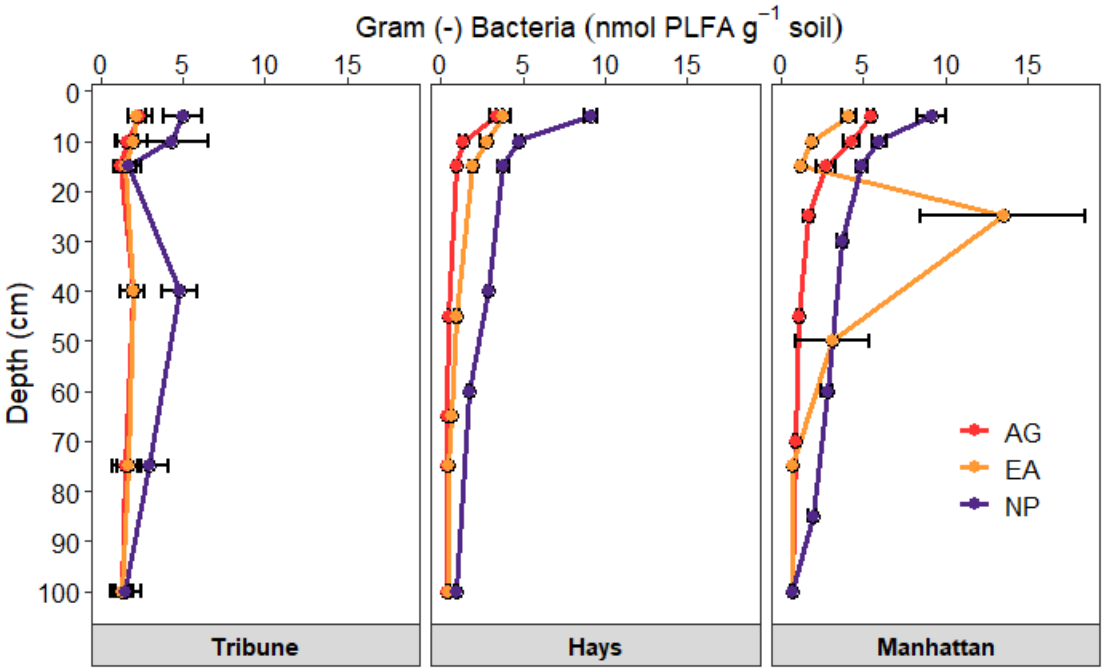

Figure 4.22. Gram-negative bacteria by land use and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

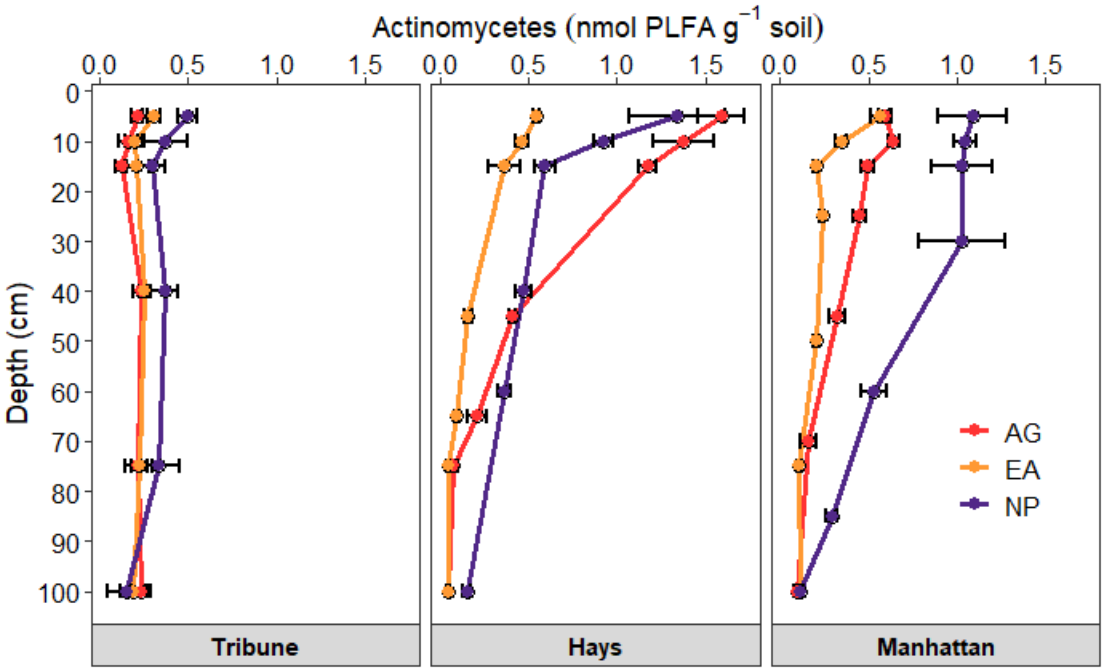

Figure 4.23. Actinomycetes by land use and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

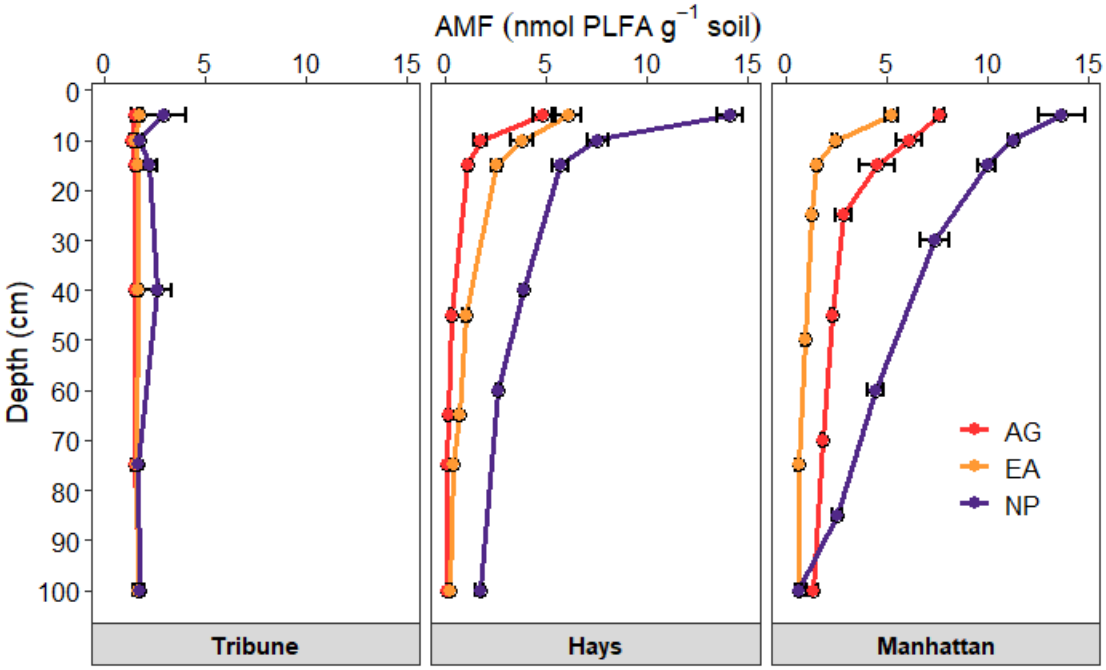

Figure 4.24. Arbuscular mycorrhizal fungi by land use and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

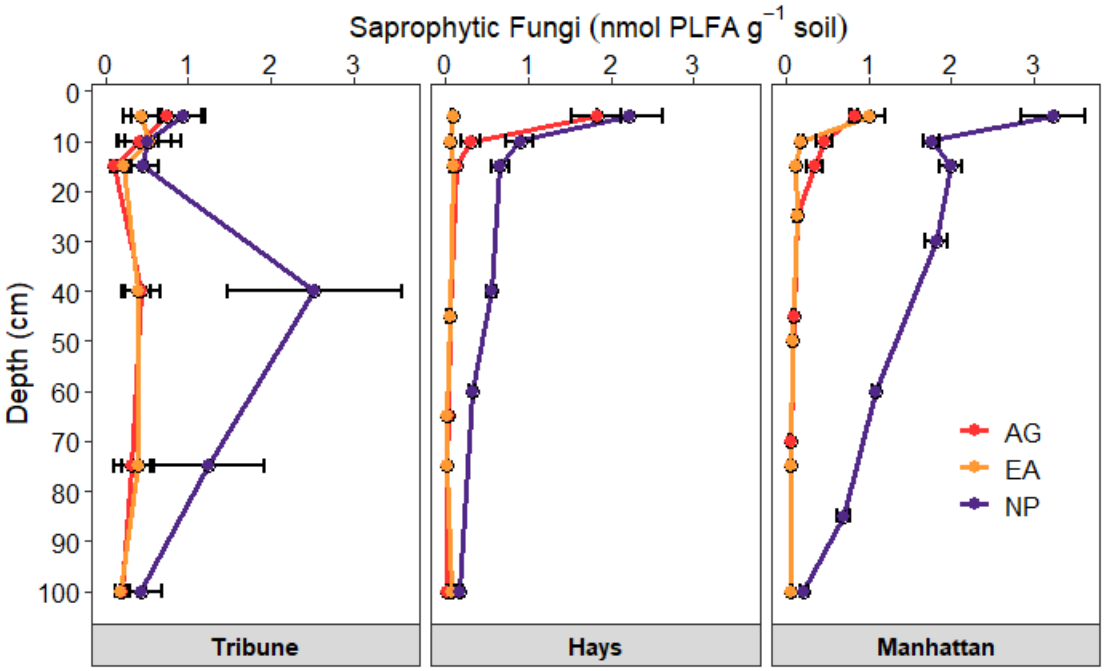

Figure 4.25. Saprophytic fungi by land use and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

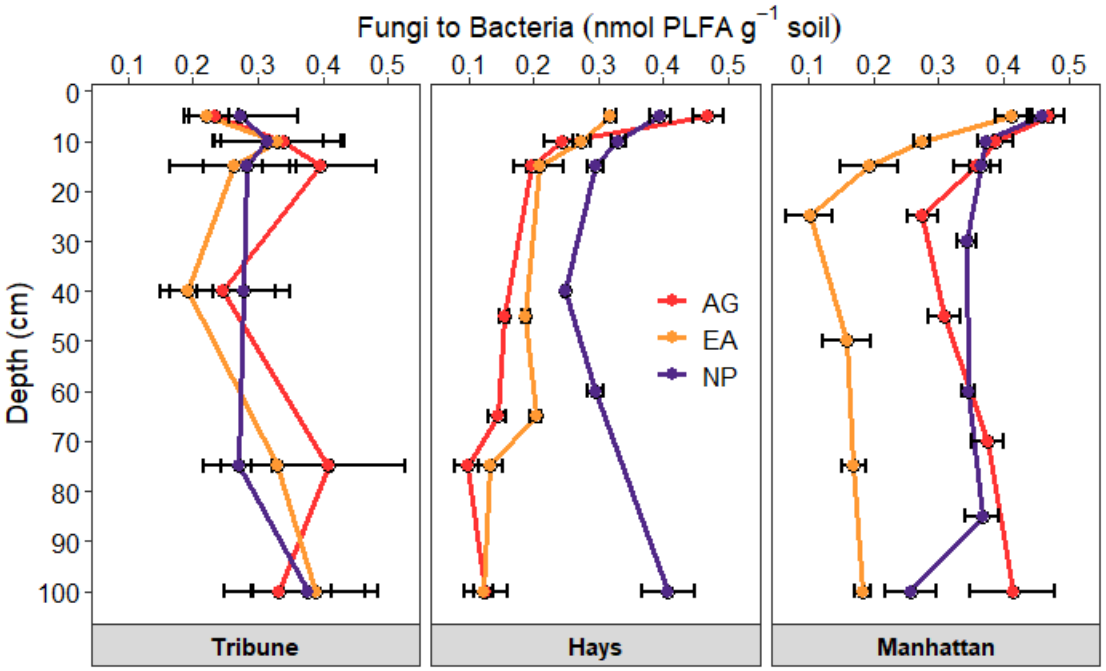

Figure 4.26. Differences in fungal to bacteria ratios by land use and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

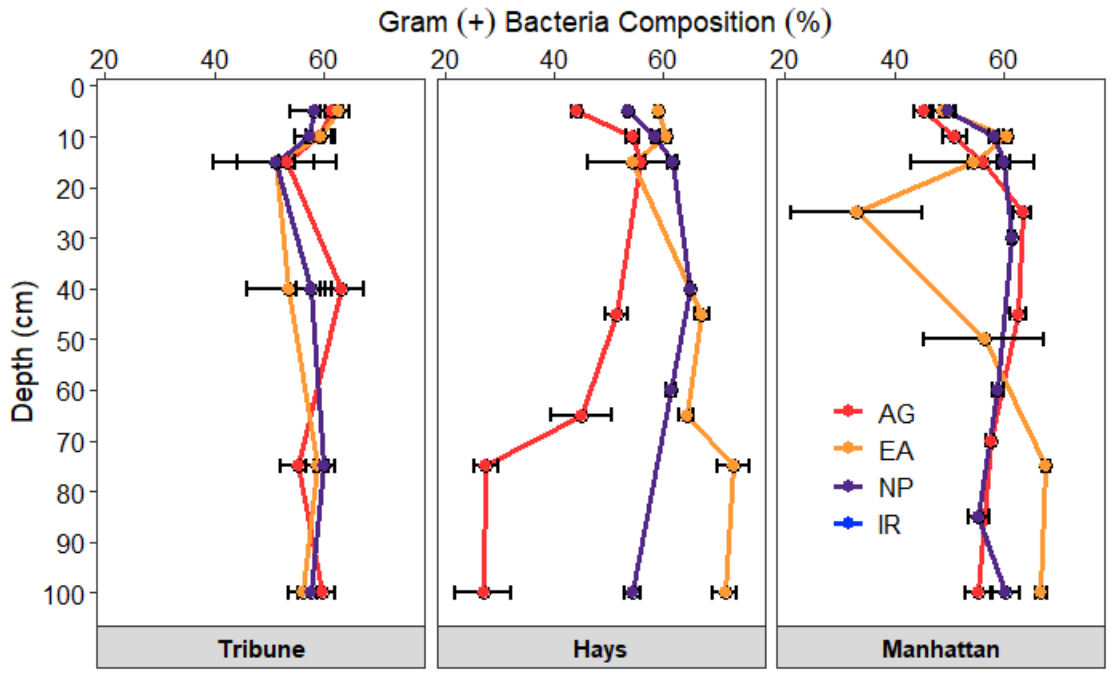

Figure 4.27. Gram positive bacteria percent composition by land use and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

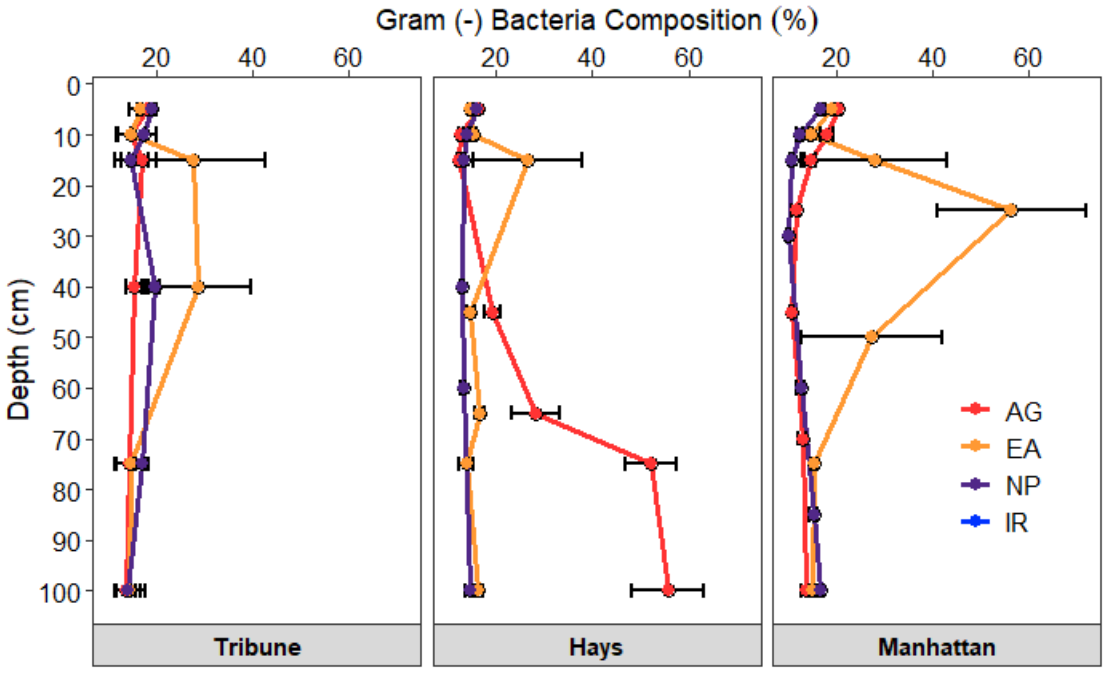

Figure 4.28. Gram-negative bacteria percent composition by land use and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

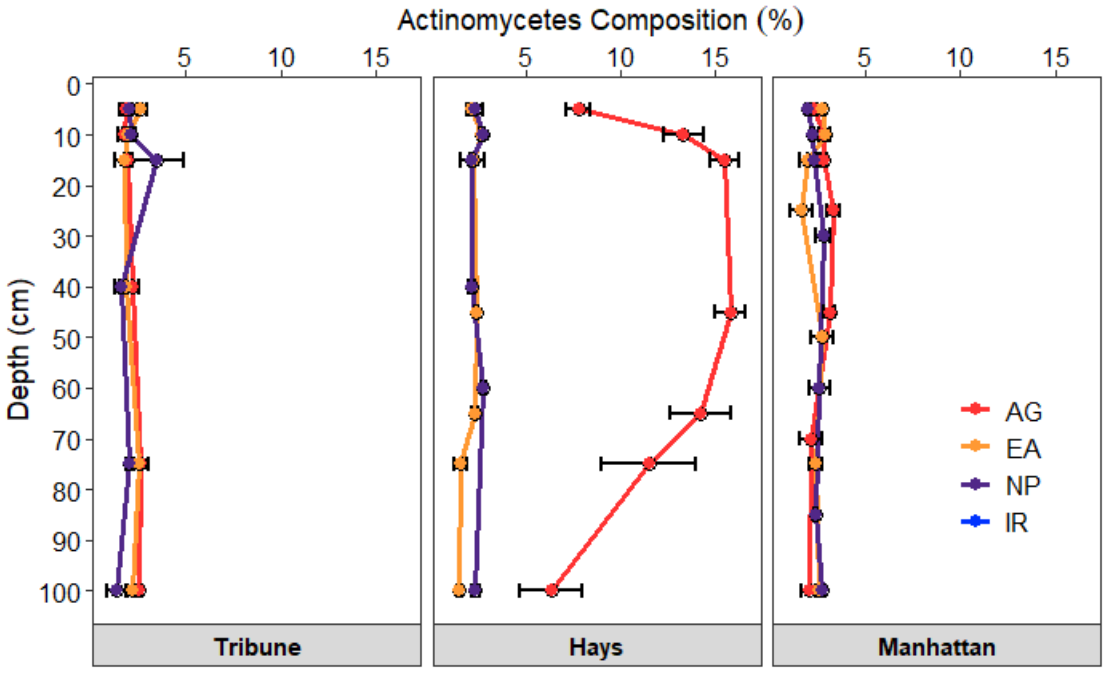

Figure 4.29. Actinomycetes percent composition by land use and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

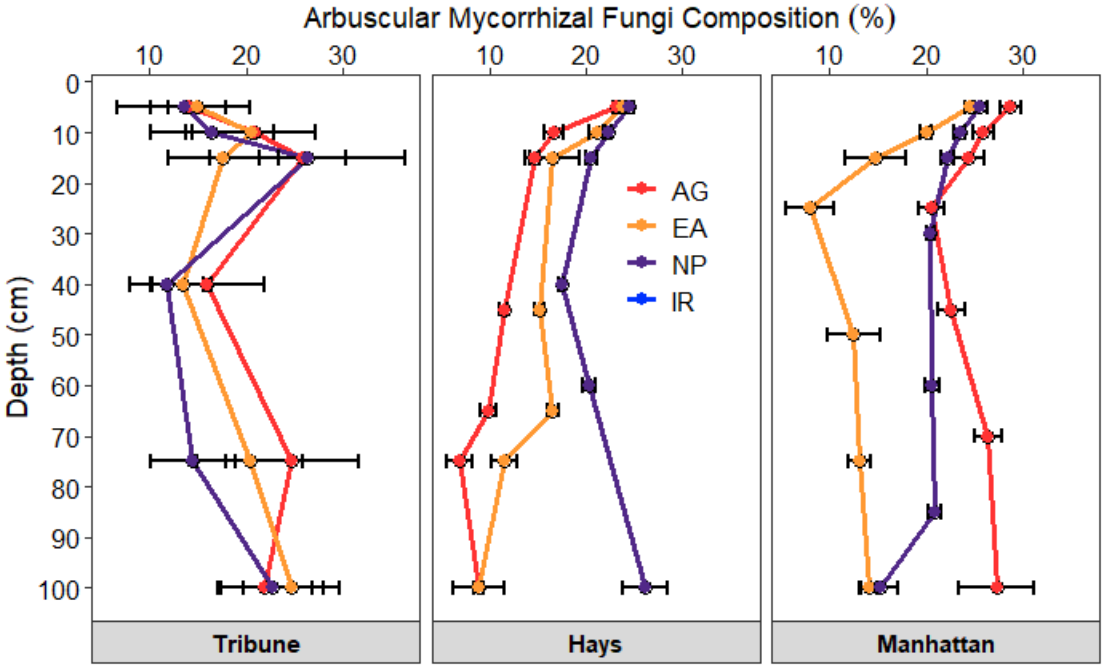

Figure 4.30. Arbuscular mycorrhizal fungi percent composition by land use and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

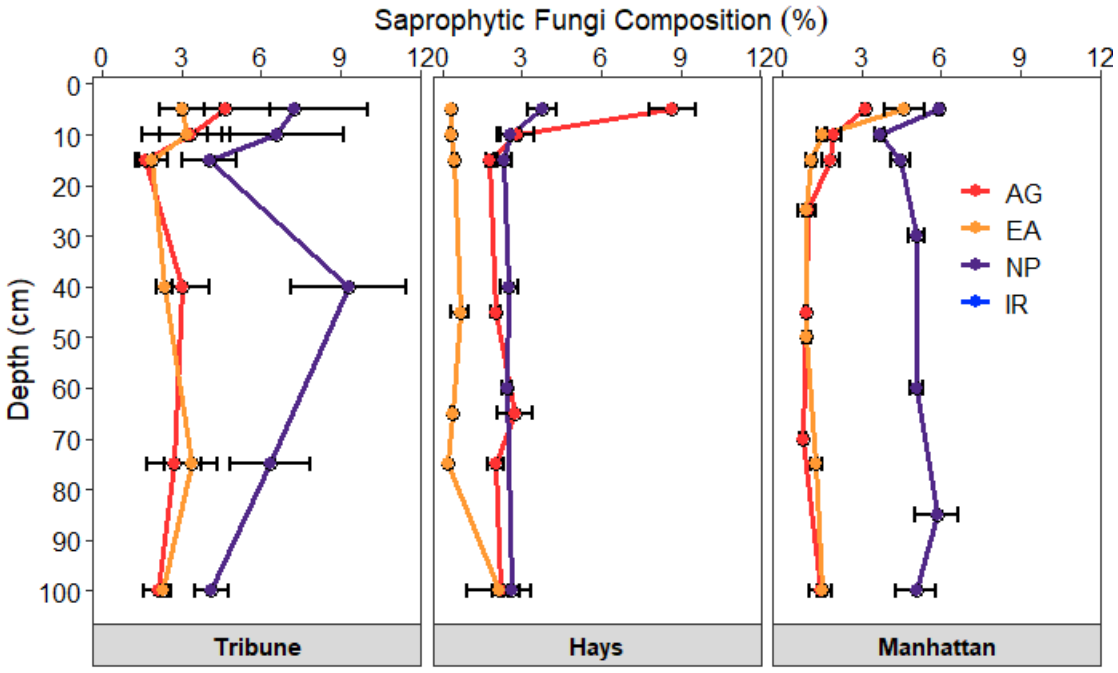

Figure 4.31. Saprophytic fungi percent composition by land use and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

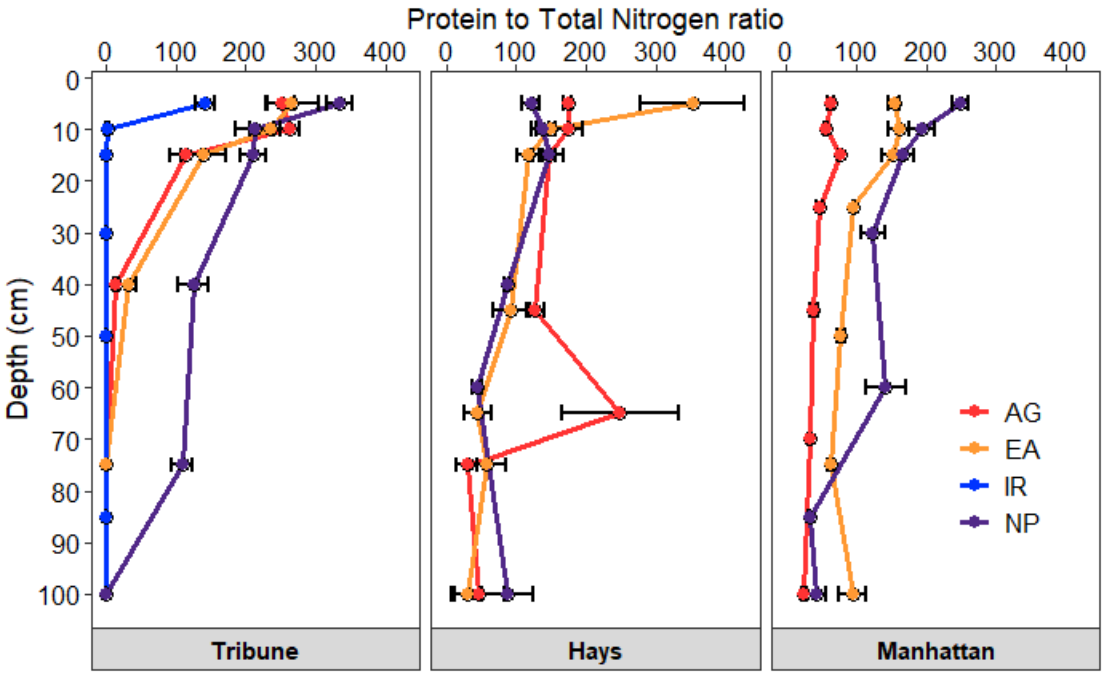

Figure 4.32. Autoclaved citrate extractable protein content to total nitrogen ratio by depth for different land uses and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

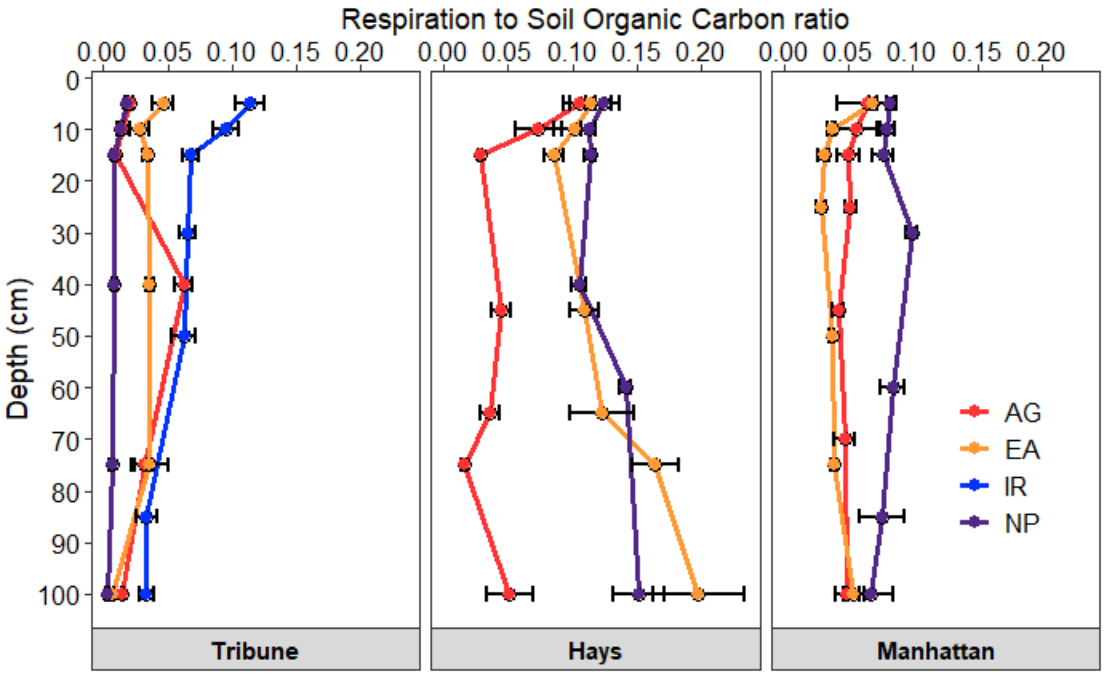

Figure 4.33. Soil respiration to soil organic carbon ratio by depth for different land uses and locations to 100 cm. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

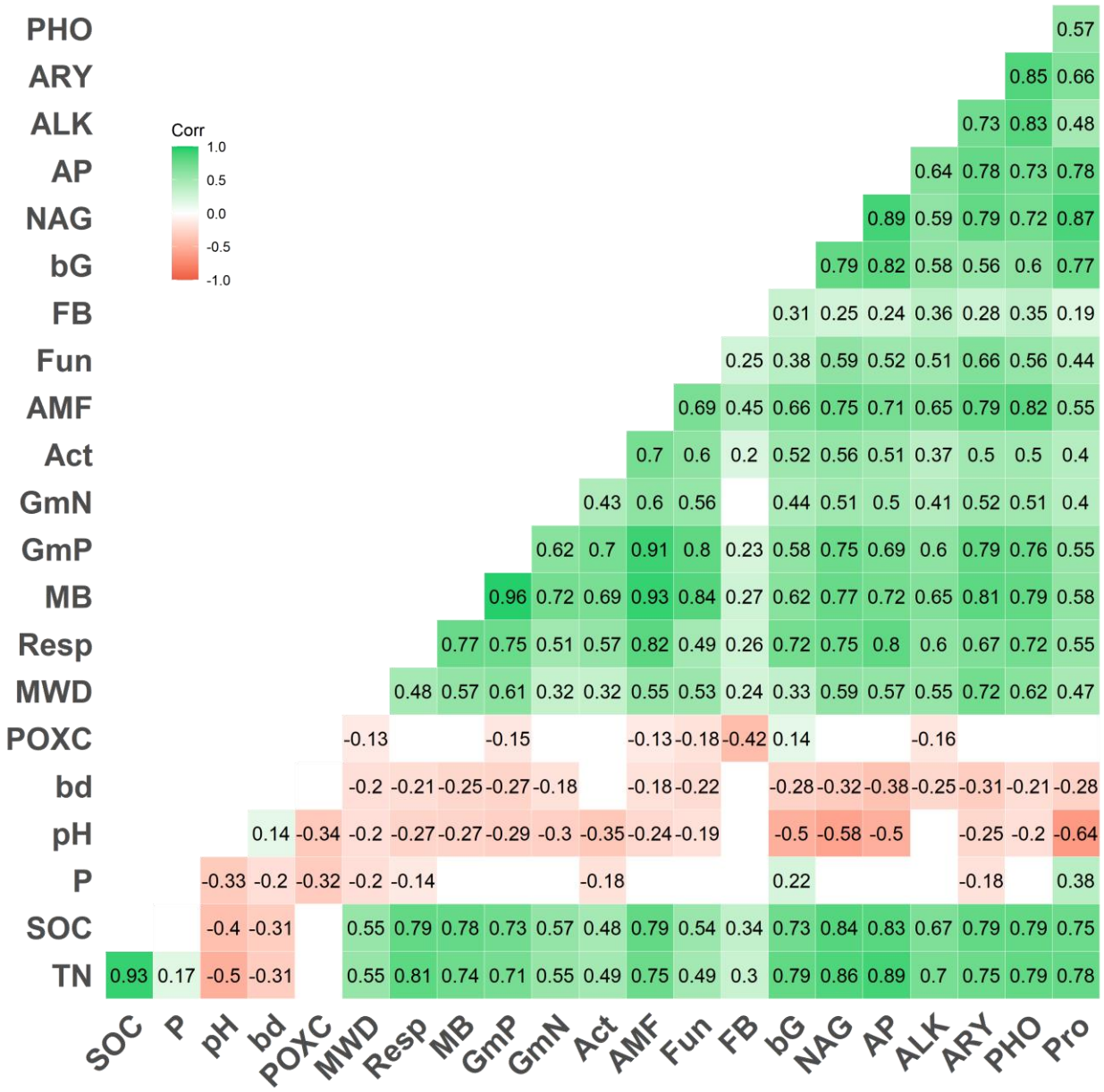

Figure 4.34. Correlation matrix of soil health properties using Spearman correlation coefficient given inside squares ($p<0.05$). MWD: mean weight diameter (mm); bd: bulk density (g cm^{-3}); SOC: soil organic carbon (%); TN: total nitrogen (%); P: phosphorus (mg kg^{-1}); pH; bG: β-glucosidase (mg $kg^{-1}hr^{-1}$); NAG: N-acetyl glucosaminidase (mg $kg^{-1}hr^{-1}$); AP: acid phosphatase (mg $kg^{-1}hr^{-1}$); ALK: alkaline phosphatase (mg $kg^{-1}hr^{-1}$); PHO: phosphodiesterase (mg $kg^{-1}hr^{-1}$); ARY: arylsulfatase (mg $kg^{-1}hr^{-1}$); Resp: soil respiration (mg CO2 g-1); POXC: permanganate-oxidizable carbon (mg kg^{-1}) ; Pro: protein content (g protein kg^{-1}); autoclavable MB: PLFA microbial biomass (nmol PLFA g^{-1}); GmP: Gram-positive bacteria (nmol PLFA g^{-1}); GmN: Gram-negative bacteria (nmol PLFA g^{-1}); Act: actinomycete (nmol PLFA g^{-1}); AMF: arbuscular mycorrhizal fungi (nmol PLFA g^{-1}); Fun: fungi (nmol PLFA g^{-1}); FB: fungi to bacteria ratio.

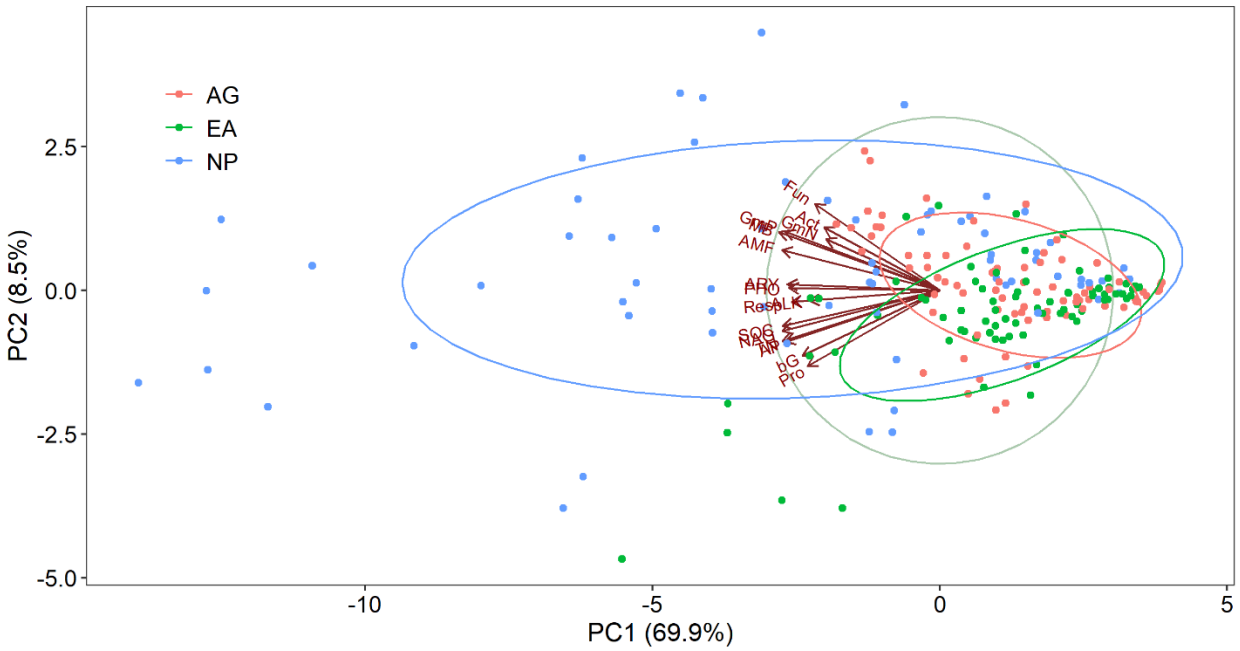

Figure 4.35. Principal component analysis biplot of soil organic carbon, total nitrogen, soil microbial community composition and enzyme activity grouped by land use.

Chapter 5 - Comparison of Single Ring and Cornell Sprinkler Infiltrometer Methods

Introduction

Numerous variations in direct infiltration methods have been developed with single- and double-ring methods as the most common, while rainfall simulator methods are more complex and require careful management (Lili et al., 2008; Barretta and Rodgers, 2015; Reynolds and Elrick, 1990). Both methods were conducted on small undisturbed areas. The objectives of the study were to (1) compare two infiltration methods (single ring and Cornell Sprinkler Infiltrometer) and (2) determine the infiltration rates of different land uses across a precipitation gradient. Infiltration rates among different land use, specifically conventional tillage (AG), no-till (EA), and native prairie (NP), were studied at different precipitation regimes across Kansas (Tribune, Hays, and Manhattan).

Materials and Methods

Manhattan, KS

Conventional agriculture was measured for infiltration on 20 September 2019 at the Konza Prairie Biological Station (KPBS). Conventional agriculture was cultivated since the 1960s with soybean (*Glycine max*), wheat (*Triticum aestivum*), and grain sorghum (*Sorghum bicolor*) (Kamlesh et al., 2010). The soil was a Reading silt loam (Fine-silty, mixed, superactive, mesic Pachic Argiudoll). The current crop had soybean in the field during AG infiltration measurements. Infiltration was taken between soybean rows. Native prairie was measured on 15 October 2019 at KPBS. Native prairie area was dominated by perennial C4 grasses (big bluestem

(*Andropogon gerardi*), Indiangrass (*Sorghastrum nutans*), and switchgrass (*Panicum virgatum*)) and C3 herbaceous forb species (Heisler-White et al., 2009; Freeman, 1998). The soil was a Reading silt loam (Fine-silty, mixed, superactive, mesic Pachic Argiudoll). Enhanced agriculture was measured on 21 October 2021 after corn harvest in a no-till corn-soybean rotation. The soil was a Tully silt clay loam (Fine, mixed, superactive, mesic Pachic Argiustolls).

Hays, KS

Enhanced agriculture was measured on 20 September 2019 near Hays Agricultural Research Center. Enhanced agriculture was characterized as a wheat-sorghum-fallow rotation with no-till and cover crop mix. Infiltration for NP and AG were taken on 15 October 2021 at Hays Agricultural Research Center. Conventional tillage had sorghum residue on the field in a wheat-sorghum-fallow rotation. Native prairie consisted of mixed-grass prairie including buffalo grass (*Buchloe dactyloides*), western wheatgrass (*Agropyron smithii*), blue grama (*Bouteloua gracilis*); side- oats grama (*Bouteloua curtipendula*), little bluestem (*Andropogon scoparius*), and big bluestem (*Andropogon gerardi*) (Jones, 1960). The soil at all three land uses was Harney silt loam (Fine, smectitic, mesic Typic Argiustolls).

Tribune, KS

Native prairie, AG, and EA were measured at the Southwest Research Center- Tribune Unit on 19-20 August 2019. Native prairie vegetation consisted of C3 and C4 grasses with the dominant species being buffalo grass (*Buchloe dactyloides*). Conventional agriculture and EA were measured after wheat harvest that was in a wheat-grain sorghum-fallow rotation with tillage and no-till for AG and EA, respectively. The soil was a Richfield silt loam (fine-smectitc, mesic Aridic Argiustolls). The experiment was started in 1989 with treatments imposed in native prairie (Blanco-Canqui et al., 2011).

Field assessment

Average infiltration rates were calculated based on four replications for each land use at each location. The lower the initial soil moisture content, the higher the initial soil infiltration rate (Lili et al., 2008). Thus, soils were prewetted to saturation before infiltration assessment to ensure similar environmental conditions and comparability (Barretta and Rodgers, 2015). Single ring infiltration (Soil Survey Staff, 2014) and Cornell Sprinkle Infiltrometer (Cornell University, 2019) were used as a physical indicator for soil health (Moebius et al., 2007) (Fig. 5.1). For NP, the above-ground biomass was trimmed for infiltration measurement.

Single ring infiltration

Single ring infiltration was determined by inserting a 15.24 cm diameter ring to a 7.62 cm depth (Soil Survey Staff, 2014). The soil at the ring boundary was firmed if loosened during the ring insertion. A plastic wrap covered the soil surface inside the metal ring to hold 444 mL of distilled water (equivalent to 1 inch of water depth). Once the water was added, the plastic wrap was removed, and the time recorded for the water to infiltrate. Repeated infiltration tests were done with the same soil and ring if the soil was not at or near field capacity. Single-ring infiltration tests were stopped after 1 hour and recorded as >2.54 cm h^{-1}.

Cornell Sprinkle Infiltrometer

The Cornell Sprinkle Infiltrometer was based on the manual (Cornell University, 2019). In general, the infiltrometer consists of a portable rainfall simulator that is placed on a single 24.1 cm inner diameter infiltration ring inserted 7.5 cm into the soil. The apparatus measures soil hydrological properties, time to runoff, sorptivity, and field saturated infiltrability. The sprinklers consist of capillary tubes at the bottom of the unit to apply water at a wide range of simulated rainfall rates, specifically 20 to 30 cm/hr. Four Cornell Sprinkle Infiltration measurement was

taken per land use at each location. Cornell sprinkler infiltrometer was stopped after reaching constant runoff rates (within 10 ml), which was after about 8-10 runoff measurements.

Data Analysis

Custom-written scripts in R version 4.0.3 (R core Team 2020) were used for graphing soil health parameters by depth, land use, and location. Linear mixed-effect models were used with the fixed effects of land use and different locations of Kansas with its interactions, while random effects included randomized, repeated measures. The differences in measured variables among land use and location were tested using type 3 two-way analysis of variance (ANOVA) with Satterthwaite's method. All error bars are reported as standard errors. Differences were determined at $p<0.05$ significance level using least-squares means separation (LSMEANS) Tukey's Honest Significant Difference (HSD) adjustment for multiple comparisons.

Results

Methods comparison

Infiltration measurements were variable by methods and did not show consistent infiltration rates between the single ring or the simulated rainfall system (Table 5.1). Cornell Sprinkle Infiltrometer generally had higher average infiltration rates than the single ring measurements except in NP at Tribune (Table 5.2 and 5.3). The single ring infiltration method was more sensitive to land management practices, specifically soil disturbance.

Land use and location comparison

There was a significant interaction ($p<0.001$) between land use and location for both infiltration methods (Table 5.1). In general, infiltration rates increased with decreased soil disturbance (Table 5.2, Fig. 5.2 and 5.3). For the single ring, native prairie had significantly higher infiltration rates at all locations than cropping systems. There were no significant

differences in single ring infiltration rates between cropping systems at Tribune and Hays. Single ring infiltration of EA at Manhattan, was not significantly different from AG or NP.

The Cornell method did not have the same trends as the single ring infiltration except at Tribune (Table 5.3, Fig. 5.2 and 5.4). In general, Cornell Sprinkler infiltration was significantly higher in EA followed by NP and then AG in Manhattan, KS. Conventional agriculture had the highest infiltration in Hays followed by NP and then EA.

Discussion

Methods comparison

There are numerous reasons the single ring and Cornell Sprinkler infiltrometer could have varying results. Soil types and conditions vary within the field (Barretta and Rodgers, 2015; Vereechen et al., 2019). Variations in soil surface conditions from vegetation type, land management, and rainfall characteristics affect hydraulic properties, runoff, and ponding (Vereechen et al., 2019; Barretta and Rodgers, 2015; Reynolds and Elrick, 1990). In this study, each method was performed next to each other on undisturbed soils to ensure similar soil conditions.

Cornell Sprinkler Infiltrometer variability in instrumentation was operationally more complex with multiple coiled capillary drip tubes to simulate gradual soil wetting by rainfall (Ogden et al., 1997; Cornell University, 2019). The method allows for different rainfall intensities while avoiding air entrapment and rapid slaking in soil (Ogden et al., 1997). However, the water flow rate through the capillaries increases with increased temperature during tests under direct sunlight (Ogden et al., 1997). In addition, the capillary tubes are fragile and prone to damage if not careful, so between-tube variations could also cause nonuniform drip rates (Ogden

et al., 1997; Cornell University, 2019). Thus, the Cornell Sprinkler Infiltrometer may have varying rainfall rates or have individually varying capillary drip rates over long use.

Land use and location comparison

Native prairie had the highest infiltration rates based on the single ring method. This was likely due to NP having greater macropores, aggregation, and root channels, while cropping systems had higher levels of surface crusting, compaction, and blocked surface pores (Morin and Benyamini, 1977). Cropping systems that have bare soils have higher surface crust formation due to raindrop impact, which reduces infiltration (Lili et al., 2008). There was no significant difference in infiltration rates between AG and EA in the Tribune and Hays. Manhattan EA was not significantly different than NP and AG with the single ring. Residue retention in EA reduces surface crusting and aggregate destruction allowing for higher infiltration rates. These soils also have good aggregate stability which facilitates infiltration, water drainage and, thus, reduces runoff, erosion, and crusting.

The Cornell Sprinkler Infiltrometer gave similar infiltration results for the Tribune site, but not for Hays and Manhattan. Conventional tillage was expected to have lower infiltration rates than EA. However, only the AG at the Manhattan site had significantly lower infiltration rates than EA (Fig. 5.2). Conversely, EA was higher than NP in Manhattan. This variability in infiltration at Manhattan was mostly due to the slightly different soil types with differences in soil texture and aggregate stability. The infiltration rate was less in NP and AG most likely due to higher clay content compared to EA at Manhattan. Hays AG had higher infiltration than NP, which is not expected or in conjunction with the results of single ring infiltration.

Conclusion

The single ring method was more sensitive to land disturbance as infiltration rate increased with decreased soil disturbance. The Cornell Sprinkler Infiltrometer method did not follow the same trends and even had greater infiltration rates than the single ring method. The variability in results and method approaches makes both infiltration assessments difficult to discern which is a better measurement. In terms of ease of use and implementation, the single ring method was more portable and required less material, training, maintenance, and water. The Cornell Sprinkler Infiltrometer can simulate a range of rainfall rates, designed to measure runoff and infiltration, and reduces unnatural macropore flow from ponding (Cornell University, 2019).

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Tables

Table 5.1. Summary of the p-values from ANOVA for effects of land use and precipitation on single ring infiltration and Cornell Sprinkler infiltrometer.

*, **, *** Significant at 0.05, 0.01, and 0.001 probability levels, respectively.

	Single Ring	Cornell
Land Use	**<0.001 *** **	**0.023 * **
Location	**<0.001 *** **	0.133
Land Use* Location	**<0.001 *** **	**<0.001 *** **

Table 5.2. Summary of the measured singe ring infiltration rates by land use and location. Averages with 2.54 cm h^{-1} were stopped due to time constraints.

Single Ring Infiltration					
Location	Treatment	Reps	Average (cm h^{-1})	Standard Deviation	Standard Error
Tribune	AG	4	4.36	1.84	0.92
	EA	4	6.40	6.29	3.15
	NP	3	28.11	5.72	3.31
Hays	AG	4	2.67	0.25	0.13
	EA	4	2.54	0.00	0.00
	NP	4	8.51	4.61	2.30
Manhattan	AG	4	1.84	1.40	0.70
	EA	4	6.03	3.50	1.75
	NP	4	8.89	1.60	0.80

Table 5.3. Summary of the measured Cornell Sprinkle Infiltrometer infiltration rates by land use and location.

Cornell Sprinkle Infiltrometer					
Location	Treatment	Reps	Average (cm h^{-1})	Standard Deviation	Standard Error
Tribune	AG	4	18.5	1.82	0.91
	EA	3	18.0	0.52	0.30
	NP	4	22.2	0.30	0.15
Hays	AG	4	21.7	3.88	1.94
	EA	4	14.0	0.87	0.44
	NP	3	20.5	0.43	0.25
Manhattan	AG	4	13.0	1.22	0.61
	EA	4	22.5	0.61	0.31
	NP	4	17.8	3.56	1.78

Figures

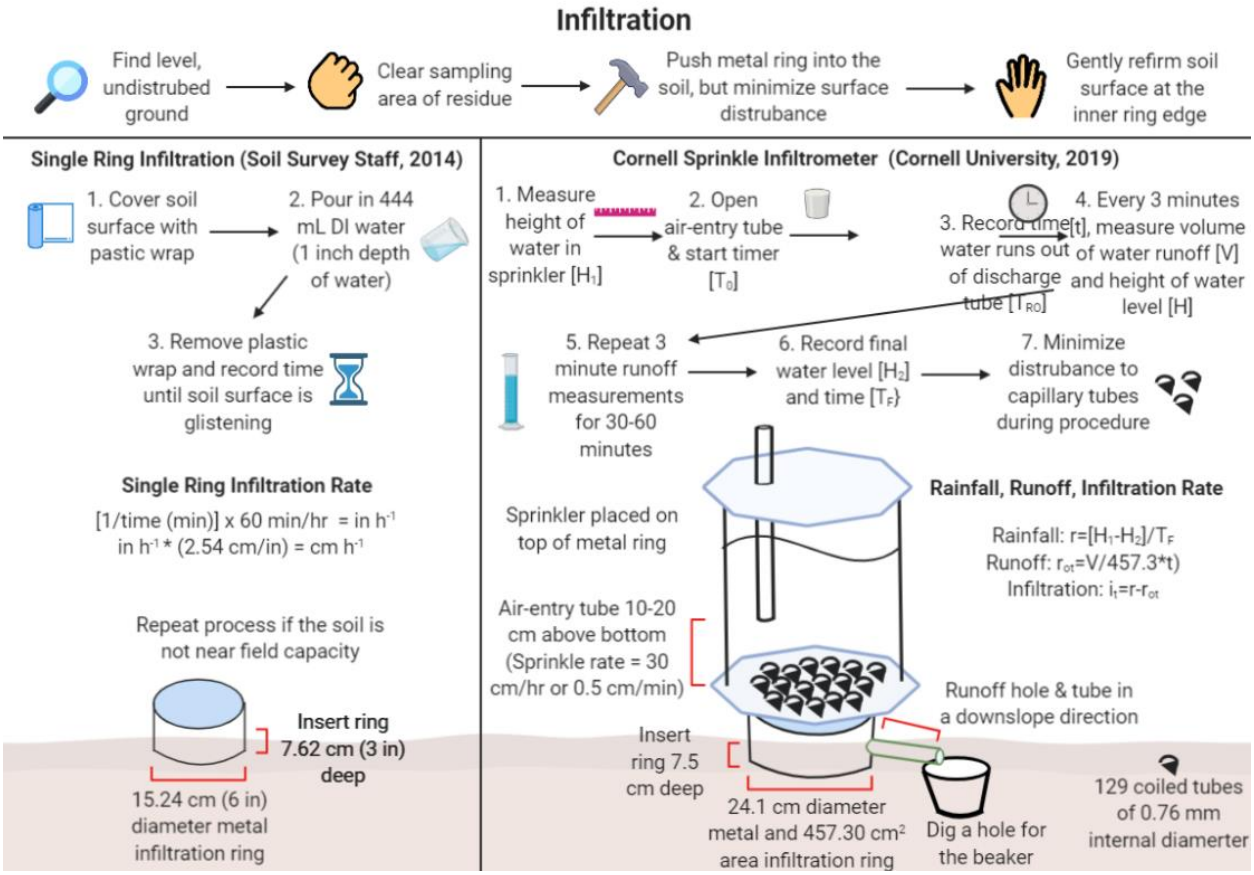

Figure 5.1. In-field infiltration methods for single-ring and Cornell Sprinkle Infiltrometer.

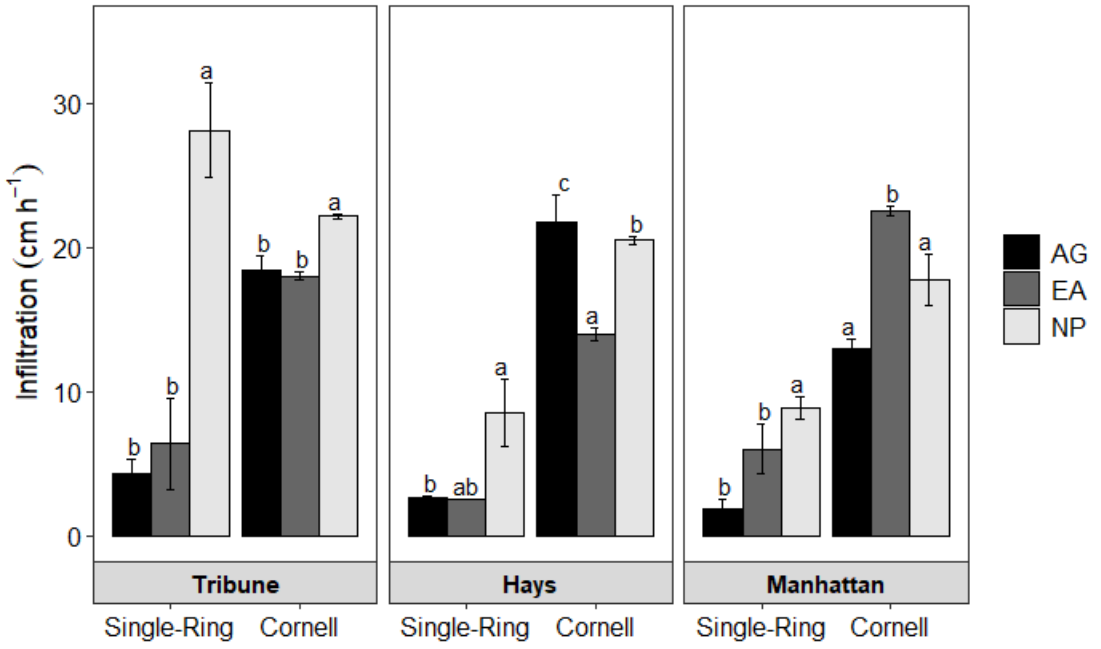

Figure 5.2. Single Ring and Cornell Sprinkle Infiltrometer infiltration rates by land use and location. Land use is labeled as conventional tillage (AG), no-till (EA), and native prairie (NP). The means of each infiltration are represented by letters to show the significance for each land-use comparison within methods and within locations.

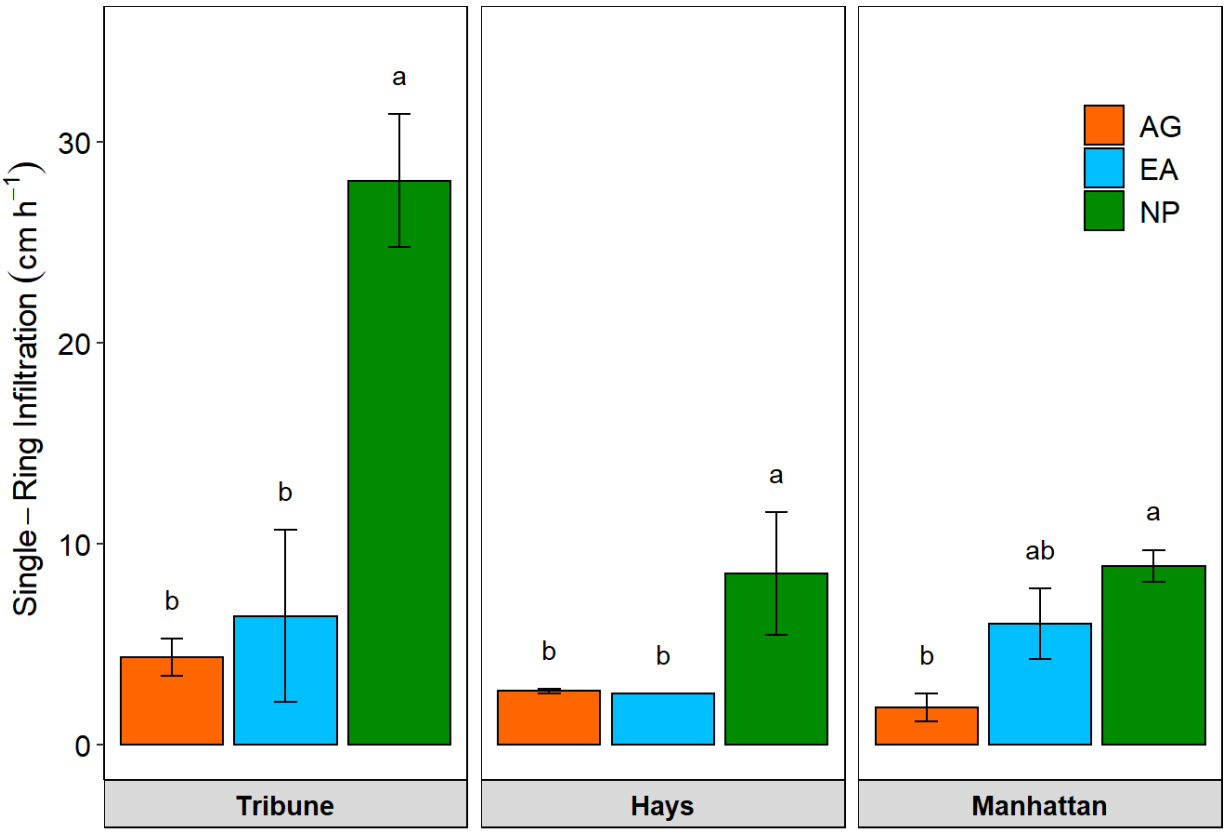

Figure 5.3. Single-ring infiltration by land use and location interaction based on two-way ANOVA with letters representing significant differences ($p<0.05$). Land use is labeled as conventional tillage (AG), no-till (EA), and native prairie (NP).

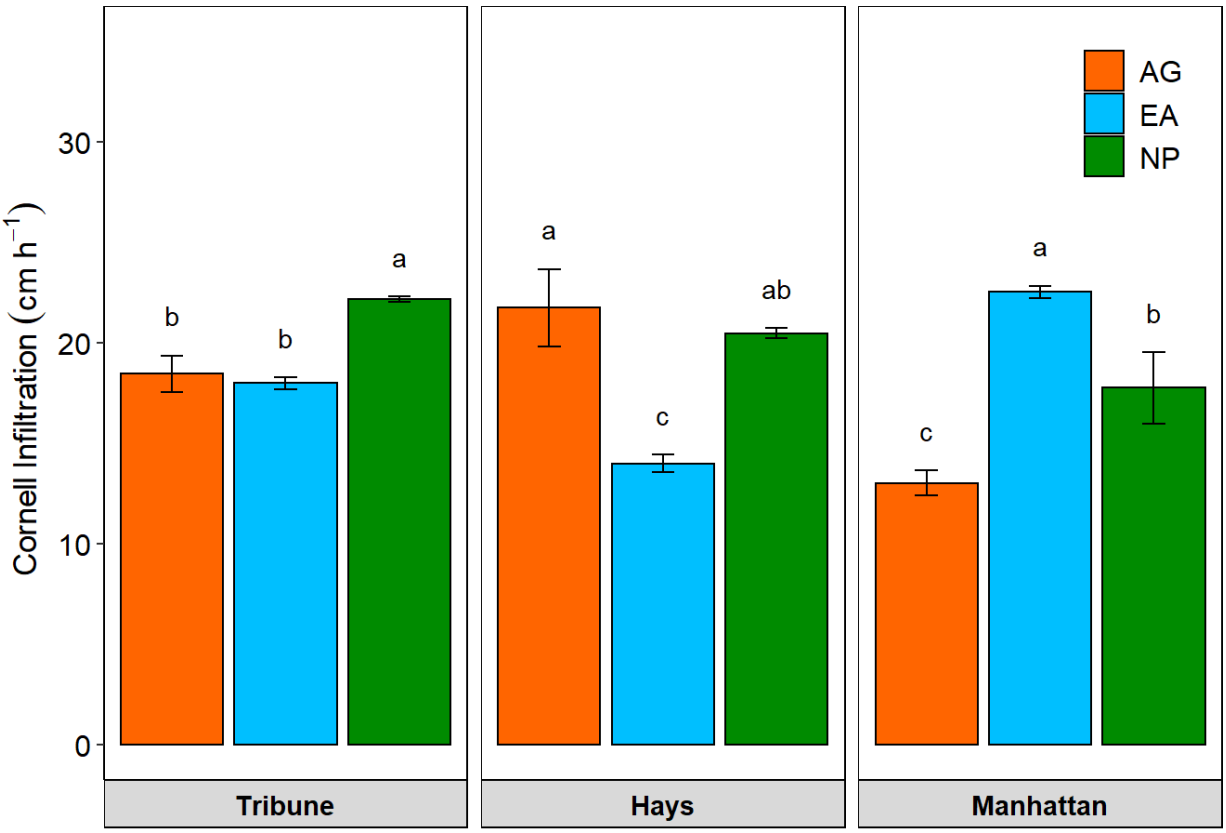

Figure 5.4. Cornell Sprinkler infiltrometer by land use and location interaction based on two-way ANOVA with letters representing significant differences ($p<0.05$). Land use is labeled as conventional tillage (AG), no-till (EA), and native prairie (NP).

Chapter 6 - Conclusion and Recommendations

Conclusion

Soil health indicators can differentiate among different agronomic systems and land uses in a precipitation gradient under different soil types with a 1 m soil depth. The set of soil health metrics are comprehensive in soil biological, chemical, and physical properties for robust and quantitative interpretation of soil health. The comparison of different soil metric method that measures the same soil property (wet aggregate stability and infiltration) vary in the level of sensitivity and detail of interest. Several soil health metrics can be improved and require modification for greater widespread adoption. Methods for possible improvement in implementation and interpretation include permanganate-oxidizable carbon, Cornell Sprinkle Infiltrometer, and wet aggregate stability by the NRCS method.

Recommended soil health metrics

Useful soil health indicators must be easy to measure, reproducible, scientifically robust, time conscious, low cost, assess changes in soil function, and be sensitive to variations in climate and land management. If possible, soil assessments should consider integration with existing soil databases for greater collaboration. Measurements should be compared using temporal change or standard reference soil. Targeted management practices and specific problems may alter the selection of recommended soil assessments. Thus, soil health practitioners should identify soil assessment constraints with expected solutions for a more thorough, holistic, adaptable, and data-driven approach. Below are recommended soil health metrics selected for monitoring soil health through time or comparison.

1. pH
2. Soil organic carbon

3. Total nitrogen
4. Water stable aggregates
5. Phospholipid fatty acid
6. Multi-enzyme assay (β-glucosidase, N-acetyl-β-glucosaminidase, phosphodiesterase)
7. Soil respiration
8. Autoclavable extractable protein content

Future research

After evaluating and assessing the set of soil health metrics by the NRCS, more samples can be analyzed from different soil types and land uses. Additional indicators can be added to the set of soil health metrics like soil biota, sequencing, plant biomass, and plant yield. The indicators can be combined through multivariate statistical methods to generate a single SH score that can be additive, weighted, or multiplicative. The single SH score could be used to compare the overall SH among different sites. However, the reduced level of detail and limit interpretability would not replace the need for reviewing soil tests. Overall, SH metrics are complex and contain collinearity with a greater number of indicators that can be simplified by developing a single score to characterize SH at each location.

Appendix A - Chapter 2- Aggregate Method

Tables

Table A. 1. Multi-enzyme substrate cost per sample.

	Cost ($)/ 1 g substrate	Weight needed (g)	Cost for 100 mL	Number of samples doable	Cost ($) /sample
β-Glucosidases	120	1.506	180.72	66	2.74
β-glucosaminidase	215	0.342	73.53	66	1.11
Arylsulfatase	73.3	1.228	90.0124	66	1.36
Phosphodiesterase	386	1.82	702.52	66	10.64
Acid Phosphate	82.6	1.86	153.636	66	2.33
Alkaline Phosphate	82.6	1.86	153.636	66	2.33

Table A. 2. The sample size for wet-sieving aggregate stability methods, by location, and by treatment within a location.

Sample Size													
Methods	20 vs 5 minutes												
Location		Tribune				Hays				Manhattan			
Treatment			AG	EA	NP		AG	EA	NP		AG	EA	NP
n	141	48	16	16	16	48	16	16	16	45	13	16	16
Methods	20 minutes vs NRCS												
Location		Tribune				Hays				Manhattan			
Treatment			AG	EA	NP		AG	EA	NP		AG	EA	NP
n	230	72	24	24	24	80	28	28	24	78	23	28	27
Methods	NRCS vs 5 minutes												
Location		Tribune				Hays				Manhattan			
Treatment			AG	EA	NP		AG	EA	NP		AG	EA	NP
n	141	48	16	16	16	48	16	16	16	45	13	16	16

Figures

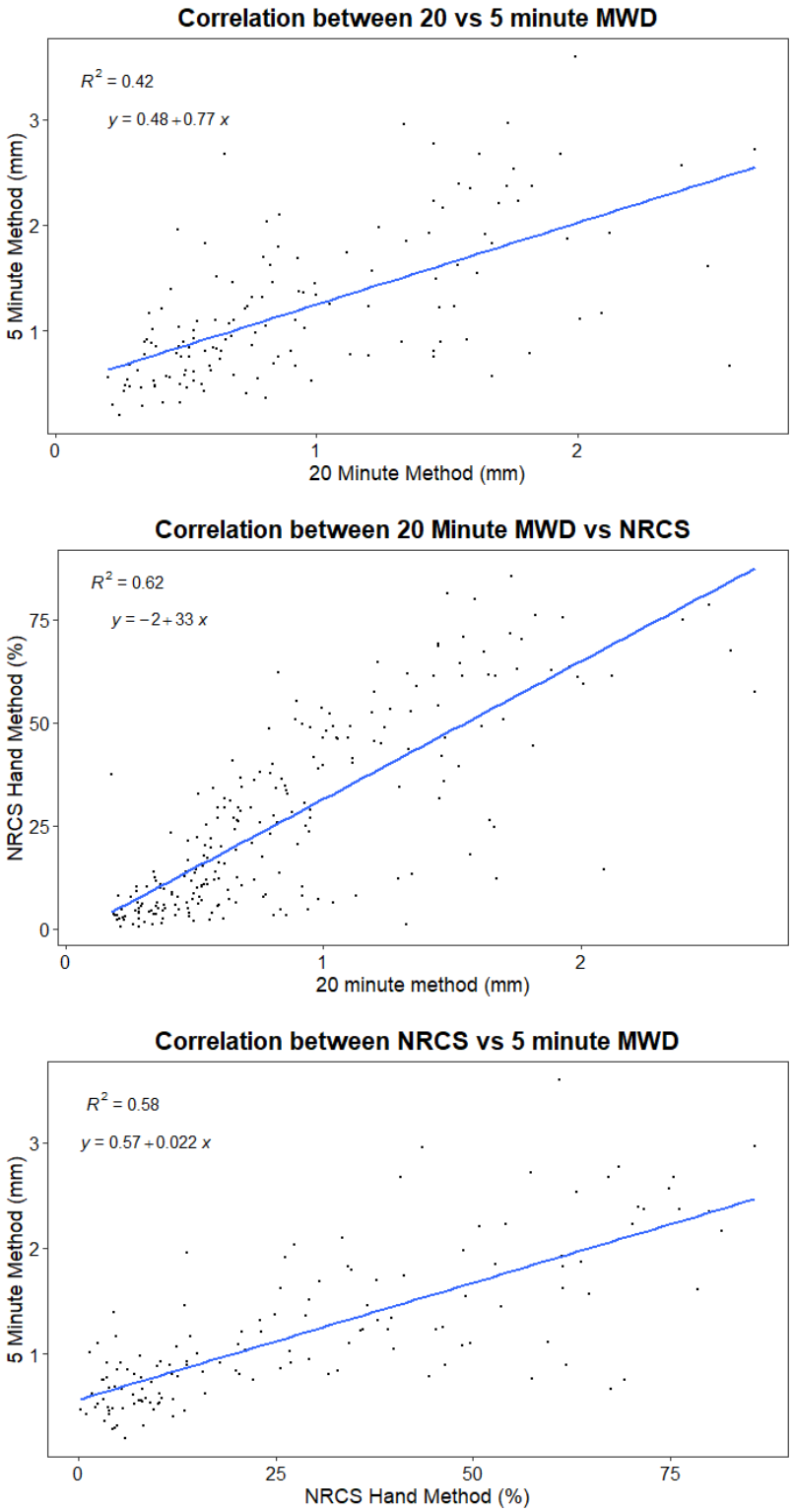

Table A. 3. Scatterplot for wet-sieving aggregate stability methods.

Supplemental Notes

Enzyme notes: determination of substrate needed for 0.05 M
Acid and Alkaline phosphatase substrate (disodium p-nitrophenyl phosphate tetrahydrate (Sigma 1040, Sigma Chemical Co., St. Louis, MO)) was discontinued. P-nitrophenyl phosphate disodium hexahydrate (Sigma 4645, Sigma Chemical Co., St. Louis, MO) was purchased in replacement. To recalculate the needed substrate amount to produce 0.05 M of 100 mL substrate, the equation below was used:

$$\frac{Mass\ (g)}{volume\ (L)} = Molarity\ \left(\frac{mol}{L}\right) * Molar\ Mass\ \left(\frac{g}{mol}\right)$$

$$\frac{Mass\ (g)}{0.1\ L} = 0.05\ \left(\frac{mol}{L}\right) * 371.14\ \left(\frac{g}{mol}\right)$$

$$Mass = 1.86\ g$$

Appendix B - Chapter 3-Topsoil

Figures

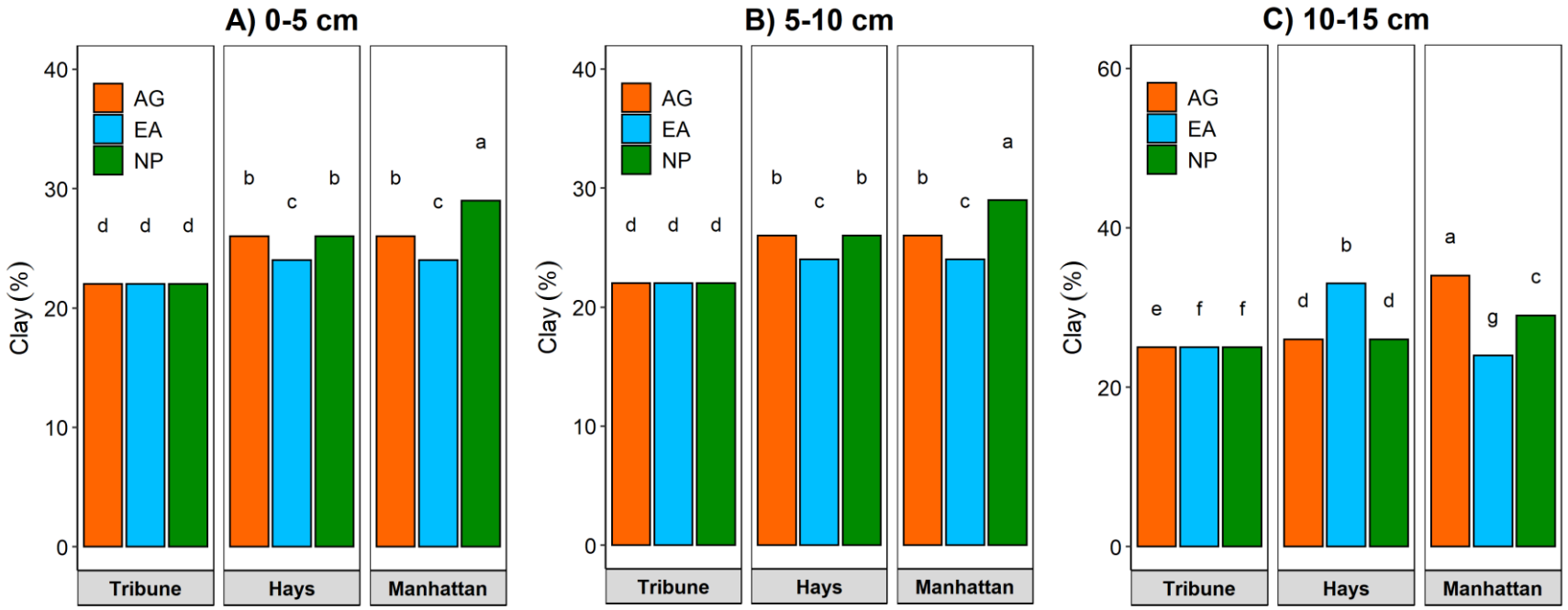

Figure B. 1. Percent clay by land use and precipitation interaction at 0-5 (A), 5-10 (B), and 10-15 (C) cm soil depths based on two-way ANOVA with letters representing significant differences ($p<0.05$).

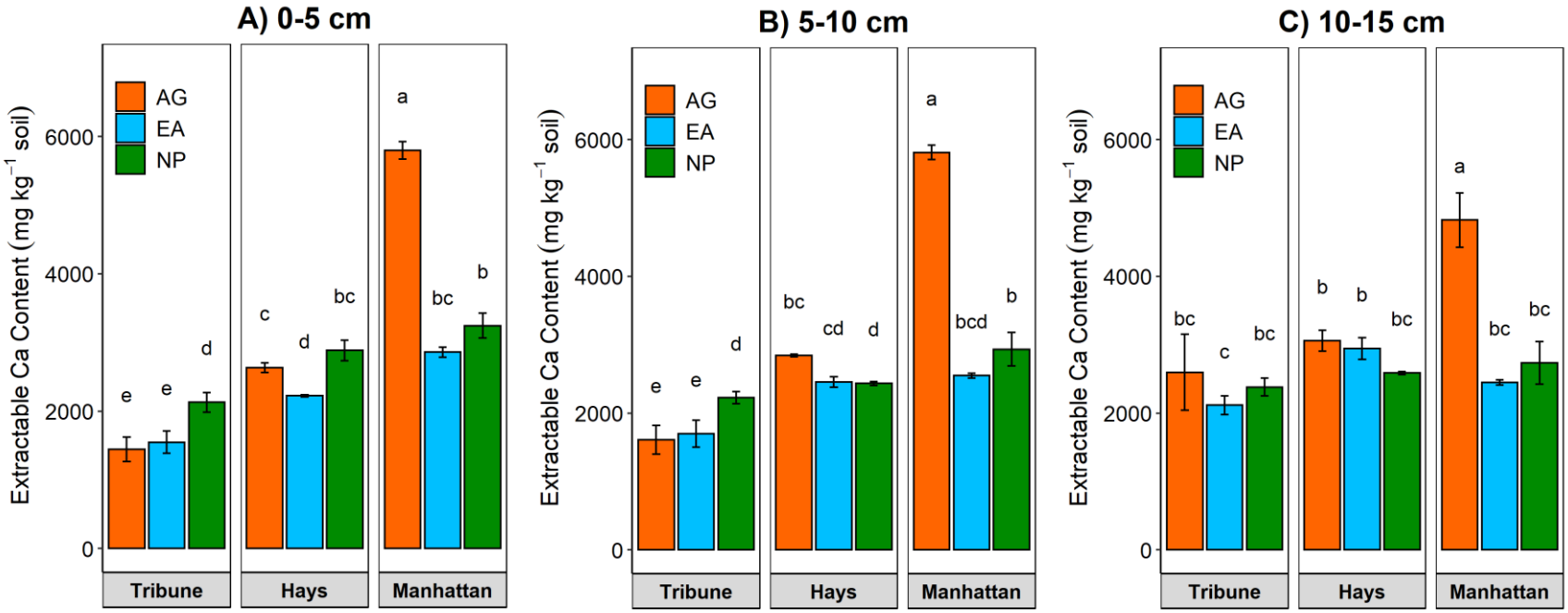

Figure B. 2. Extractable calcium content by land use and precipitation interaction at 0-5 (A), 5-10 (B), and 10-15 (C) cm soil depths based on two-way ANOVA with letters representing significant differences ($p<0.05$).

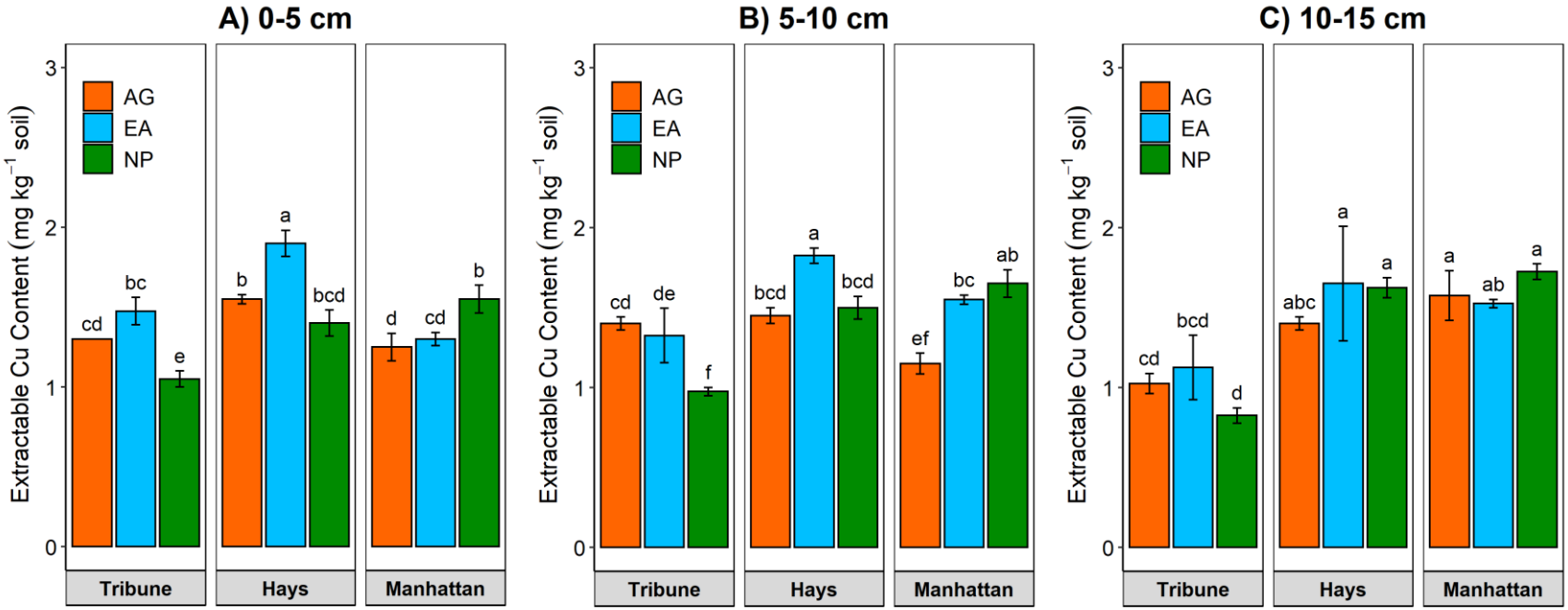

Figure B. 3. Extractable copper content by land use and precipitation interaction at 0-5 (A), 5-10 (B), and 10-15 (C) cm soil depths based on two-way ANOVA with letters representing significant differences ($p<0.05$).

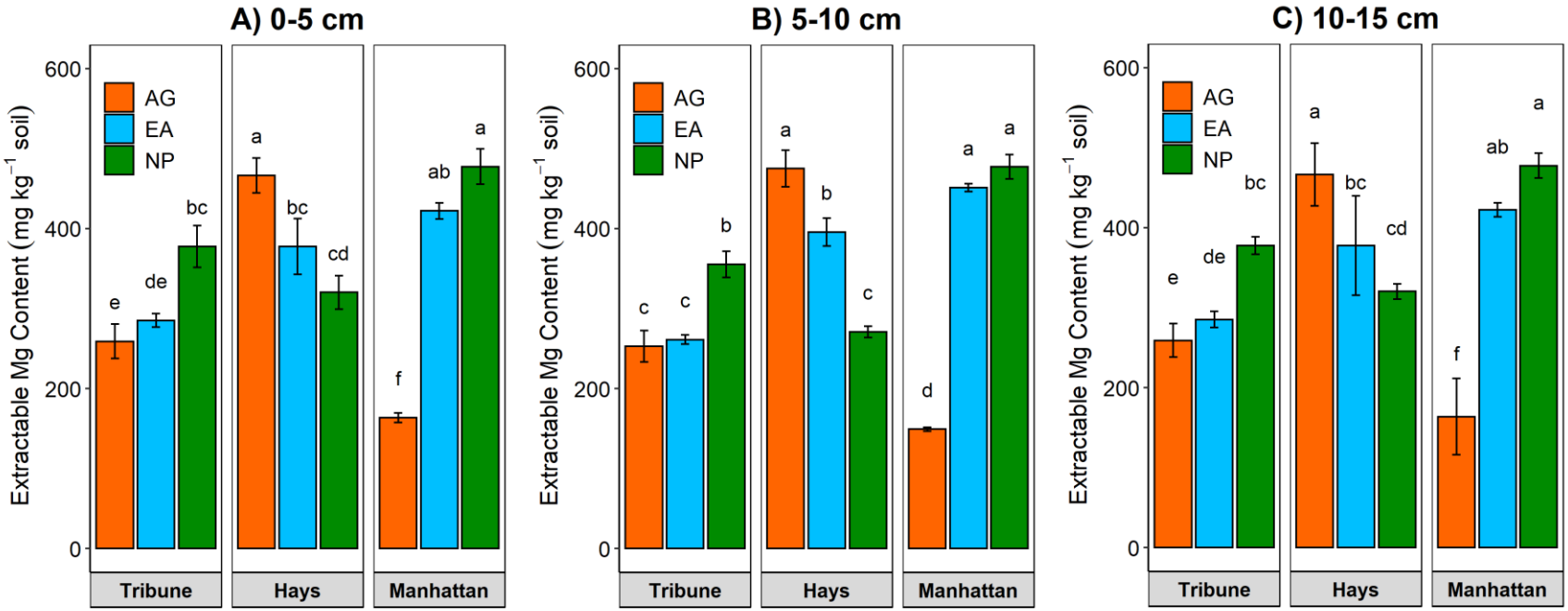

Figure B. 4. Extractable magnesium content by land use and precipitation interaction at 0-5 (A), 5-10 (B), and 10-15 (C) cm soil depths based on two-way ANOVA with letters representing significant differences ($p<0.05$).

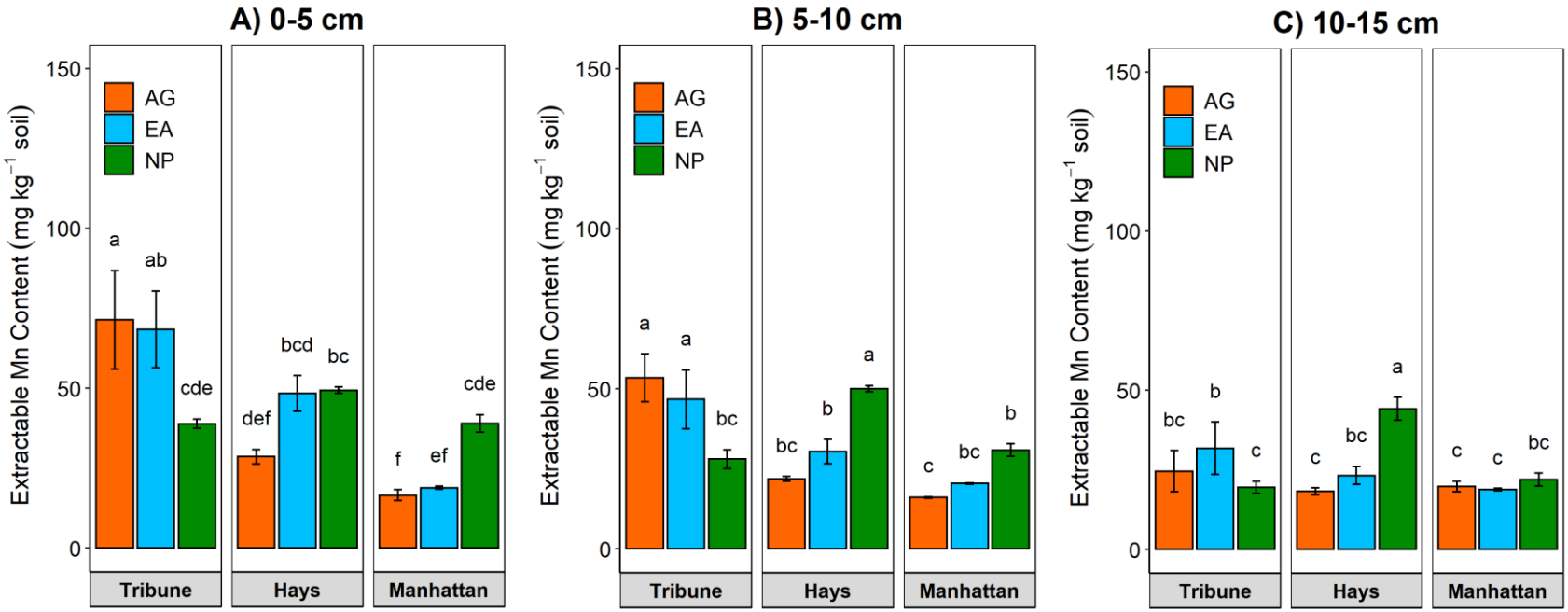

Figure B. 5. Extractable manganese content by land use and precipitation interaction at 0-5 (A), 5-10 (B), and 10-15 (C) cm soil depths based on two-way ANOVA with letters representing significant differences ($p<0.05$).

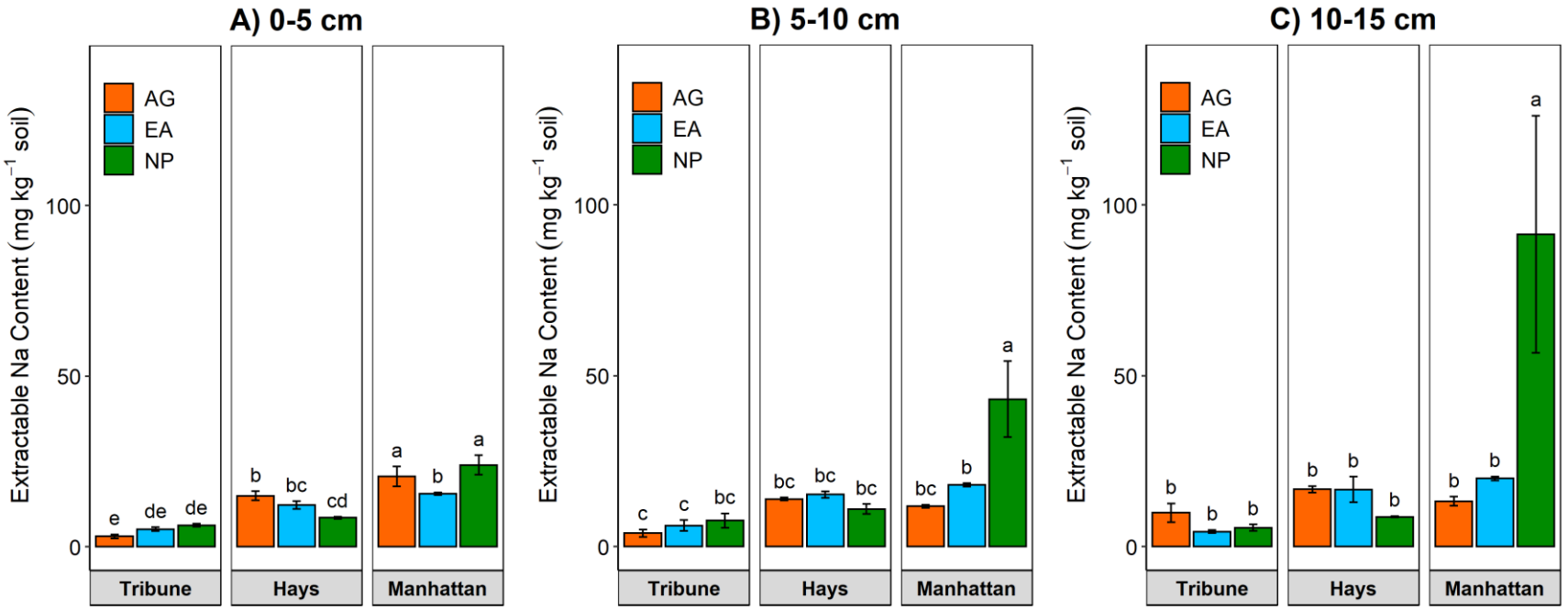

Figure B. 6. Extractable sodium content by land use and precipitation interaction at 0-5 (A), 5-10 (B), and 10-15 (C) cm soil depths based on two-way ANOVA with letters representing significant differences ($p<0.05$).

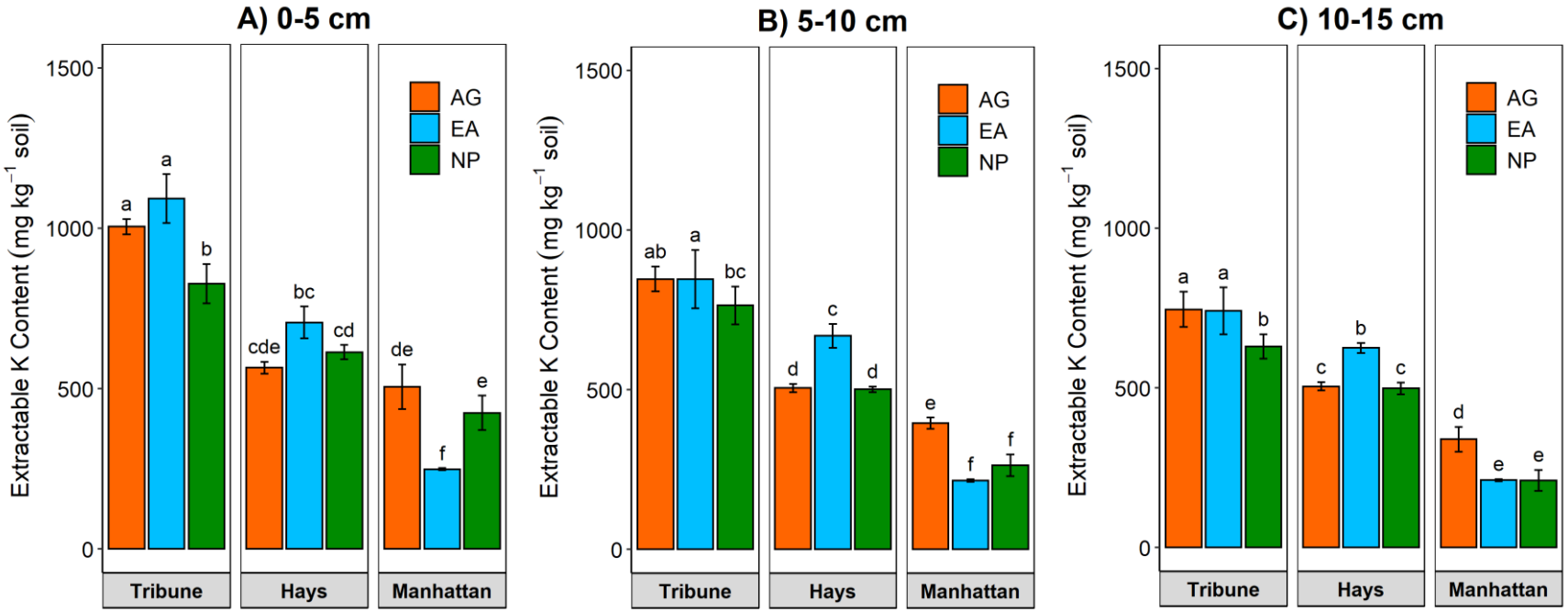

Figure B. 7. Extractable potassium content by land use and precipitation interaction at 0-5 (A), 5-10 (B), and 10-15 (C) cm soil depths based on two-way ANOVA with letters representing significant differences ($p<0.05$).

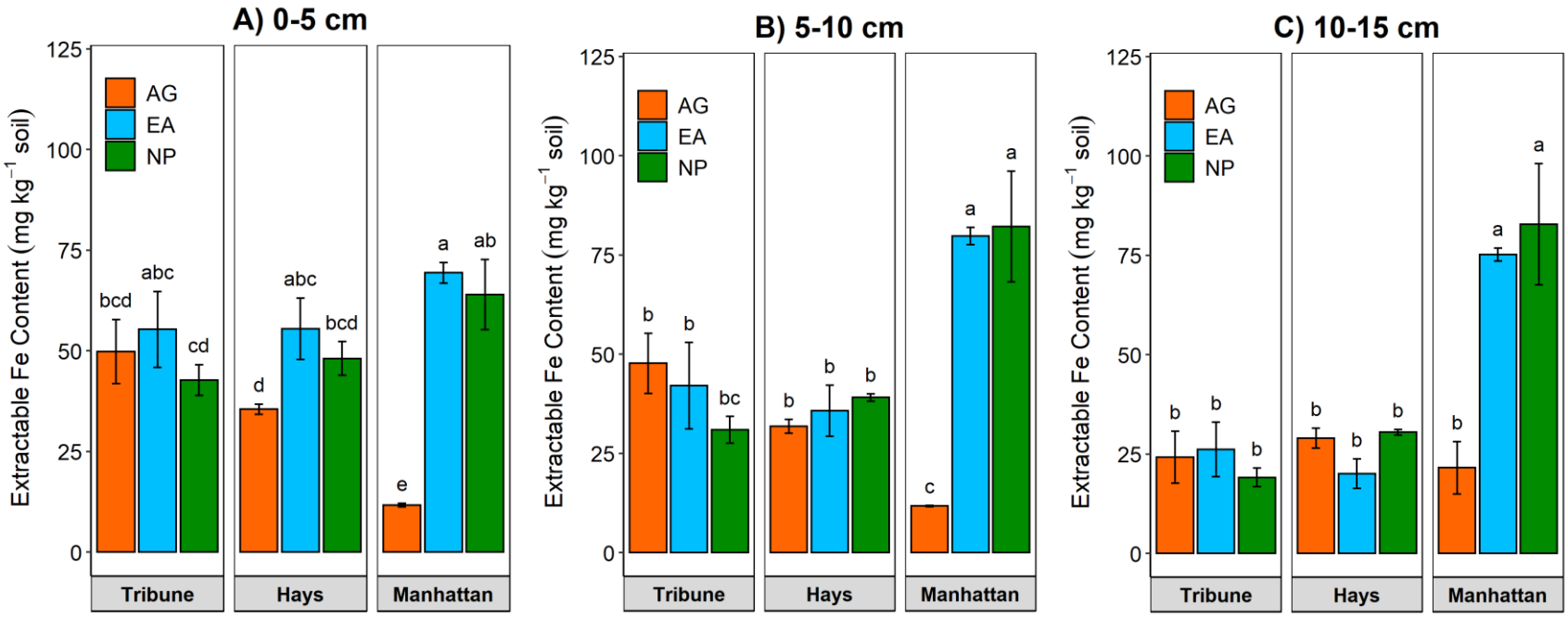

Figure B. 8. Extractable iron content by land use and precipitation interaction at 0-5 (A), 5-10 (B), and 10-15 (C) cm soil depths based on two-way ANOVA with letters representing significant differences ($p<0.05$).

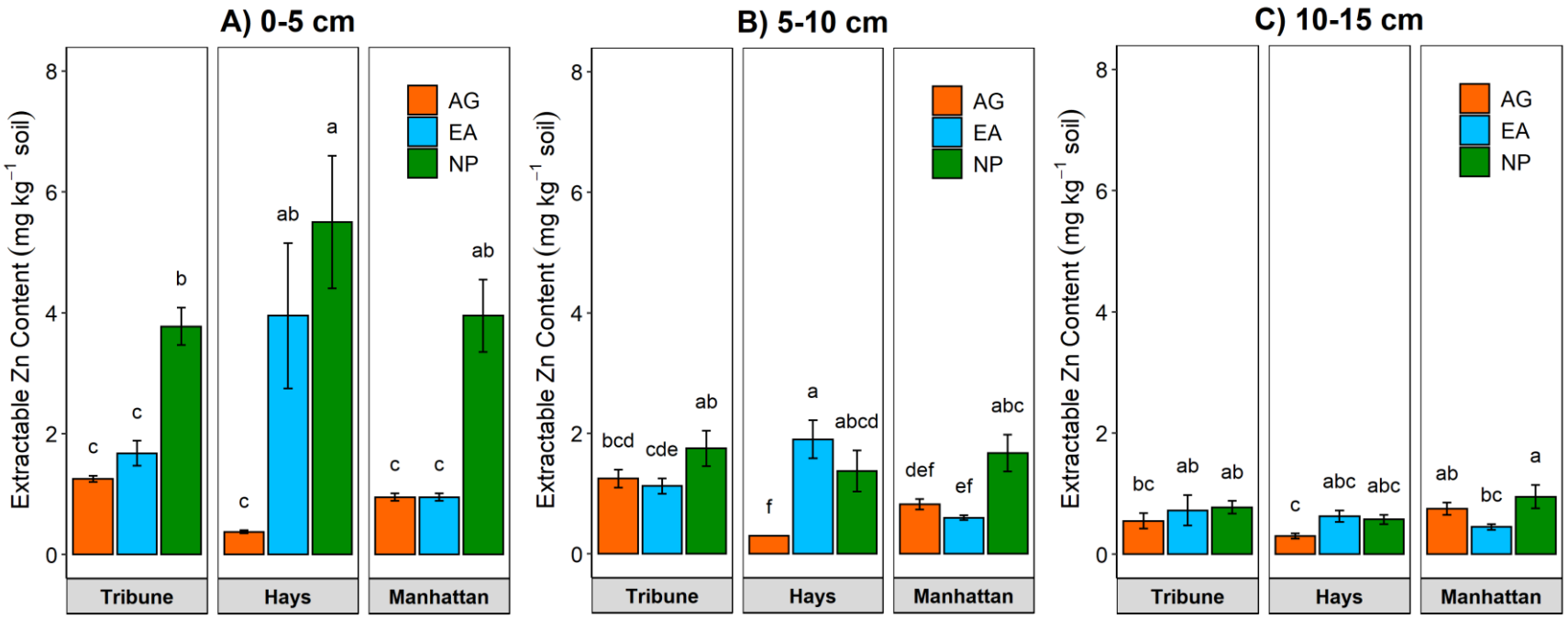

Figure B. 9. Extractable zinc content by land use and precipitation interaction at 0-5 (A), 5-10 (B), and 10-15 (C) cm soil depths based on two-way ANOVA with letters representing significant differences ($p<0.05$).

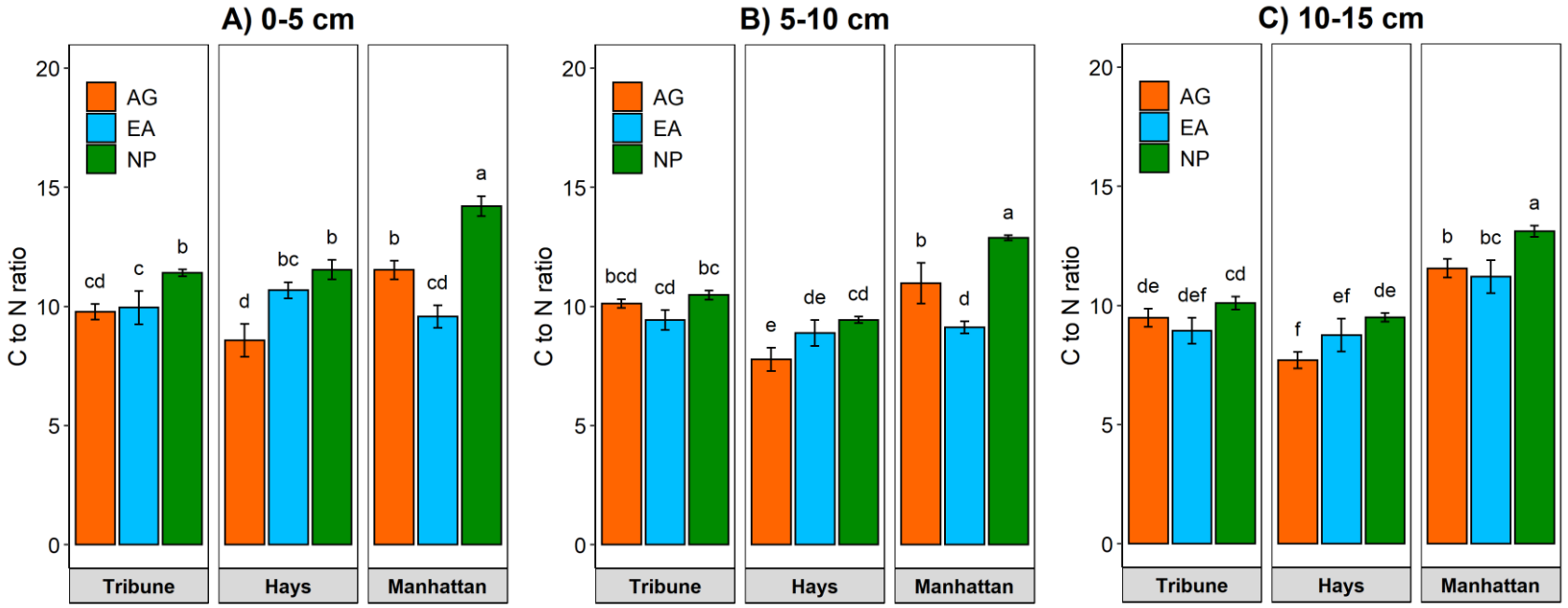

Figure B. 10. Soil organic carbon to total nitrogen ratio by land use and precipitation interaction at 0-5 (A), 5-10 (B), and 10-15 (C) cm soil depths based on two-way ANOVA with letters representing significant differences ($p<0.05$).

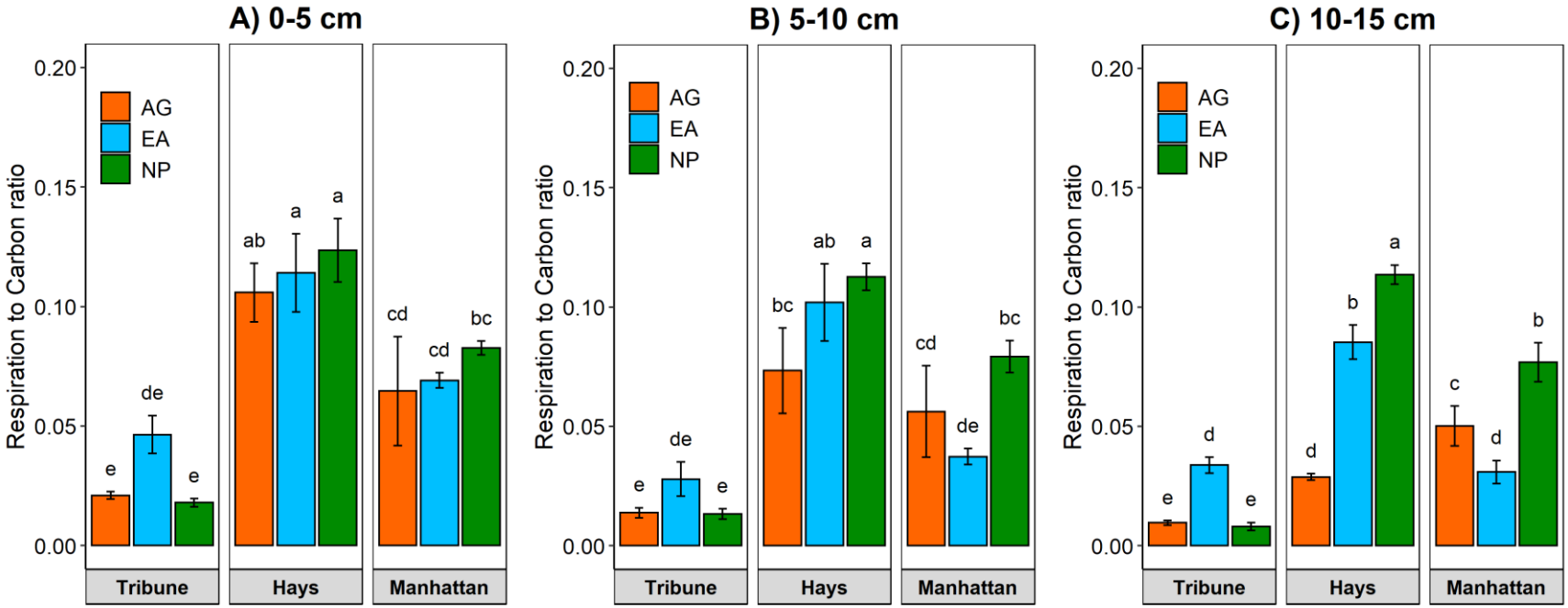

Figure B. 11. Soil respiration to soil organic carbon ratio by land use and precipitation interaction at 0-5 (A), 5-10 (B), and 10-15 (C) cm soil depths based on two-way ANOVA with letters representing significant differences ($p<0.05$).

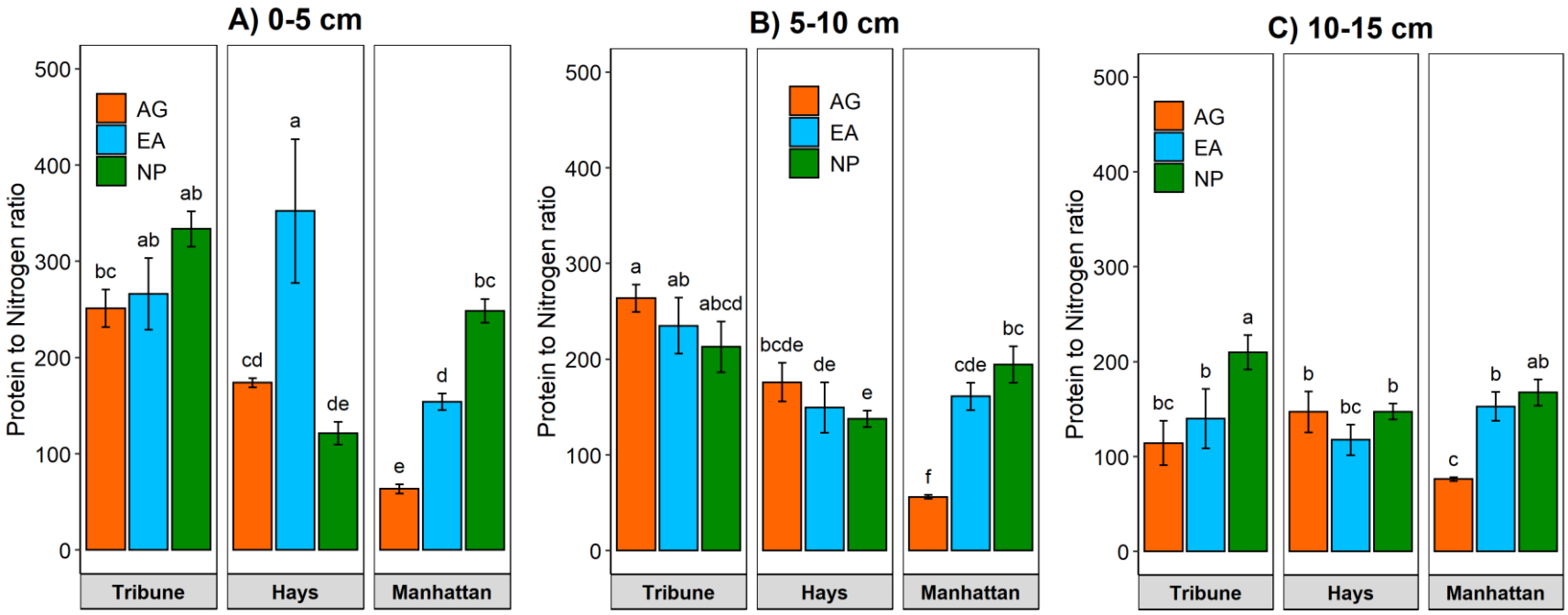

Figure B. 12. Autoclaved citrate extractable protein content to total nitrogen ratio by land use and precipitation interaction at 0-5 (A), 5-10 (B), and 10-15 (C) cm soil depths based on two-way ANOVA with letters representing significant differences ($p<0.05$).

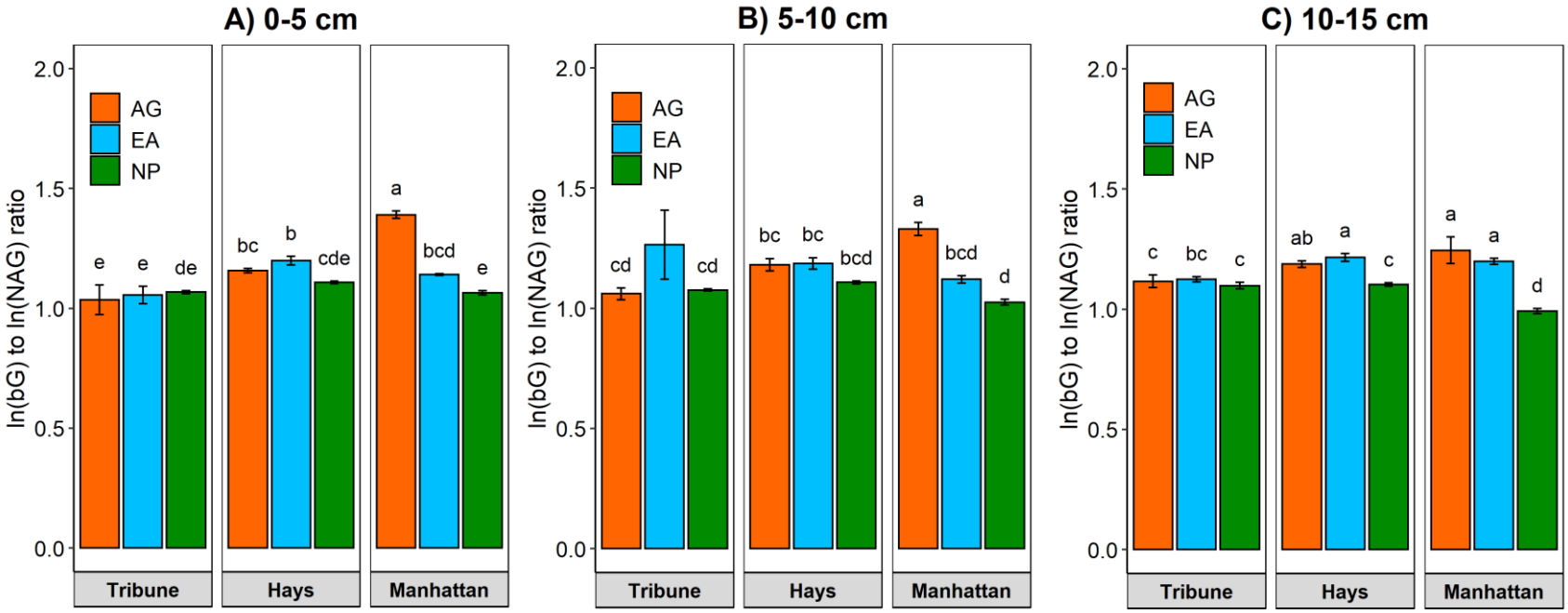

Figure B. 13. Differences in C-acquiring to N-acquiring enzyme activities by land use and precipitation interaction at 0-5 (A), 5-10 (B), and 10-15 (C) cm soil depths based on two-way ANOVA with letters representing significant differences ($p<0.05$).

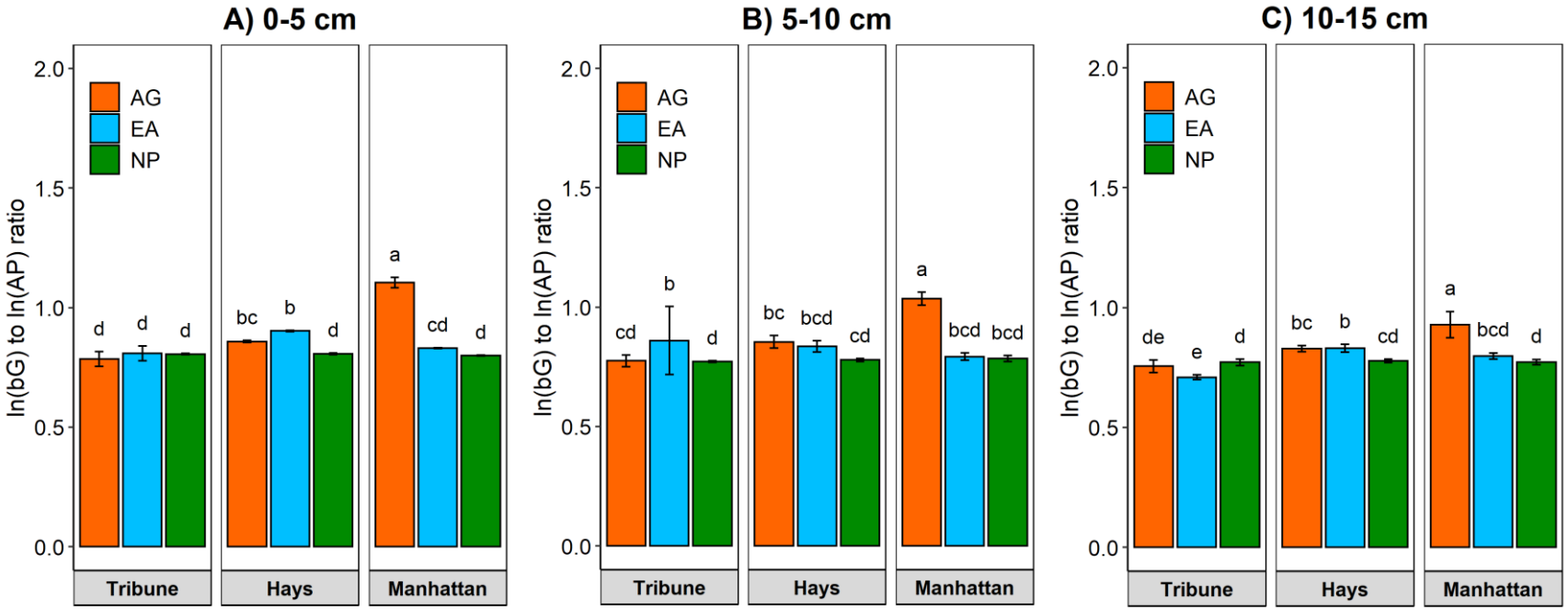

Figure B. 14. Differences in C-acquiring to lower pH P-acquiring enzyme activities by land use and precipitation interaction at 0-5 (A), 5-10 (B), and 10-15 (C) cm soil depths based on two-way ANOVA with letters representing significant differences ($p<0.05$).

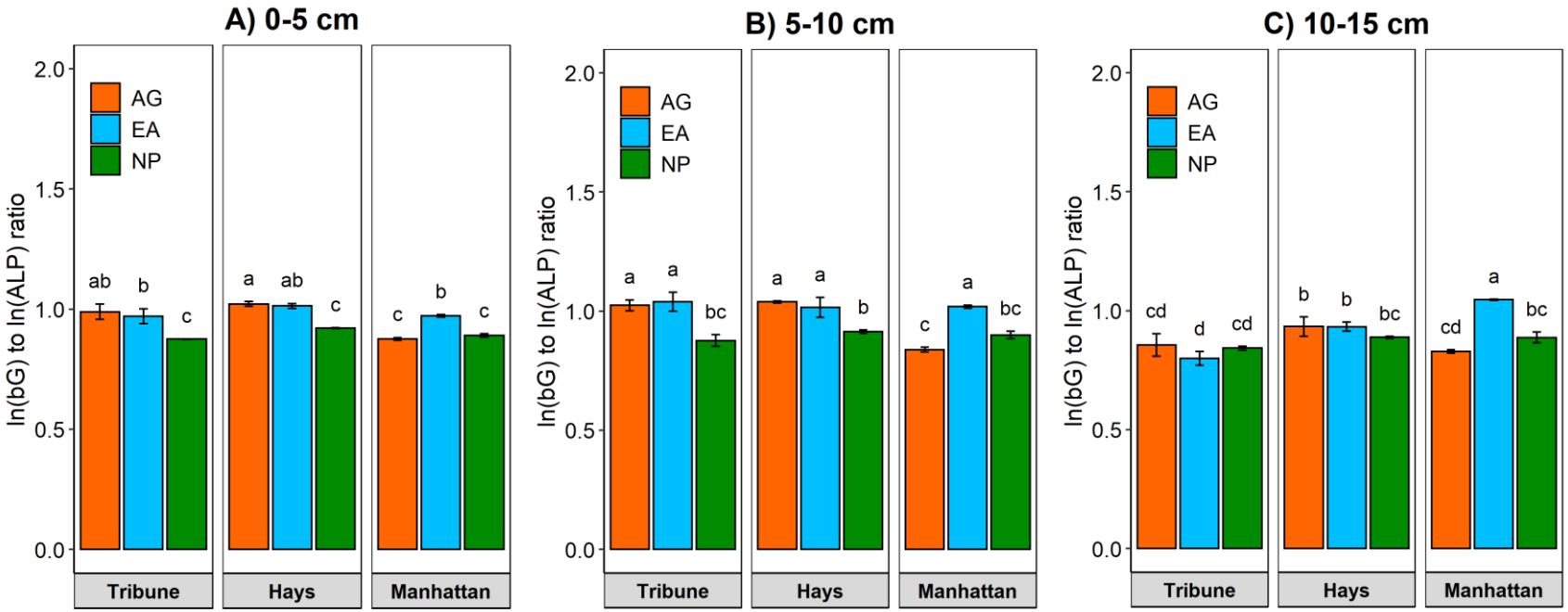

Figure B. 15. Differences in C-acquiring to higher pH P-acquiring enzyme activities by land use and precipitation interaction at 0-5 (A), 5-10 (B), and 10-15 (C) cm soil depths based on two-way ANOVA with letters representing significant differences ($p<0.05$).

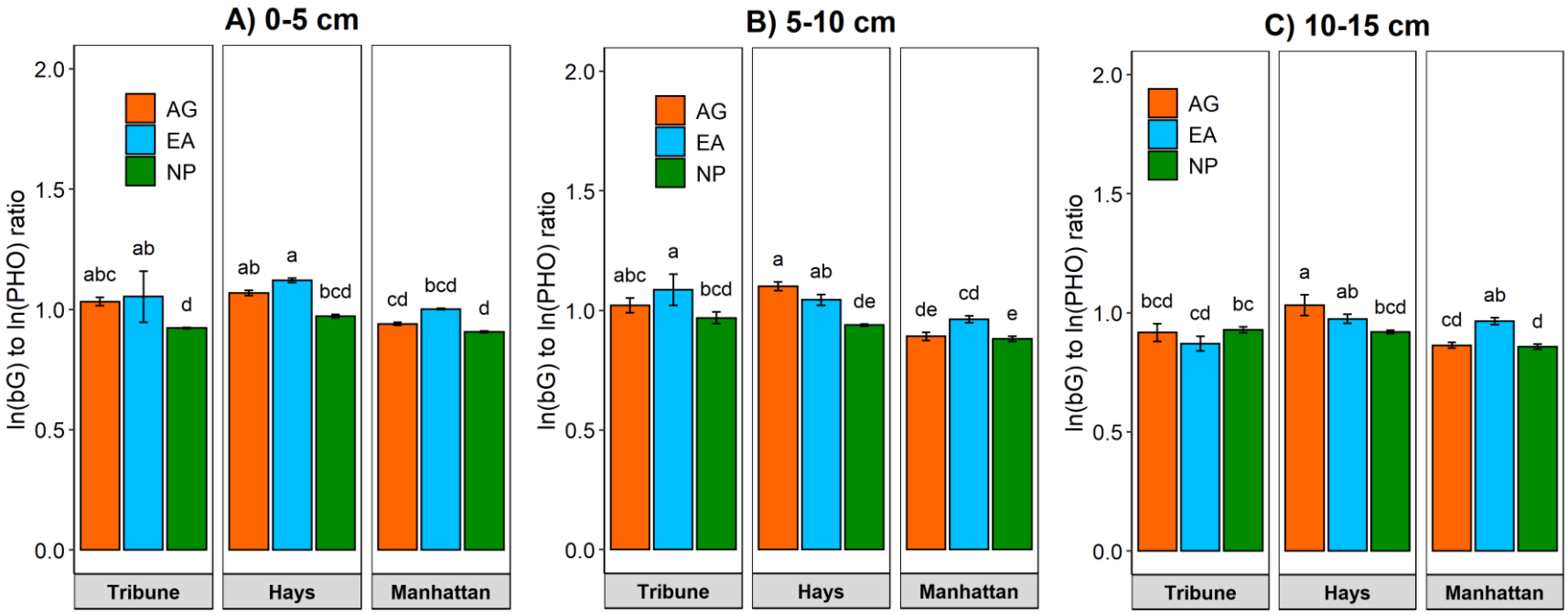

Figure B. 16. Differences in C-acquiring to P-acquiring enzyme activities by land use and precipitation interaction at 0-5 (A), 5-10 (B), and 10-15 (C) cm soil depths based on two-way ANOVA with letters representing significant differences ($p<0.05$).

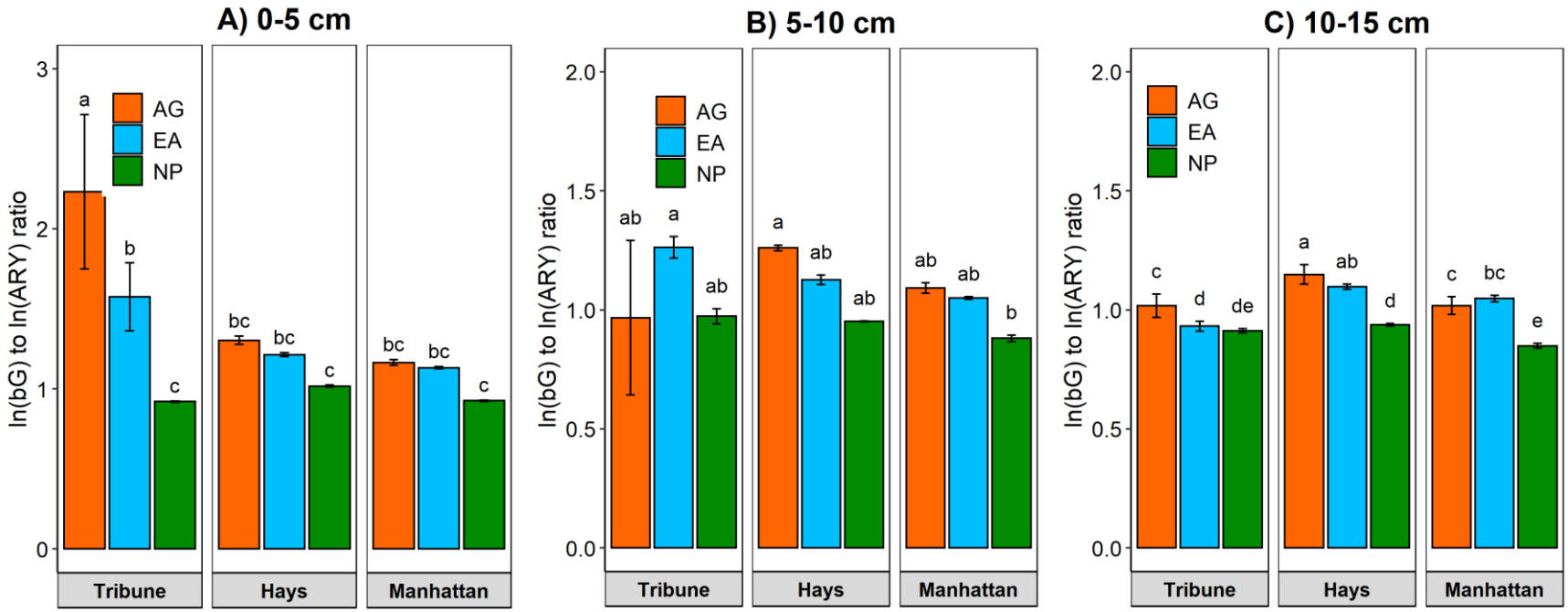

Figure B. 17. Differences in C-acquiring to S-acquiring enzyme activities by land use and precipitation interaction at 0-5 (A), 5-10 (B), and 10-15 (C) cm soil depths based on two-way ANOVA with letters representing significant differences ($p<0.05$).

Tables

Table B. 1. Summary of the p-values from ANOVA for effects of land use and precipitation on ratios of soil properties in the 0-5, 5-10, and 10-15 cm depth. SOC: soil organic carbon; TN: total nitrogen; ln(bG): natural log of β-glucosidase; ln(NAG): natural log of N-acetyl-β-glucosaminidase; ln(AP): natural log of acid phosphatase; ln(ALP): natural log of alkaline phosphatase; ln(PHO): natural log of phosphodiesterase; ln(ARY): natural log of arylsulfatase.
*, **, *** Significant at 0.05, 0.01, and 0.001 probability levels, respectively.

0-5 cm	SOC: TN	ACE P: TN	Respiration: SOC	ln(bG): ln(NAG)
Land Use (LU)	**<0.001 *** **	0.002 **	0.303	**<0.001 *** **
Location (L)	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **
LU*L	**<0.001 *** **	**<0.001 *** **	0.344	**<0.001 *** **
0-5 cm	ln(bG): ln(AP)	ln(bG): ln(ALP)	ln(bG): ln(PHO)	ln(bG): ln(ARY)
Land Use (LU)	**<0.001 *** **	**<0.001 *** **	**0.001 ** **	**<0.001 *** **
Location (L)	**<0.001 *** **	**<0.001 *** **	**0.006 ** **	**0.004 ** **
LU*L	**<0.001 *** **	**0.002 ** **	0.837	**0.036 * **
5-10 cm	SOC: TN	ACE P: TN	Respiration: SOC	ln(bG): ln(NAG)
Land Use (LU)	**<0.001 *** **	0.462	0.088	**0.005 ** **
Location (L)	**<0.001 *** **	**0.001 ** **	**<0.001 *** **	0.867
LU*L	0.002	**<0.001 *** **	0.07	**0.009 ** **
5-10 cm	ln(bG): ln(AP)	ln(bG): ln(ALP)	ln(bG): ln(PHO)	ln(bG): ln(ARY)
Land Use (LU)	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **	0.061
Location (L)	0.015	**0.002 ** **	**<0.001 *** **	0.514
LU*L	**<0.001 *** **	**<0.001 *** **	0.07	0.369
10-15 cm	SOC: TN	ACE P: TN	Respiration: SOC	ln(bG): ln(NAG)
Land Use (LU)	**0.001 ** **	**0.002 ** **	**<0.001 *** **	**<0.001 *** **
Location (L)	**<0.001 *** **	0.448	**<0.001 *** **	**0.022 * **
LU*L	0.285	**0.03 * **	**<0.001 *** **	**<0.001 *** **
10-15 cm	ln(bG): ln(AP)	ln(bG): ln(ALP)	ln(bG): ln(PHO)	ln(bG): ln(ARY)
Land Use (LU)	**<0.001 *** **	**0.02 ** **	0.149	**<0.001 *** **
Location (L)	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **	**<0.001 *** **
LU*L	**<0.001 *** **	**<0.001 *** **	**0.002 ** **	**0.018 * **

Appendix C - Chapter 4-Depth

Tables

Table C. 1. Raw data for each soil health parameter for each sample depth with standard deviation in parentheses.

Sample Label	Location	Land Use	Depth cm	Horizon	Texture	Sand %	Silt %	Clay %	Bulk Density g cm^{-3}
ManhattanAG0-5	Manhattan	AG	0-5	Ap1	Silt loam	5.2	61.7	26	1.44 (0.18)
ManhattanAG5-10	Manhattan	AG	5-10	Ap1	Silt loam	5.2	61.7	26	1.35 (0.11)
ManhattanAG10-15	Manhattan	AG	10-15	Ap1	Silt loam	5.2	61.7	34	1.34 (0.13)
ManhattanAG15-25	Manhattan	AG	15-25	Ap2	Silty clay loam	4	61.1	34	1.35 (0.03)
ManhattanAG25-45	Manhattan	AG	25-45	Bt	Silty clay	2.7	48	41	1.33 (0.06)
ManhattanAG45-70	Manhattan	AG	45-70	Bt	Silty clay	2.7	48	41	1.42 (0.06)
ManhattanAG70-100	Manhattan	AG	70-100	Btss1	Silty clay	3.1	48.6	54	1.51 (0.08)
ManhattanEA0-5	Manhattan	EA	0-5	A	Silt loam			24	1.25 (0.22)
ManhattanEA5-10	Manhattan	EA	5-10	A	Silt loam			24	1.32 (0.08)
ManhattanEA10-15	Manhattan	EA	10-15	A	Silt loam			24	1.47 (0.12)
ManhattanEA15-25	Manhattan	EA	15-25	BA	Silty clay loam			28	1.34 (0.04)
ManhattanEA25-50	Manhattan	EA	25-50	BA	Silty clay loam			31	1.19 (0.08)
ManhattanEA50-75	Manhattan	EA	50-75	B	Silty clay loam			37	1.31 (0.05)
ManhattanEA75-100	Manhattan	EA	75-100	B	Silty clay loam			40	1.44 (0.04)
ManhattanNP0-5	Manhattan	NP	0-5	A1	Silt loam	10	61.8	29	1.27 (0.11)
ManhattanNP5-10	Manhattan	NP	5-10	A1	Silt loam	10	61.8	29	1.26 (0.1)
ManhattanNP10-15	Manhattan	NP	10-15	A1	Silt loam	10	61.8	29	1.24 (0.11)
ManhattanNP15-30	Manhattan	NP	15-30	A2	Silt loam	8.8	58.9	31	1.26 (0.01)
ManhattanNP30-60	Manhattan	NP	30-60	Bt1	Silty clay loam	4	42.7	38	1.32 (0.07)
ManhattanNP60-85	Manhattan	NP	60-85	Bt2	Silty clay loam	4.4	46	43	1.38 (0.07)
ManhattanNP85-100	Manhattan	NP	85-100	Btk1	Silty clay loam	3.9	50.1	46	1.3 (0.16)

Table C.1. Continued.

Sample Label	20-minutes MWD mm	20-minute WSA 8-2 mm %	20-minute WSA 2-0.25 mm %	20-minute WSA 0.25-0.053 mm %	20-minute WSA 0.053-0.02 mm %	NRCS Aggregate Stability %
ManhattanAG0-5	0.39 (0.11)	1.98 (0.72)	17.6 (7.73)	61.2 (5.62)	7.25 (2.04)	1.96 (1.75)
ManhattanAG5-10	0.46 (0.12)	3 (1.52)	19.0 (5.21)	60.5 (7.16)	4.81 (0.38)	4.82 (2.36)
ManhattanAG10-15	0.55 (0.13)	2.65 (1.02)	29.5 (9.36)	54.0 (10.51)	3.47 (0.92)	9.89 (6.99)
ManhattanAG15-25	1.06 (0.12)	9.42 (2.2)	48.2 (4.15)	30.1 (5.78)	2.6 (0.42)	37.6 (9.93)
ManhattanAG25-45	1.04 (0.16)	8.42 (2.65)	51.0 (2.53)	28.5 (3.18)	2.07 (1.19)	50.6 (2.65)
ManhattanAG45-70	1.09 (0.08)	8.54 (1.14)	55.6 (4.62)	23.3 (4.74)	1.89 (1.02)	48.4 (2.97)
ManhattanAG70-100	0.89 (0.08)	5.08 (1.11)	52.6 (4.83)	27.4 (3.33)	2.97 (2.03)	42.2 (6.2)
ManhattanEA0-5	0.93 (0.19)	11.49 (2.57)	25 (7.12)	47.4 (9.68)	5.15 (1.22)	45.9 (4.35)
ManhattanEA5-10	0.84 (0.24)	8.2 (4.02)	32 (8.34)	45.0 (9)	5.05 (1.68)	32.1 (6.11)
ManhattanEA10-15	0.59 (0.12)	4.38 (1.23)	25.8 (6.19)	52.4 (6.48)	6.94 (2.08)	20.9 (5.5)
ManhattanEA15-25	0.57 (0.05)	3.93 (0.71)	25.3 (2.03)	55.4 (2.5)	4.72 (1.42)	13.3 (1.96)
ManhattanEA25-50	0.59 (0.04)	2.58 (0.56)	34.6 (4.64)	48.4 (7.6)	5.62 (2.36)	28.2 (2.55)
ManhattanEA50-75	0.75 (0.16)	4.21 (2.49)	42.4 (4.27)	38.9 (7.07)	5.09 (2.34)	29.4 (6.56)
ManhattanEA75-100	1.09 (0.2)	9.51 (3.7)	51.8 (3.77)	22.8 (7.32)	4.68 (0.88)	45.6 (12.83)
ManhattanNP0-5	1.71 (0.55)	25.31 (11.97)	37.3 (4.69)	16.6 (6.94)	1.93 (0.14)	71.1 (9.45)
ManhattanNP5-10	1.41 (0.29)	19.54 (5.8)	35.2 (2.49)	23.6 (8)	3.04 (0.58)	61.8 (7.09)
ManhattanNP10-15	1.72 (0.38)	25.37 (7.45)	37.6 (3.37)	19.5 (9.83)	1.73 (1)	54.9 (9.87)
ManhattanNP15-30	1.93 (0.52)	28.2 (12.69)	44.2 (11.62)	14.0 (4.17)	1.98 (0.73)	64.5 (10.44)
ManhattanNP30-60	1.52 (0.36)	19.03 (5.61)	48.1 (10.74)	18.3 (13.4)	2.13 (1.08)	60.2 (5.45)
ManhattanNP60-85	1.07 (0.24)	13.04 (4.36)	33.2 (6.3)	26.2 (11.7)	6.37 (1.5)	40.8 (27.48)
ManhattanNP85-100	0.44 (0.13)	4.25 (2.11)	12.6 (3.9)	54.7 (8.19)	11.3 (1.36)	7.07 (2.34)

Table C.1. Continued.

Sample Label	ARS 5-minute MWD mm	5-minute WSA 8-2 mm %	5-minute WSA 2-0.25 mm %	5-minute WSA 0.25-0.053 mm %	5-minute WSA 0.053-0.02 mm %	SOC %
ManhattanAG0-5	0.51 (0.08)	2.86 (0.5)	28.05 (6.59)	52.78 (8.33)	3.98 (1.65)	2.04 (0.06)
ManhattanAG5-10	0.74 (0.14)	4.7 (2.19)	41.28 (12.41)	42.54 (12.57)	2.25 (0.87)	1.96 (0.07)
ManhattanAG10-15	0.85 (0.22)	4.47 (1.49)	52.69 (19.97)	33.1 (17.69)	3.07 (1.62)	1.88 (0.19)
ManhattanAG15-25	1.2 (0.13)	12.42 (2.87)	48.44 (2.06)	28.13 (3.64)	2.42 (0.11)	1.68 (0.51)
ManhattanAG25-45						1.54 (0.27)
ManhattanAG45-70						1.18 (0.16)
ManhattanAG70-100						1.05 (0.05)
ManhattanEA0-5	1.11 (0.08)	14.24 (2.65)	31.32 (7.8)	30.86 (7.43)	3.78 (0.75)	1.99 (0.11)
ManhattanEA5-10	1.39 (0.33)	18.6 (6.96)	37.57 (5.54)	23.88 (6.66)	4.25 (0.82)	1.52 (0.07)
ManhattanEA10-15	1.21 (0.53)	15.12 (11.3)	36.02 (7.24)	29.54 (8.91)	4.2 (1.32)	1.39 (0.04)
ManhattanEA15-25	0.87 (0.06)	8.45 (0.71)	34.31 (7.01)	36.3 (7.82)	5.13 (2.24)	1.67 (0.26)
ManhattanEA25-50						1.87 (0.13)
ManhattanEA50-75						1.18 (0.09)
ManhattanEA75-100						0.6 (0.13)
ManhattanNP0-5	1.78 (0.38)	25.43 (8.39)	44.26 (3.85)	12.95 (5.14)	1.43 (0.46)	4.97 (0.68)
ManhattanNP5-10	1.9 (0.38)	27.72 (7.95)	44.21 (2.8)	12.83 (6.36)	1.72 (0.76)	3.41 (0.44)
ManhattanNP10-15	1.78 (0.2)	26.75 (3.77)	37.69 (3.03)	20.07 (7.11)	1.41 (0.49)	2.95 (0.56)
ManhattanNP15-30	2.39 (0.23)	38.7 (5.91)	39.24 (5.96)	8.34 (1.55)	1.18 (0.52)	2 (0.14)
ManhattanNP30-60						1.1 (0.16)
ManhattanNP60-85						0.96 (0.46)
ManhattanNP85-100						0.4 (0.03)

Table C.1. Continued.

Sample Label	SOC Stock Mg SOC ha^{-1}	TN %	TN Mg TN ha^{-1}	Ca g kg^{-1}	Cu mg kg^{-1}	Mg mg kg^{-1}	Mn mg kg^{-1}
ManhattanAG0-5	14.73 (2.11)	0.18 (0.02)	1.29 (0.25)	5.8 (0.26)	1.25 (0.17)	164 (12.11)	16.58 (3.35)
ManhattanAG5-10	13.25 (0.84)	0.18 (0.03)	1.23 (0.2)	5.81 (0.21)	1.15 (0.13)	149 (4.87)	16.05 (0.47)
ManhattanAG10-15	12.63 (1.72)	0.16 (0.01)	1.09 (0.14)	4.82 (0.8)	1.58 (0.31)	224 (95.24)	19.83 (3.27)
ManhattanAG15-25	24.98 (7.53)	0.17 (0.02)	2.46 (0.34)	5.21 (0.24)	1.88 (0.15)	250 (35.65)	16.2 (0.88)
ManhattanAG25-45	42.94 (6.56)	0.17 (0.02)	4.64 (0.77)	5.05 (0.31)	2.23 (0.6)	287 (100.93)	15.55 (2.06)
ManhattanAG45-70	40.28 (4.72)	0.15 (0.03)	4.95 (0.99)	5.45 (0.4)	2.2 (0.34)	331 (58.36)	17.55 (3.37)
ManhattanAG70-100	46.04 (1.87)	0.13 (0.03)	5.65 (1.24)	6.09 (0.23)	1.73 (0.48)	297 (45.52)	13.03 (2.84)
ManhattanEA0-5	12.53 (2.8)	0.21 (0.03)	1.33 (0.42)	2.86 (0.15)	1.3 (0.08)	422 (20.18)	18.88 (0.92)
ManhattanEA5-10	10.03 (1.04)	0.17 (0.02)	1.1 (0.14)	2.55 (0.07)	1.55 (0.06)	451 (9.53)	20.45 (0.39)
ManhattanEA10-15	10.2 (1.06)	0.13 (0.01)	0.91 (0.08)	2.45 (0.08)	1.53 (0.05)	485 (17.34)	18.83 (0.83)
ManhattanEA15-25	22.29 (2.77)	0.16 (0.03)	2.17 (0.31)	2.35 (0.03)	1.45 (0.1)	454 (15.55)	15.45 (1.19)
ManhattanEA25-50	55.45 (3.38)	0.17 (0.01)	4.91 (0.62)	2.32 (0.07)	1.65 (0.1)	450 (17.71)	10.03 (0.83)
ManhattanEA50-75	38.72 (4.2)	0.12 (0.01)	3.77 (0.4)	2.55 (0.43)	1.78 (0.46)	527 (135.34)	11.35 (2.22)
ManhattanEA75-100	21.5 (4.97)	0.07 (0.01)	2.44 (0.49)	3.23 (0.26)	1.5 (0.14)	686 (97.71)	7.33 (2.41)
ManhattanNP0-5	31.57 (5.46)	0.35 (0.05)	2.22 (0.37)	3.25 (0.36)	1.55 (0.17)	478 (43.67)	39 (5.47)
ManhattanNP5-10	21.52 (3.47)	0.27 (0.03)	1.67 (0.27)	2.93 (0.49)	1.65 (0.17)	477 (30.54)	30.88 (3.95)
ManhattanNP10-15	18.38 (4.32)	0.23 (0.04)	1.4 (0.31)	2.73 (0.63)	1.73 (0.1)	478 (31)	21.93 (4.04)
ManhattanNP15-30	35.3 (2.28)	0.18 (0.01)	3.22 (0.18)	3.92 (0.51)	3.18 (0.57)	774 (155.47)	17.63 (1.28)
ManhattanNP30-60	43.4 (6.14)	0.11 (0.03)	4.26 (1.21)	4.28 (0.29)	2.45 (0.75)	969 (34)	17.6 (1.81)
ManhattanNP60-85	35.64 (16.76)	0.11 (0.01)	3.9 (0.43)	4.83 (1.06)	1.78 (0.25)	810 (124.65)	13.33 (2.13)
ManhattanNP85-100	5.43 (3.63)	0.07 (0.04)	0.97 (0.78)	3.83 (0.05)	1.57 (0.31)	793 (60.46)	13.77 (3.78)

Table C.1. Continued.

Sample Label	Na mg kg^{-1}	P mg kg^{-1}	K mg kg^{-1}	Zn mg kg^{-1}	Fe mg kg^{-1}	pH	Water Content %
ManhattanAG0-5	20.65 (5.77)	78.23 (8.1)	506 (140.07)	0.95 (0.13)	11.7 (0.89)	7.9 (0.08)	26.85 (1.38)
ManhattanAG5-10	11.83 (0.89)	67.88 (17.19)	396 (34.43)	0.83 (0.17)	11.75 (0.33)	7.93 (0.05)	24.5 (1.23)
ManhattanAG10-15	13.3 (2.64)	61.35 (39.47)	339 (78.16)	0.75 (0.21)	21.58 (13.13)	7.43 (0.59)	24.45 (2.48)
ManhattanAG15-25	16.83 (1.2)	18.55 (17.87)	320 (12.46)	0.43 (0.1)	18.13 (1.98)	7.68 (0.1)	24.84 (1.16)
ManhattanAG25-45	15.1 (1.31)	17.15 (13.69)	310 (6.35)	0.58 (0.25)	21.08 (4.61)	7.63 (0.17)	25.1 (1.34)
ManhattanAG45-70	20.08 (1.97)	6.7 (4.95)	315 (7.1)	0.53 (0.13)	21.4 (5.62)	7.68 (0.19)	24.06 (1.22)
ManhattanAG70-100	19.88 (2.16)	4.58 (1.46)	320 (22.15)	0.38 (0.17)	17.38 (2.05)	7.9 (0.2)	22.76 (1.27)
ManhattanEA0-5	15.58 (0.84)	44.95 (24.86)	249 (6.4)	0.95 (0.13)	69.38 (5.15)	6.23 (0.17)	14.15 (3.19)
ManhattanEA5-10	18.1 (0.93)	9.23 (3.11)	216 (8.22)	0.6 (0.08)	79.78 (4.36)	5.78 (0.05)	18.63 (0.77)
ManhattanEA10-15	19.95 (1.17)	4.43 (0.71)	211 (7.3)	0.45 (0.1)	75.2 (3.26)	5.7 (0.08)	19.66 (0.44)
ManhattanEA15-25	20.13 (0.9)	2.7 (0.42)	185 (4.36)	0.28 (0.05)	79.1 (8.26)	5.75 (0.24)	22.19 (2.1)
ManhattanEA25-50	23.25 (0.76)	2.95 (0.79)	192 (5.73)	0.15 (0.06)	82.5 (4.25)	5.85 (0.06)	20.97 (1.68)
ManhattanEA50-75	34.4 (7.74)	2.38 (0.7)	244 (48.64)	0.13 (0.05)	57.33 (2.16)	6.1 (0.14)	18.47 (1.13)
ManhattanEA75-100	54.85 (7.78)	2.75 (1.18)	377 (37.6)	0.13 (0.05)	40.48 (3.98)	6.48 (0.17)	20.42 (2)
ManhattanNP0-5	23.98 (5.76)	3.43 (0.71)	424 (107.57)	3.95 (1.19)	64 (17.41)	6.53 (0.05)	47.42 (3.88)
ManhattanNP5-10	43.18 (22.15)	2.28 (0.43)	263 (67.32)	1.68 (0.61)	82.18 (27.94)	6.25 (0.24)	38.21 (4.34)
ManhattanNP10-15	91.43 (69.48)	2.08 (0.17)	210 (65.6)	0.95 (0.39)	82.8 (30.47)	6.2 (0.14)	34.42 (0.87)
ManhattanNP15-30	370.5 (123.77)	1.7 (0.14)	248 (17.12)	1.13 (0.15)	46.75 (13.64)	6.5 (0.32)	31.45 (2.99)
ManhattanNP30-60	776.1 (141.22)	2.23 (1)	246 (17.95)	0.83 (0.36)	20.1 (3.05)	7.65 (0.33)	27.23 (2.56)
ManhattanNP60-85	870.1 (172.8)	3.1 (0.57)	229 (19.77)	0.4 (0.08)	13 (1.52)	7.98 (0.19)	24.58 (1.48)
ManhattanNP85-100	965.83 (356.03)	10.8 (4.62)	211 (15.19)	0.47 (0.21)	10.93 (2.5)	8 (0.1)	24.58 (4.82)

Table C.1. Continued.

Sample Label	β - Glucosidase mg kg^{-1} hr^{-1}	N-acetyl-β-D-Glucosaminidase mg kg^{-1} hr^{-1}	Acid Phosphatase mg kg^{-1} hr^{-1}	Alkaline Phosphatase mg kg^{-1} hr^{-1}	Phosphodiesterase mg kg^{-1} hr^{-1}	Arylsulfatase mg kg^{-1} hr^{-1}
ManhattanAG0-5	16.76 (1.8)	2.11 (0.37)	8.6 (2.17)	47.81 (3.16)	27 (3.33)	5.94 (1.1)
ManhattanAG5-10	12.39 (2.43)	2.12 (0.31)	9.66 (1.35)	48.01 (2.72)	29.15 (2.18)	6.71 (0.47)
ManhattanAG10-15	9.02 (3.61)	2.26 (0.41)	14.38 (3.08)	37.64 (17.6)	25.51 (9.09)	7.38 (0.07)
ManhattanAG15-25	4.95 (1.71)	2.05 (0.22)	26.91 (4.36)	44.15 (4.79)	42.75 (3.94)	9.61 (1.16)
ManhattanAG25-45	2.63 (0.87)	1.78 (0.47)	20.28 (5.32)	32.69 (1.65)	29.49 (3.01)	8.08 (0.79)
ManhattanAG45-70	1.92 (0.58)	1.49 (0.54)	12.4 (2.74)	27.84 (5.3)	19.96 (4.03)	5.95 (0.75)
ManhattanAG70-100	0.95 (0.65)	1.14 (0.25)	8.88 (1.28)	18.09 (3.98)	14.7 (1.59)	3.69 (0.52)
ManhattanEA0-5	24.49 (1.2)	9.33 (0.31)	120.63 (3.27)	30.97 (3.86)	24.2 (1.46)	9.88 (0.8)
ManhattanEA5-10	10.73 (2.11)	5.02 (0.38)	66.3 (12.15)	9.4 (1.4)	14.59 (4.5)	7.63 (0.94)
ManhattanEA10-15	8.34 (1.92)	2.75 (0.64)	45.45 (10.33)	6.21 (1.29)	10.64 (2.2)	6.05 (0.51)
ManhattanEA15-25	6.35 (2.66)	3.01 (0.87)	34.47 (3.84)	7.33 (2.11)	10.54 (1.55)	6.68 (1.95)
ManhattanEA25-50	5.11 (1.27)	5.55 (0.49)	29.33 (2.27)	10.22 (0.9)	16.72 (2.72)	9.26 (0.93)
ManhattanEA50-75	2.2 (0.83)	3.43 (0.99)	15.42 (1.54)	6.05 (1.09)	8.73 (0.65)	5 (1.06)
ManhattanEA75-100	1.9 (0.27)	2.38 (0.49)	14.6 (2.09)	7.78 (2.93)	7.7 (1.64)	3.04 (0.71)
ManhattanNP0-5	30.41 (0.21)	18.92 (2.58)	228.81 (9.9)	82.17 (13.09)	70.07 (5.98)	57.56 (4.68)
ManhattanNP5-10	17.07 (4.13)	13.96 (1.84)	130.9 (35.17)	40.16 (13.11)	45.9 (7.77)	45.63 (3.71)
ManhattanNP10-15	10.16 (1.42)	10.87 (2.12)	79.77 (20.87)	26.59 (10.41)	32.42 (6.96)	35.18 (6.66)
ManhattanNP15-30	9.14 (2.12)	9.39 (1.81)	53.09 (3.74)	26.71 (2.73)	26.13 (6.36)	21.79 (6.99)
ManhattanNP30-60	2.81 (0.68)	4.01 (1.23)	26.36 (10.84)	22.13 (11.87)	19.1 (5.05)	5.18 (1.38)
ManhattanNP60-85	2.39 (0.3)	2.4 (0.37)	11.13 (3.77)	22.7 (4.18)	11.33 (2.06)	4.84 (2.34)
ManhattanNP85-100	1.29 (0.5)	0.41 (0.22)	4.84 (0.74)	3.46 (2.92)	3.86 (1.21)	1.12 (0.39)

Table C.1. Continued.

Sample Label	CO2 Respiration mg CO2 g soil^{-1}	ACE Protein Content mg protein g soil^{-1}	POXC mg reactive C kg soil^{-1}	Total Microbial Biomass nmol g^{-1}	Gram (+) Bacteria nmol g^{-1}
ManhattanAG0-5	1.32 (0.92)	1.13 (0.17)	1368 (15.27)	45.64 (2.3)	12.06 (1.17)
ManhattanAG5-10	1.11 (0.78)	1.02 (0.13)	1356 (18.29)	38.04 (6.77)	11.88 (1.2)
ManhattanAG10-15	0.94 (0.29)	1.24 (0.05)	1364 (16.75)	28.57 (9.42)	10.06 (1.6)
ManhattanAG15-25	0.85 (0.18)	0.77 (0.09)	1363 (16.99)	19.48 (4.78)	8.84 (1.6)
ManhattanAG25-45	0.63 (0.08)	0.62 (0.12)	1368 (11.97)	13.55 (2.73)	6.55 (1.41)
ManhattanAG45-70	0.54 (0.15)	0.49 (0.07)	1342 (14.88)	9.75 (0.73)	4.08 (0.53)
ManhattanAG70-100	0.52 (0.2)	0.33 (0.09)	1342 (13.13)	6.56 (0.96)	2.66 (0.51)
ManhattanEA0-5	1.38 (0.13)	3.22 (0.42)	1507 (12.51)	30.65 (4.22)	10.41 (1.22)
ManhattanEA5-10	0.57 (0.08)	2.67 (0.26)	1531 (16.94)	17.36 (0.95)	7.46 (0.42)
ManhattanEA10-15	0.43 (0.13)	1.89 (0.26)	1520 (10.74)	17.3 (8.66)	5.73 (0.61)
ManhattanEA15-25	0.48 (0.17)	1.56 (0.25)	1525 (25.48)	24.15 (9.46)	5.08 (0.59)
ManhattanEA25-50	0.7 (0.09)	1.28 (0.12)	1530 (26.24)	12.69 (3.53)	4.43 (1.32)
ManhattanEA50-75	0.46 (0.05)	0.72 (0.06)	1509 (12.99)	7.88 (1.69)	3.17 (0.75)
ManhattanEA75-100	0.32 (0.09)	0.6 (0.11)	1509 (16.15)	8.02 (1.37)	3.04 (0.74)
ManhattanNP0-5	4.11 (0.66)	8.63 (0.57)	1400 (33.53)	106.61 (22.61)	27.26 (7.51)
ManhattanNP5-10	2.67 (0.27)	5.22 (1.65)	1380 (17.71)	79.36 (8.77)	28.11 (2.64)
ManhattanNP10-15	2.26 (0.61)	3.81 (1.15)	1374 (13.14)	69.34 (9.47)	27.36 (4.97)
ManhattanNP15-30	1.99 (0.28)	2.25 (0.58)	1372 (11.71)	53.65 (10.73)	22.3 (4.46)
ManhattanNP30-60	0.91 (0.19)	1.4 (0.41)	1357 (16.94)	33 (4.25)	12.78 (1.29)
ManhattanNP60-85	0.67 (0.23)	0.35 (0.05)	1338 (12.97)	18.9 (3.92)	6.94 (1.95)
ManhattanNP85-100	0.26 (0.1)	0.25 (0.04)	1331 (17.68)	6.2 (1.01)	2.54 (0.28)

Table C.1. Continued.

Sample Label	Gram (-) Bacteria nmol g^{-1}	Actinomycete nmol g^{-1}	Arbuscular Mycorrhizal Fungi nmol g^{-1}	Saphrophytic fungi nmol g^{-1}	Fungi to Bacteria Ratio nmol g^{-1}
ManhattanAG0-5	5.47 (0.37)	0.59 (0.07)	7.63 (0.48)	0.83 (0.09)	0.47 (0.05)
ManhattanAG5-10	4.32 (1.02)	0.64 (0.07)	6.12 (1.27)	0.47 (0.19)	0.39 (0.05)
ManhattanAG10-15	2.77 (1.21)	0.49 (0.08)	4.56 (1.8)	0.35 (0.21)	0.36 (0.07)
ManhattanAG15-25	1.67 (0.54)	0.45 (0.07)	2.88 (0.75)	0.14 (0.07)	0.28 (0.05)
ManhattanAG25-45	1.12 (0.24)	0.32 (0.1)	2.31 (0.16)	0.1 (0.03)	0.31 (0.05)
ManhattanAG45-70	0.92 (0.17)	0.16 (0.09)	1.86 (0.16)	0.06 (0.02)	0.38 (0.05)
ManhattanAG70-100	0.65 (0.06)	0.09 (0.02)	1.34 (0.5)	0.07 (0.03)	0.41 (0.13)
ManhattanEA0-5	4.13 (0.87)	0.57 (0.11)	5.23 (0.64)	1 (0.4)	0.41 (0.05)
ManhattanEA5-10	1.84 (0.17)	0.35 (0.07)	2.46 (0.24)	0.18 (0.05)	0.27 (0.02)
ManhattanEA10-15	1.14 (0.13)	0.2 (0.03)	1.55 (0.22)	0.12 (0.02)	0.19 (0.09)
ManhattanEA15-25	13.5 (10)	0.24 (0.02)	1.27 (0.08)	0.14 (0.03)	0.1 (0.07)
ManhattanEA25-50	3.16 (4.49)	0.2 (0.04)	0.98 (0.38)	0.07 (0.01)	0.16 (0.07)
ManhattanEA50-75	0.71 (0.13)	0.11 (0.03)	0.63 (0.26)	0.06 (0.03)	0.17 (0.04)
ManhattanEA75-100	0.67 (0.11)	0.12 (0.04)	0.64 (0.18)	0.07 (0.03)	0.18 (0.02)
ManhattanNP0-5	9.19 (1.8)	1.09 (0.39)	13.72 (2.3)	3.23 (0.77)	0.46 (0.04)
ManhattanNP5-10	5.99 (0.85)	1.04 (0.13)	11.29 (0.52)	1.76 (0.18)	0.37 (0.02)
ManhattanNP10-15	4.93 (0.71)	1.03 (0.34)	10 (0.81)	2 (0.27)	0.36 (0.03)
ManhattanNP15-30	3.7 (0.56)	1.03 (0.49)	7.41 (1.4)	1.82 (0.27)	0.34 (0.03)
ManhattanNP30-60	2.8 (0.65)	0.53 (0.14)	4.5 (0.8)	1.09 (0.08)	0.35 (0.02)
ManhattanNP60-85	1.93 (0.54)	0.29 (0.07)	2.58 (0.45)	0.71 (0.16)	0.37 (0.05)
ManhattanNP85-100	0.72 (0.12)	0.11 (0.03)	0.66 (0.24)	0.22 (0.09)	0.26 (0.08)

Table C.1. Continued.

Sample Label	Location	Land Use	Depth cm	Horizon	Texture	Sand %	Silt %	Clay %	Bulk Density g cm^{-3}
HaysAG0-5	Hays	AG	0-5	Ap	Silt loam	19.1	44.8	26	1.44 (0.2)
HaysAG5-10	Hays	AG	5-10	Ap	Silt loam	19.1	44.8	26	1.37 (0.18)
HaysAG10-15	Hays	AG	10-15	Ap	Silt loam	19.1	44.8	26	1.44 (0.2)
HaysAG15-45	Hays	AG	15-45	Bt1	Silty clay loam	8.6	48.4	31	1.44 (0.04)
HaysAG45-65	Hays	AG	45-65	Bt2	Silty clay loam	12.2	48.6	38	1.49 (0.03)
HaysAG65-75	Hays	AG	65-75	Btk1	Silty clay loam	17.4	47.6	31	1.56 (0.17)
HaysAG75-100	Hays	AG	75-100	Btk2	Silt loam	13.8	46.9	26	0.8 (0.12)
HaysEA0-5	Hays	EA	0-5	Ap	Silt loam			24	1.21 (0.08)
HaysEA5-10	Hays	EA	5-10	Ap	Silt loam			24	1.39 (0.07)
HaysEA10-15	Hays	EA	10-15	Ab	Silty clay loam			33	1.39 (0.03)
HaysEA15-45	Hays	EA	15-45	Bt1	Silty clay loam			39	1.36 (0.02)
HaysEA45-65	Hays	EA	45-65	C	Silt loam			25	1.39 (0.05)
HaysEA65-75	Hays	EA	65-75	C	Silt loam			25	1.39 (0.13)
HaysEA75-100	Hays	EA	75-100	C	Silt loam			25	1.29 (0.15)
HaysNP0-5	Hays	NP	0-5	A	Silt loam	14.3	56.9	26	0.99 (0.06)
HaysNP5-10	Hays	NP	5-10	A	Silt loam	14.3	56.9	26	1.22 (0.04)
HaysNP10-15	Hays	NP	10-15	A	Silt loam	14.3	56.9	26	1.18 (0.07)
HaysNP15-40	Hays	NP	15-40	A	Silt loam	14.3	56.9	26	1.21 (0.02)
HaysNP40-60	Hays	NP	40-60	BA	Silty clay loam	13.3	44	30	1.36 (0.05)
HaysNP60-100	Hays	NP	60-100	Bt	Silty clay loam	10.2	51	32	1.41 (0.06)

Table C.1. Continued.

Sample Label	20 minutes MWD mm	20 minute WSA 8-2 mm %	20 minute WSA 2-0.25 mm %	20 minute WSA 0.25-0.053 mm %	20 minute WSA 0.053-0.02 mm %	NRCS Aggregate Stability %
HaysAG0-5	0.29 (0.07)	0.93 (0.66)	11.97 (3.7)	69.8 (4.72)	5.28 (1.12)	8.4 (2.54)
HaysAG5-10	0.3 (0.1)	1.37 (1.25)	12.45 (4.93)	61.04 (4.03)	8.78 (1.37)	6.4 (1.88)
HaysAG10-15	0.54 (0.23)	1.93 (1.19)	32.94 (27.36)	44.04 (23.1)	7.83 (2.52)	17.44 (10.79)
HaysAG15-45	0.67 (0.07)	5.61 (1.45)	27.86 (2.64)	46.69 (3.61)	4.24 (0.98)	33.7 (6.2)
HaysAG45-65	0.63 (0.1)	6.78 (2.05)	19.54 (1.71)	46.64 (5.91)	8.6 (2.8)	18.95 (1.99)
HaysAG65-75	0.37 (0.13)	2.69 (2.28)	11.96 (2.84)	61.89 (7.52)	6.64 (1.93)	10.51 (4.97)
HaysAG75-100	0.2 (0.03)	0.79 (0.51)	5.27 (1.17)	65.08 (5.23)	9.5 (0.86)	4.16 (1.53)
HaysEA0-5	0.79 (0.08)	9.33 (1.27)	22.02 (3.09)	47.94 (6.92)	3.38 (0.98)	33.66 (5.48)
HaysEA5-10	0.62 (0.18)	4.31 (2.26)	29.77 (23.33)	47.55 (21.48)	3.78 (1.23)	7.6 (4.49)
HaysEA10-15	0.43 (0.08)	2.56 (0.41)	18.87 (7.66)	59.99 (8.82)	5.56 (1.93)	7.01 (5.78)
HaysEA15-45	0.53 (0.15)	0.85 (0.82)	37.1 (16.47)	45.48 (14.96)	4.26 (2.24)	21.85 (10.77)
HaysEA45-65	0.59 (0.17)	3.15 (2.8)	31.52 (9.88)	47.97 (12.03)	4.62 (0.97)	15.57 (12.66)
HaysEA65-75	0.41 (0.18)	3.23 (2.37)	13.22 (8.33)	65.41 (6.18)	5.31 (5.25)	5.77 (3.53)
HaysEA75-100	0.3 (0.06)	2.1 (0.89)	8.3 (2.82)	64.08 (4.73)	8.88 (0.85)	2.55 (2.67)
HaysNP0-5	1.89 (0.39)	30.84 (8.13)	28.54 (2.35)	14.91 (4.89)	1.05 (0.54)	79.34 (5.15)
HaysNP5-10	1.7 (0.23)	27.93 (5.61)	22.88 (4.52)	28.36 (3.45)	1.76 (0.91)	67.06 (4.49)
HaysNP10-15	1.51 (0.26)	23.87 (5.28)	23.26 (4)	32.69 (4.02)	2.44 (1.44)	51.53 (8.31)
HaysNP15-40	0.87 (0.07)	10.63 (1.38)	22.81 (3.29)	51.21 (3.1)	2.97 (2.07)	26.44 (3.25)
HaysNP40-60	0.77 (0.15)	5.47 (2.99)	38.7 (23.31)	42.26 (21.64)	2.17 (0.98)	28.56 (4.36)
HaysNP60-100	0.58 (0.11)	5.67 (1.79)	18.33 (5.16)	55.24 (6.9)	4.44 (2.62)	18.03 (7.73)

Table C.1. Continued.

Sample Label	ARS 5 minute MWD mm	5 minute WSA 8-2 mm %	5 minute WSA 2-0.25 mm %	5 minute WSA 0.25-0.053 mm %	5 minute WSA 0.053-0.02 mm %	SOC %
HaysAG0-5	0.46 (0.11)	1.56 (0.65)	27.65 (10.66)	46.22 (6.28)	6.05 (1.41)	1.13 (0.16)
HaysAG5-10	0.44 (0.17)	3.55 (3.16)	16.11 (8.64)	53.84 (10.17)	5.63 (4.2)	0.99 (0.13)
HaysAG10-15	0.99 (0.74)	11.64 (14.92)	32.01 (13.19)	32.27 (16.61)	5.85 (2.21)	0.95 (0.18)
HaysAG15-45	1.62 (0.81)	23.98 (16.93)	34.16 (6.39)	21.96 (12.38)	2.67 (0.88)	0.6 (0.09)
HaysAG45-65						0.59 (0.43)
HaysAG65-75						0.79 (0.19)
HaysAG75-100						0.25 (0.12)
HaysEA0-5	1.64 (0.14)	25.9 (3.82)	26.6 (11.26)	39.82 (0.83)	16.82 (13.6)	2.98 (1.19)
HaysEA5-10	1.04 (0.27)	11 (5.03)	38.09 (12.56)	52.74 (11.71)	11.55 (1.55)	1.45 (0.16)
HaysEA10-15	0.95 (0.08)	7.69 (2.74)	45.46 (11.04)	49.6 (9.08)	10.87 (1.57)	1.23 (0.17)
HaysEA15-45	1.06 (0.14)	9.2 (2.44)	49.01 (2.36)	43.06 (4.87)	10.82 (0.5)	0.83 (0.2)
HaysEA45-65						0.63 (0.4)
HaysEA65-75						0.34 (0.06)
HaysEA75-100						0.32 (0.07)
HaysNP0-5	2.59 (0.33)	44.07 (7.17)	32.57 (2.47)	18.92 (3.8)	8.62 (0.37)	5.79 (1.37)
HaysNP5-10	2.85 (0.53)	47.95 (7.81)	37.44 (13.64)	26 (2.62)	9.02 (0.63)	2.59 (0.18)
HaysNP10-15	2.42 (0.42)	40.5 (10.1)	32.09 (7.26)	26.42 (3.51)	8.93 (0.5)	2.11 (0.16)
HaysNP15-40	1.6 (0.33)	23.78 (6.4)	32.58 (5.94)	42.25 (9.52)	9.83 (0.68)	1.39 (0.12)
HaysNP40-60						0.84 (0.04)
HaysNP60-100						0.61 (0.05)

Table C.1. Continued.

Sample Label	SOC Stock Mg SOC ha^{-1}	TN %	TN Mg TN ha^{-1}	Ca g kg^{-1}	Cu mg kg^{-1}	Mg mg kg^{-1}	Mn mg kg^{-1}
HaysAG0-5	8.08 (1.22)	0.13 (0.01)	0.95 (0.11)	2.63 (0.14)	1.55 (0.06)	466 (43.6)	28.6 (4.53)
HaysAG5-10	6.75 (1.05)	0.13 (0.01)	0.88 (0.16)	2.84 (0.04)	1.45 (0.1)	475 (45.85)	21.88 (1.51)
HaysAG10-15	6.8 (1.48)	0.12 (0.02)	0.88 (0.13)	3.06 (0.31)	1.4 (0.08)	508 (78.04)	18.28 (2.1)
HaysAG15-45	25.8 (3.65)	0.09 (0.02)	3.76 (0.68)	4.62 (0.71)	1.05 (0.13)	532 (75.63)	6.85 (4.48)
HaysAG45-65	17.72 (13.24)	0.06 (0.03)	1.79 (0.91)	5.1 (0.28)	0.93 (0.15)	501 (87)	2 (0.73)
HaysAG65-75	12.24 (3.24)	0.06 (0.01)	0.93 (0.08)	4.87 (0.09)	0.83 (0.1)	457 (14.5)	1.45 (0.21)
HaysAG75-100	4.91 (2.43)	0.04 (0.01)	0.7 (0.3)	4.8 (0.06)	0.88 (0.17)	528 (31.35)	1.45 (0.19)
HaysEA0-5	17.93 (6.96)	0.28 (0.11)	1.67 (0.6)	2.22 (0.03)	1.9 (0.16)	378 (69.67)	48.35 (11.13)
HaysEA5-10	10.06 (0.83)	0.17 (0.03)	1.14 (0.15)	2.45 (0.15)	1.83 (0.1)	396 (34.63)	30.4 (7.56)
HaysEA10-15	8.56 (1.17)	0.14 (0.03)	0.99 (0.15)	2.94 (0.32)	1.65 (0.71)	482 (124.24)	23.25 (5.68)
HaysEA15-45	33.91 (7.85)	0.12 (0.04)	4.69 (1.47)	3.57 (0.19)	1.6 (0.42)	714 (113.36)	11.85 (3.06)
HaysEA45-65	17.68 (11.67)	0.1 (0.04)	2.81 (1.08)	3.92 (0.87)	1.73 (0.46)	752 (161.42)	9.5 (8.87)
HaysEA65-75	4.72 (1.18)	0.07 (0.02)	0.99 (0.33)	4.48 (0.63)	1.88 (0.32)	842 (27.18)	3.95 (1.4)
HaysEA75-100	10.12 (2.47)	0.09 (0.01)	2.75 (0.41)	4.6 (0.31)	1.53 (0.13)	851 (43.21)	2.88 (1.55)
HaysNP0-5	28.58 (6.93)	0.5 (0.09)	2.45 (0.46)	2.89 (0.3)	1.4 (0.16)	320 (41.88)	49.4 (2.02)
HaysNP5-10	15.86 (1.13)	0.28 (0.02)	1.68 (0.15)	2.44 (0.06)	1.5 (0.14)	271 (14.45)	50.05 (1.96)
HaysNP10-15	12.45 (0.86)	0.22 (0.02)	1.31 (0.08)	2.59 (0.05)	1.63 (0.13)	295 (18.82)	44.23 (7.21)
HaysNP15-40	41.93 (3.71)	0.16 (0.01)	4.77 (0.33)	3.15 (0.04)	1.48 (0.17)	401 (30.45)	31.48 (2.26)
HaysNP40-60	22.73 (1.66)	0.11 (0.01)	3.05 (0.31)	3.6 (0.08)	1.53 (0.22)	545 (71.56)	24 (2.9)
HaysNP60-100	34.5 (3.67)	0.08 (0.02)	4.37 (1.09)	4.34 (0.53)	1.5 (0.08)	527 (19.77)	8.23 (1.04)

Table C.1. Continued.

Sample Label	Na mg kg^{-1}	P mg kg^{-1}	K mg kg^{-1}	Zn mg kg^{-1}	Fe mg kg^{-1}	pH	Water Content %
HaysAG0-5	14.98 (2.55)	19.28 (7.29)	565 (36.14)	0.38 (0.05)	35.53 (2.49)	5.75 (0.06)	9.9 (3.32)
HaysAG5-10	13.95 (0.93)	12.08 (6.27)	505 (26.04)	0.3 (0)	31.83 (3.49)	5.93 (0.1)	16.45 (4.07)
HaysAG10-15	16.8 (1.92)	12.35 (8.56)	505 (26.25)	0.3 (0.08)	29.03 (5.06)	6.15 (0.19)	21.09 (4.41)
HaysAG15-45	23.45 (2.22)	1.6 (1.43)	429 (12.15)	0.1 (0)	16.88 (3.67)	7.43 (0.43)	21.42 (0.96)
HaysAG45-65	23.03 (5.36)	5.58 (5.99)	372 (38.12)	0.1 (0)	11.78 (1.8)	7.98 (0.19)	19.7 (1.49)
HaysAG65-75	20.13 (1.72)	12.83 (6.55)	315 (14.14)	0.1 (0)	9.65 (0.45)	8.23 (0.05)	16.68 (0.68)
HaysAG75-100	21.95 (2.9)	20.2 (6.28)	330 (26.02)	0.05 (0.06)	9.78 (0.26)	8.2 (0)	15.64 (0.35)
HaysEA0-5	12.25 (2.22)	71.03 (30.34)	706 (99.24)	3.95 (2.4)	55.5 (15.28)	5.85 (0.29)	11.51 (2.42)
HaysEA5-10	15.25 (1.89)	68.33 (25.8)	669 (74.74)	1.9 (0.63)	35.75 (12.84)	6.45 (0.37)	19.8 (3.82)
HaysEA10-15	16.75 (7.41)	26.85 (17.02)	625 (31.15)	0.63 (0.19)	20.1 (7.37)	6.9 (0.29)	22.59 (3.14)
HaysEA15-45	34.5 (15.95)	4.25 (1.31)	465 (18.84)	0.25 (0.06)	11.15 (1.55)	7.33 (0.17)	26.54 (0.38)
HaysEA45-65	56.75 (40.66)	16.83 (13.99)	440 (97.63)	0.28 (0.24)	11.05 (7.36)	7.65 (0.7)	26.07 (1.39)
HaysEA65-75	94.5 (61.69)	22.53 (4.44)	412 (47.99)	0.6 (0.24)	6.38 (1.24)	8.08 (0.19)	24.55 (0.94)
HaysEA75-100	147.75 (112.33)	32.33 (9.85)	430 (52.08)	0.35 (0.13)	4.78 (1.87)	8.25 (0.24)	25.15 (1.83)
HaysNP0-5	8.5 (0.58)	10.93 (4.57)	614 (44.59)	5.5 (2.2)	48.1 (8.35)	6.28 (0.19)	13.4 (0.73)
HaysNP5-10	11 (2.94)	4.13 (0.5)	501 (17.78)	1.38 (0.68)	39.1 (1.79)	6.35 (0.1)	13.36 (0.97)
HaysNP10-15	8.75 (0.5)	3.75 (1.58)	499 (36.21)	0.58 (0.15)	30.5 (1.49)	6.53 (0.15)	13.68 (0.89)
HaysNP15-40	16 (1.63)	2.55 (0.19)	490 (37.78)	0.3 (0)	17.08 (1.82)	7.05 (0.06)	18.14 (1.5)
HaysNP40-60	33.5 (6.19)	2.35 (0.17)	468 (65.23)	0.23 (0.05)	12.23 (1.02)	7.43 (0.05)	21.07 (2.85)
HaysNP60-100	66.5 (18.36)	10.65 (4.46)	372 (30.16)	0.3 (0)	7.8 (0.75)	7.9 (0.12)	18.26 (3.64)

Table C.1. Continued.

Sample Label	B-Glucosidase mg kg^{-1} hr^{-1}	N-acetyl-β-D-Glucosaminidase mg kg^{-1} hr^{-1}	Acid Phosphatase mg kg^{-1} hr^{-1}	Alkaline Phosphatase mg kg-1 hr^{-1}	Phosphodiesterase mg kg^{-1} hr^{-1}	Arylsulfatase mg kg^{-1} hr^{-1}
HaysAG0-5	15.19 (2.35)	5.69 (1.31)	51.09 (10.07)	12.94 (1.08)	9.63 (1.97)	2.86 (0.77)
HaysAG5-10	15.67 (3.51)	5.4 (2.1)	54.09 (9.06)	11.9 (2.3)	8.34 (2.8)	3.47 (0.83)
HaysAG10-15	9.55 (3.5)	3.16 (0.85)	39.07 (14.5)	15.01 (2.89)	7.55 (1.93)	3.74 (0.35)
HaysAG15-45	3.15 (1.18)	1.81 (0.71)	6.84 (8.58)	35.6 (9.96)	10.61 (3.15)	3.82 (1.36)
HaysAG45-65	1.17 (0.12)	0.73 (0.2)	3.14 (1)	12.21 (2.29)	3.99 (1.02)	2.31 (0.53)
HaysAG65-75	0.5 (0.24)	0.45 (0.23)	2.03 (1.04)	5.43 (3.19)	1.96 (1.46)	1.43 (0.5)
HaysAG75-100	0.22 (0.21)	0.07 (0.14)	1.63 (0.4)	2.81 (1.53)	0.63 (0.49)	0.84 (0.48)
HaysEA0-5	59.39 (15.33)	14.1 (3.65)	150.85 (37.3)	56.08 (25.08)	23.41 (6.27)	13.01 (3.54)
HaysEA5-10	15.3 (5.49)	4.87 (1.59)	61.56 (3.35)	15.41 (10.36)	11.5 (4.58)	6.73 (2.05)
HaysEA10-15	14.03 (2.16)	3.86 (0.18)	60.9 (6.19)	24.21 (5.8)	17.68 (5.73)	7.37 (0.86)
HaysEA15-45	5.34 (1.6)	1.85 (0.45)	34.47 (8.32)	37.13 (0.95)	17.52 (4.49)	4.34 (1.1)
HaysEA45-65	1.69 (1.17)	1 (0.53)	5.02 (3.2)	11.16 (6.96)	6.59 (3.91)	1.84 (0.69)
HaysEA65-75	0.67 (0.59)	0.41 (0.3)	3 (1.2)	7.59 (4.51)	2.57 (2)	1.45 (0.48)
HaysEA75-100	0.49 (0.56)	0.43 (0.24)	2.53 (0.82)	4.68 (1.54)	1.4 (0.64)	1.77 (0.46)
HaysNP0-5	45.89 (2.36)	20.15 (0.88)	344.75 (12.07)	94.05 (6.61)	58.59 (4.72)	39.7 (3.39)
HaysNP5-10	22.49 (3.11)	10.64 (1.44)	200.03 (11.25)	46.38 (5.97)	37.26 (4.83)	33.15 (4.51)
HaysNP10-15	17.84 (1.06)	8.96 (1.28)	152.68 (19.03)	46.13 (4.1)	34.29 (3.57)	29.47 (2.2)
HaysNP15-40	12.71 (0.99)	6.75 (0.26)	66.87 (7.46)	42.52 (5.54)	34 (1.63)	14.33 (0.96)
HaysNP40-60	5.1 (0.35)	4.62 (0.15)	10.22 (6.86)	33.71 (1.82)	18.37 (0.76)	5.8 (0.87)
HaysNP60-100	1.7 (0.19)	1.47 (0.34)	6.22 (2.2)	14.57 (3.25)	7.67 (2.14)	2.8 (0.78)

Table C.1. Continued.

Sample Label	CO_2 Respiration mg CO2 g soil^{-1}	ACE Protein Content mg protein g soil^{-1}	POXC mg reactive C kg soil^{-1}	Total Microbial Biomass nmol g^{-1}	Gram (+) Bacteria nmol g^{-1}
HaysAG0-5	1.17 (0.11)	2.31 (0.24)	1488 (4.78)	30.47 (6.65)	9.15 (2.01)
HaysAG5-10	0.71 (0.31)	2.22 (0.37)	1491 (16.92)	15.5 (3.77)	5.63 (1.22)
HaysAG10-15	0.27 (0.04)	1.78 (0.46)	1503 (11.08)	11.75 (1.66)	4.28 (0.64)
HaysAG15-45	0.27 (0.08)	1.11 (0.27)	1509 (15.67)	4.75 (0.95)	1.36 (0.36)
HaysAG45-65	0.17 (0.02)	1.17 (0.26)	1492 (5.54)	3 (1.72)	0.81 (0.74)
HaysAG65-75	0.12 (0.02)	0.19 (0.18)	1479 (7.37)	1.34 (0.19)	0.19 (0.05)
HaysAG75-100	0.1 (0.02)	0.11 (0.15)	1470 (3.18)	1.43 (0.44)	0.21 (0.14)
HaysEA0-5	3.16 (0.89)	8.84 (2.2)	1463 (15.05)	39.75 (6.92)	15.14 (2.15)
HaysEA5-10	1.5 (0.61)	2.52 (1.06)	1453 (20.12)	26.23 (7.01)	10.7 (2.4)
HaysEA10-15	1.04 (0.17)	1.66 (0.5)	1472 (10.52)	23.94 (12.15)	8.47 (1.7)
HaysEA15-45	0.88 (0.12)	0.92 (0.27)	1472 (16.47)	10.62 (3.38)	4.68 (1.9)
HaysEA45-65	0.65 (0.14)	0.41 (0.36)	1478 (13.08)	6.96 (1.21)	2.64 (0.46)
HaysEA65-75	0.56 (0.17)	0.36 (0.27)	1473 (12.93)	5.43 (0.49)	2.44 (0.5)
HaysEA75-100	0.58 (0.04)	0.26 (0.3)	1464 (14.79)	5.11 (0.52)	2.15 (0.13)
HaysNP0-5	7.15 (2.5)	5.88 (0.29)	1468 (20.44)	102.97 (12.37)	30.97 (3.45)
HaysNP5-10	2.91 (0.18)	3.76 (0.19)	1460 (11.89)	51.78 (6.37)	19.92 (2.3)
HaysNP10-15	2.39 (0.18)	3.27 (0.33)	1464 (7.98)	41.48 (6.91)	17.41 (3.54)
HaysNP15-40	1.45 (0.04)	1.37 (0.15)	1481 (3.89)	31.47 (1.38)	14.42 (0.6)
HaysNP40-60	1.18 (0.02)	0.5 (0.13)	1477 (23.75)	18.25 (2.63)	8.06 (1.44)
HaysNP60-100	0.92 (0.22)	0.65 (0.47)	1442 (22.16)	10.7 (2.26)	3.62 (0.78)

Table C.1. Continued.

Sample Label	Gram (-) Bacteria nmol g^{-1}	Actinomycete nmol g^{-1}	Arbuscular Mycorrhizal Fungi nmol g^{-1}	Saphrophytic fungi nmol g^{-1}	Fungi to Bacteria Ratio nmol g^{-1}
HaysAG0-5	3.4 (0.79)	1.59 (0.26)	4.81 (0.95)	1.83 (0.6)	0.47 (0.05)
HaysAG5-10	1.34 (0.36)	1.37 (0.34)	1.76 (0.62)	0.31 (0.23)	0.24 (0.05)
HaysAG10-15	0.94 (0.13)	1.18 (0.1)	1.13 (0.24)	0.14 (0.03)	0.2 (0.02)
HaysAG15-45	0.5 (0.04)	0.41 (0.04)	0.3 (0.08)	0.05 (0.01)	0.16 (0.02)
HaysAG45-65	0.37 (0.08)	0.21 (0.11)	0.17 (0.15)	0.04 (0.02)	0.14 (0.03)
HaysAG65-75	0.35 (0.06)	0.08 (0.04)	0.05 (0.02)	0.01 (0)	0.1 (0.04)
HaysAG75-100	0.38 (0.07)	0.04 (0.02)	0.07 (0.06)	0.01 (0)	0.13 (0.07)
HaysEA0-5	3.81 (0.71)	0.54 (0.03)	6.13 (1.13)	0.09 (0.02)	0.32 (0.02)
HaysEA5-10	2.77 (0.75)	0.46 (0.07)	3.81 (1.18)	0.06 (0.02)	0.27 (0.03)
HaysEA10-15	1.94 (0.42)	0.37 (0.18)	2.53 (0.44)	0.09 (0.09)	0.21 (0.08)
HaysEA15-45	0.99 (0.25)	0.16 (0.05)	1.04 (0.35)	0.05 (0.05)	0.19 (0.01)
HaysEA45-65	0.7 (0.2)	0.09 (0.03)	0.69 (0.17)	0.02 (0.01)	0.2 (0.02)
HaysEA65-75	0.45 (0.04)	0.05 (0.01)	0.38 (0.05)	0.01 (0)	0.13 (0.04)
HaysEA75-100	0.49 (0.09)	0.05 (0.01)	0.27 (0.03)	0.07 (0.08)	0.12 (0.03)
HaysNP0-5	9.14 (0.77)	1.34 (0.55)	14.16 (1.3)	2.23 (0.8)	0.4 (0.03)
HaysNP5-10	4.72 (0.39)	0.93 (0.1)	7.58 (0.98)	0.9 (0.33)	0.33 (0.02)
HaysNP10-15	3.79 (0.7)	0.59 (0.11)	5.73 (0.8)	0.66 (0.22)	0.3 (0.03)
HaysNP15-40	2.88 (0.17)	0.47 (0.09)	3.87 (0.26)	0.56 (0.13)	0.25 (0.01)
HaysNP40-60	1.73 (0.22)	0.36 (0.08)	2.65 (0.25)	0.32 (0.07)	0.29 (0.03)
HaysNP60-100	0.97 (0.17)	0.16 (0.05)	1.73 (0.43)	0.18 (0.06)	0.41 (0.08)

Table C.1. Continued.

Sample Label	Location	Land Use	Depth cm	Horizon	Texture	Sand %	Silt %	Clay %	Bulk Density g cm^{-3}
TribuneAG0-5	Tribune	AG	0-5	Ap	Silt loam			22	1.23 (0.16)
TribuneAG5-10	Tribune	AG	5-10	Ap	Silt loam			22	1.12 (0.28)
TribuneAG10-15	Tribune	AG	10-15	Ab	Silt loam			25	1.26 (0.11)
TribuneAG15-40	Tribune	AG	15-40	Bt1	Silty clay loam			32	1.17 (0.08)
TribuneAG40-75	Tribune	AG	40-75	Bt2	Silty clay loam			34	1.24 (0.09)
TribuneAG75-100	Tribune	AG	75-100	Btk1	Silty clay loam			32	1.28 (0.1)
TribuneEA0-5	Tribune	EA	0-5	Ap	Silt loam			22	1.22 (0.16)
TribuneEA5-10	Tribune	EA	5-10	Ap	Silt loam			22	1.2 (0.18)
TribuneEA10-15	Tribune	EA	10-15	Ab	Silt loam			25	1.26 (0.11)
TribuneEA15-40	Tribune	EA	15-40	Bt1	Silty clay loam			32	1.17 (0.08)
TribuneEA40-75	Tribune	EA	40-75	Bt2	Silty clay loam			34	1.24 (0.09)
TribuneEA75-100	Tribune	EA	75-100	Btk1	Silty clay loam			32	1.28 (0.1)
TribuneIR0-5	Tribune	IR	0-5	Ap	Silt loam			26	
TribuneIR5-10	Tribune	IR	5-10	Ap	Silt loam			26	
TribuneIR10-15	Tribune	IR	10-15	Ap	Silt loam			26	
TribuneIR15-30	Tribune	IR	15-30	Bt	Silty clay loam			33	
TribuneIR30-50	Tribune	IR	30-50	Btk	Silty clay loam			28	
TribuneIR50-85	Tribune	IR	50-85	Bk1	Silt loam			26	
TribuneIR85-100	Tribune	IR	85-100	Bk2	Silt loam			25	
TribuneNP0-5	Tribune	NP	0-5	Ap	Silt loam			22	1.03 (0.11)
TribuneNP5-10	Tribune	NP	5-10	Ap	Silt loam			22	1.03 (0.13)
TribuneNP10-15	Tribune	NP	10-15	Ab	Silt loam			25	1.13 (0.12)
TribuneNP15-40	Tribune	NP	15-40	Bt1	Silty clay loam			32	1.12 (0.12)
TribuneNP40-75	Tribune	NP	40-75	Bt2	Silty clay loam			34	1.3 (0.09)
TribuneNP75-100	Tribune	NP	75-100	Btk1	Silt loam			32	1.26 (0.08)

Table C.1. Continued.

Sample Label	20 minutes MWD mm	20 minute WSA 8-2 mm %	20 minute WSA 2-0.25 mm %	20 minute WSA 0.25-0.053 mm %	20 minute WSA 0.053-0.02 mm %	NRCS Aggregate Stability %
TribuneAG0-5	0.68 (0.34)	8.73 (6.52)	14.45 (2.76)	53.07 (10.76)	6.16 (2.98)	8.55 (3.29)
TribuneAG5-10	0.77 (0.15)	7.16 (4.22)	31.38 (10.56)	40.25 (7.98)	4.11 (0.76)	5.72 (2.92)
TribuneAG10-15	0.74 (0.19)	7.34 (4.06)	27.33 (3.94)	43.86 (7.48)	4.41 (2.51)	4.16 (2)
TribuneAG15-40	0.38 (0.1)	1.79 (1.3)	18.88 (4.9)	53.44 (7.78)	4.66 (1.58)	15.96 (14.44)
TribuneAG40-75	0.44 (0.1)	3.8 (1.12)	15.14 (5.55)	54.04 (4.43)	5.41 (0.56)	12.47 (5.19)
TribuneAG75-100	0.27 (0.08)	1.74 (1.45)	7.56 (1.63)	60.23 (9.12)	8.31 (1)	3.68 (1.25)
TribuneEA0-5	0.7 (0.08)	8.84 (1.92)	16.28 (7.83)	49.13 (7.88)	3.99 (2.02)	18.06 (13.67)
TribuneEA5-10	0.39 (0.09)	2.3 (1.14)	15.89 (4.57)	60.54 (6.68)	5.41 (2.38)	3.69 (2.03)
TribuneEA10-15	0.41 (0.11)	3.06 (1.67)	15.88 (4.27)	51.13 (10.03)	8.42 (4.1)	4.31 (1.75)
TribuneEA15-40	0.52 (0.22)	4.39 (4.11)	20.38 (7.11)	46.41 (12.85)	5.47 (1.86)	11 (3.03)
TribuneEA40-75	0.54 (0.29)	5.28 (3.54)	18.16 (11.75)	44.18 (19.05)	14.69 (11.82)	6.87 (1.75)
TribuneEA75-100	0.24 (0.04)	1.2 (0.67)	6.67 (0.97)	71.22 (4.28)	5.67 (1.16)	2.22 (0.59)
TribuneIR0-5	0.63 (0.25)	4.78 (2.23)	30.8 (14.32)	40.32 (14)	2.57 (0.57)	
TribuneIR5-10	0.52 (0.11)	5.48 (1.91)	16.72 (2.86)	55.64 (5.71)	4.95 (0.78)	
TribuneIR10-15	0.42 (0.19)	4.59 (3.12)	11.41 (7.77)	61.74 (10.4)	5.79 (1.51)	
TribuneIR15-30	0.2 (0.08)	0.99 (0.78)	7.36 (4.31)	68.23 (5.8)	6.6 (0.86)	
TribuneIR30-50	0.29 (0.14)	0.89 (0.17)	16.37 (13.13)	61.86 (15.78)	5.49 (2.78)	
TribuneIR50-85	0.39 (0.07)	1.24 (0.49)	23.82 (7.42)	56.26 (8.65)	4.32 (0.38)	
TribuneIR85-100	0.33 (0.06)	1.34 (0.23)	17.86 (5.06)	56.96 (5.52)	6.18 (0.89)	
TribuneNP0-5	1.64 (0.64)	26.33 (13.53)	25.61 (4.31)	22.3 (7.33)	1.95 (0.71)	63.97 (5.33)
TribuneNP5-10	1.41 (0.38)	19.87 (6.81)	33.76 (6.66)	24.34 (9.43)	2.18 (1.58)	35.75 (12.13)
TribuneNP10-15	1.7 (0.27)	26.3 (4.84)	31.52 (5.79)	20.87 (9.65)	1.62 (0.36)	19.99 (10.77)
TribuneNP15-40	1.7 (0.21)	25.62 (5.11)	34.52 (6.58)	19.97 (5.4)	1.36 (0.84)	43.49 (14.2)
TribuneNP40-75	1.25 (0.32)	17.92 (6.34)	26.65 (3.85)	34.13 (5.54)	2.74 (1.33)	27.34 (13.11)
TribuneNP75-100	1.08 (0.31)	12.63 (8.61)	35.93 (12.02)	31.33 (8.4)	2.75 (1.46)	9.5 (3.69)

Table C.1. Continued.

Sample Label	ARS 5 minute MWD mm	5 minute WSA 8-2 mm %	5 minute WSA 2-0.25 mm %	5 minute WSA 0.25-0.053 mm %	5 minute WSA 0.053-0.02 mm %	SOC %
TribuneAG0-5	0.5 (0.21)	6.62 (3.75)	9.93 (3.77)	51.28 (9.89)	6.82 (3.05)	1.81 (0.13)
TribuneAG5-10	0.6 (0.1)	7.36 (2.07)	15.93 (3.65)	48.79 (7.85)	7.58 (2.46)	1.67 (0.15)
TribuneAG10-15	0.61 (0.34)	6.61 (8.86)	19.6 (11.68)	54.06 (15.05)	5.56 (0.86)	1.33 (0.07)
TribuneAG15-40	0.82 (0.3)	5.57 (5.2)	45.64 (6.85)	30.9 (11.77)	2.84 (0.73)	0.86 (0.15)
TribuneAG40-75						1.15 (0.36)
TribuneAG75-100						1.54 (0.39)
TribuneEA0-5	0.87 (0.34)	10.19 (4.94)	29.02 (10.62)	35.12 (16.63)	4.97 (1.94)	2.44 (0.91)
TribuneEA5-10	0.45 (0.11)	3.99 (2.11)	17.13 (6.81)	56.27 (12.02)	6.5 (1.69)	1.42 (0.26)
TribuneEA10-15	0.74 (0.13)	6.57 (0.84)	32.72 (14.7)	41.1 (12.43)	5.68 (1.77)	1.3 (0.22)
TribuneEA15-40	0.82 (0.49)	9.79 (9.87)	25.73 (7)	36.52 (17.95)	2.86 (1.73)	1.01 (0.04)
TribuneEA40-75						1.15 (0.63)
TribuneEA75-100						1.54 (0.47)
TribuneIR0-5						2.08 (0.36)
TribuneIR5-10						0.94 (0.08)
TribuneIR10-15						0.61 (0.04)
TribuneIR15-30						0.54 (0.11)
TribuneIR30-50						0.39 (0.03)
TribuneIR50-85						0.47 (0.16)
TribuneIR85-100						0.46 (0.17)
TribuneNP0-5	0.77 (0.09)	8.82 (1.59)	27.01 (8.12)	23.41 (9.41)	5.26 (2.77)	3.94 (0.29)
TribuneNP5-10	0.82 (0.05)	7.78 (1.07)	36 (4.84)	28.54 (8.99)	4.9 (0.8)	2.52 (0.35)
TribuneNP10-15	0.97 (0.3)	14.58 (4.72)	18.03 (6.18)	33.01 (3.53)	5.09 (0.49)	1.76 (0.13)
TribuneNP15-40	1.45 (0.36)	21.63 (7.84)	30.4 (4.26)	24.66 (7.19)	3.44 (1.41)	1.24 (0.1)
TribuneNP40-75						1.37 (0.54)
TribuneNP75-100						1.75 (0.47)

Table C.1. Continued.

Sample Label	SOC Stock Mg SOC ha^{-1}	TN %	TN Mg TN ha^{-1}	Ca g kg^{-1}	Cu mg kg^{-1}	Mg mg kg^{-1}	Mn mg kg^{-1}
TribuneAG0-5	11.03 (1.23)	0.19 (0.01)	1.13 (0.09)	1.45 (0.36)	1.3 (0)	259 (43.06)	71.43 (30.77)
TribuneAG5-10	9.37 (2.76)	0.17 (0.02)	0.92 (0.26)	1.61 (0.42)	1.4 (0.08)	253 (38.76)	53.43 (14.98)
TribuneAG10-15	8.37 (0.77)	0.14 (0.01)	0.89 (0.11)	2.6 (1.11)	1.03 (0.13)	311 (41.69)	24.58 (12.96)
TribuneAG15-40	25.19 (4.97)	0.11 (0.02)	3.24 (0.8)	3.51 (0.34)	0.83 (0.22)	385 (47.23)	6.23 (1.61)
TribuneAG40-75	49.71 (17.1)	0.11 (0.01)	4.55 (0.57)	4.69 (0.2)	0.85 (0.1)	511 (41.84)	3.25 (0.62)
TribuneAG75-100	48.67 (10.28)	0.07 (0.01)	2.24 (0.25)	4.57 (0.16)	0.68 (0.1)	654 (68.93)	2.28 (0.29)
TribuneEA0-5	15.23 (6.82)	0.24 (0.06)	1.48 (0.5)	1.55 (0.32)	1.48 (0.17)	285 (16.99)	68.4 (24.08)
TribuneEA5-10	8.53 (2.2)	0.15 (0.02)	0.9 (0.19)	1.7 (0.39)	1.33 (0.34)	261 (11.56)	46.73 (18.33)
TribuneEA10-15	8.28 (1.95)	0.15 (0.01)	0.92 (0.13)	2.12 (0.28)	1.13 (0.4)	275 (19.98)	31.83 (16.46)
TribuneEA15-40	29.58 (1.67)	0.13 (0.01)	3.66 (0.39)	3.48 (0.67)	0.73 (0.1)	379 (32.16)	12.83 (5.27)
TribuneEA40-75	49.45 (28.1)	0.1 (0.01)	4.11 (0.37)	4.24 (0.78)	0.9 (0.18)	479 (66.97)	5.65 (2.72)
TribuneEA75-100	49.12 (14.43)	0.08 (0.01)	2.56 (0.19)	4.72 (0.1)	0.85 (0.06)	585 (72.01)	2.78 (0.68)
TribuneIR0-5		0.22 (0.02)		2.83 (0.08)	4.13 (0.76)	586 (19.32)	7.55 (2.81)
TribuneIR5-10		0.16 (0.02)		5.79 (0.04)	3.4 (0.86)	621 (19.31)	3.43 (1.51)
TribuneIR10-15		0.11 (0.03)		5.8 (0.04)	2.7 (0.53)	605 (16.43)	1.35 (0.06)
TribuneIR15-30		0.08 (0.02)		5.6 (0.14)	2.4 (0.42)	731 (39.53)	1.5 (0.29)
TribuneIR30-50		0.07 (0.02)		5.08 (0.11)	2.23 (0.31)	954 (12.4)	1.28 (0.15)
TribuneIR50-85		0.07 (0)		4.78 (0.05)	1.85 (0.48)	920 (16.78)	0.78 (0.1)
TribuneIR85-100		0.1 (0.03)		4.81 (0.04)	1.63 (0.15)	807 (42.28)	0.78 (0.1)
TribuneNP0-5	20.39 (3.4)	0.35 (0.02)	1.79 (0.29)	2.13 (0.29)	1.05 (0.1)	378 (52.05)	38.9 (2.93)
TribuneNP5-10	12.93 (1.77)	0.24 (0.03)	1.23 (0.17)	2.23 (0.18)	0.98 (0.05)	355 (32.9)	28.05 (5.87)
TribuneNP10-15	9.91 (0.9)	0.18 (0.02)	0.98 (0.11)	2.38 (0.26)	0.83 (0.1)	299 (21.59)	19.55 (3.87)
TribuneNP15-40	34.66 (5.28)	0.15 (0.01)	4.06 (0.51)	3.04 (0.48)	1 (0.36)	357 (30.9)	10.73 (4.03)
TribuneNP40-75	61.25 (21.67)	0.11 (0.01)	4.89 (0.24)	4.31 (0.81)	0.93 (0.15)	552 (51.82)	4.05 (2.32)
TribuneNP75-100	54.41 (12.33)	0.08 (0.02)	2.63 (0.83)	4.54 (0.16)	0.73 (0.05)	719 (117.3)	2.28 (0.42)

Table C.1. Continued.

Sample Label	Na mg kg^{-1}	P mg kg^{-1}	K mg kg^{-1}	Zn mg kg^{-1}	Fe mg kg^{-1}	pH	Water Content %
TribuneAG0-5	3.05 (1.21)	153.33 (17.27)	1005 (47.99)	1.25 (0.1)	49.83 (16)	5.3 (0.54)	7.99 (1.8)
TribuneAG5-10	3.93 (2.2)	138.4 (14.09)	847 (78.11)	1.25 (0.3)	47.73 (15.18)	5.6 (0.67)	19.81 (2.9)
TribuneAG10-15	9.93 (5.5)	84.58 (26.77)	746 (111.32)	0.55 (0.25)	24.25 (13.11)	6.6 (0.88)	24.15 (2.06)
TribuneAG15-40	15.48 (3.57)	18.63 (6.75)	480 (39.59)	0.13 (0.05)	8.68 (2.42)	7.8 (0.14)	20.42 (0.9)
TribuneAG40-75	20.25 (6.32)	32.88 (6.53)	517 (49.29)	0.08 (0.05)	5.15 (1.49)	8.1 (0.12)	18.68 (2.07)
TribuneAG75-100	19.7 (13.5)	34.18 (11.94)	676 (103.66)	0.03 (0.05)	4.35 (0.99)	8.18 (0.05)	18.16 (3.52)
TribuneEA0-5	5.15 (1.1)	155.08 (19.64)	1092 (152.71)	1.68 (0.41)	55.33 (18.8)	5.18 (0.59)	18.48 (8.24)
TribuneEA5-10	6.18 (3.13)	131.9 (26.45)	846 (182.63)	1.13 (0.25)	42.1 (21.85)	5.83 (0.83)	22.68 (1.84)
TribuneEA10-15	4.43 (1)	86.18 (24.34)	741 (147.36)	0.73 (0.5)	26.2 (13.77)	6.6 (0.72)	24.13 (1.98)
TribuneEA15-40	11.05 (4.74)	29.63 (18.61)	520 (26.13)	0.15 (0.1)	9.55 (3.35)	7.65 (0.31)	21.96 (0.84)
TribuneEA40-75	8.73 (1.36)	34.85 (19.34)	462 (29.49)	0.1 (0)	6.2 (2.74)	7.95 (0.3)	21.17 (0.98)
TribuneEA75-100	9.03 (1.27)	37.25 (9.47)	598 (27.46)	0.08 (0.05)	4.38 (1.31)	8.28 (0.13)	21.36 (1.78)
TribuneIR0-5	51.78 (5.37)	41.58 (21.97)	813 (18.75)	2.15 (0.51)	5.53 (1.82)	7.46 (0.25)	22.12 (2.21)
TribuneIR5-10	53.28 (3.01)	5.8 (1.14)	545 (66.54)	0.58 (0.17)	4.85 (3.54)	8.05 (0.19)	19.66 (0.98)
TribuneIR10-15	65.65 (5.77)	8.55 (0.72)	297 (12.26)	0.43 (0.1)	1.55 (0.17)	8.45 (0.07)	17.89 (0.25)
TribuneIR15-30	92.6 (5.76)	6.1 (0.39)	418 (54.85)	0.4 (0.08)	2.13 (0.69)	8.42 (0.09)	16.23 (0.28)
TribuneIR30-50	108.9 (3.6)	5.38 (0.42)	768 (33.03)	0.4 (0.08)	2.25 (0.06)	8.44 (0.05)	14.45 (0.63)
TribuneIR50-85	137.75 (2.28)	6.53 (1.05)	992 (4.36)	0.33 (0.13)	2.3 (0.08)	8.47 (0.08)	13.41 (1.88)
TribuneIR85-100	155.33 (3.26)	11.93 (2.27)	906 (42.02)	0.3 (0)	2.13 (0.17)	8.35 (0.07)	14.54 (0.3)
TribuneNP0-5	6.3 (0.92)	92.65 (1.76)	827 (122.95)	3.78 (0.62)	42.7 (7.63)	6.05 (0.1)	23.09 (5.01)
TribuneNP5-10	7.63 (4.24)	76.6 (9.98)	764 (117.95)	1.75 (0.59)	30.98 (6.66)	6.25 (0.21)	20.33 (2.05)
TribuneNP10-15	5.55 (1.98)	61.78 (15.72)	630 (76.46)	0.78 (0.21)	19.15 (4.62)	7 (0.35)	17.84 (2.94)
TribuneNP15-40	10.4 (1.59)	24.28 (17.28)	464 (57.8)	0.15 (0.06)	9.75 (2.47)	7.65 (0.13)	10.28 (1.92)
TribuneNP40-75	16.43 (2.81)	35.68 (9.36)	572 (41.05)	0.1 (0.08)	6.28 (2.23)	8.05 (0.33)	11.25 (0.96)
TribuneNP75-100	21.83 (8.98)	35.1 (11.37)	736 (58.56)	0.1 (0)	4.38 (0.61)	8.28 (0.05)	11.04 (1.82)

Table C.1. Continued.

Sample Label	B-Glucosidase mg kg^{-1} hr^{-1}	N-acetyl-β-D-Glucosaminidase mg kg^{-1} hr^{-1}	Acid Phosphatase mg kg^{-1} hr^{-1}	Alkaline Phosphatase mg kg^{-1} hr^{-1}	Phosphodiesterase mg kg^{-1} hr^{-1}	Arylsulfatase mg kg^{-1} hr^{-1}
TribuneAG0-5	12.7 (8.36)	8.53 (1.11)	72.5 (15.45)	11.83 (3.51)	9.43 (4.77)	0.83 (0.88)
TribuneAG5-10	10.68 (3.78)	6.97 (1.64)	75.83 (11.89)	8.84 (2.41)	9.32 (3.13)	1.65 (1.1)
TribuneAG10-15	7.39 (2.56)	3.59 (0.56)	63.53 (25.95)	26 (13.43)	13.82 (4.87)	7.05 (2.91)
TribuneAG15-40	2.75 (1.17)	1.96 (0.37)	25.18 (6.52)	40.05 (21.88)	14.94 (4.81)	7.62 (4.12)
TribuneAG40-75	2.09 (0.27)	1 (0.3)	6.14 (1.32)	32.6 (7.19)	7.92 (1.54)	7.36 (2.46)
TribuneAG75-100	1.23 (0.55)	0.76 (0.1)	3.24 (0.99)	9.3 (3.52)	2.82 (0.79)	3.32 (1.2)
TribuneEA0-5	16.86 (11.11)	11.22 (8.04)	76.89 (42.03)	18.2 (11.04)	10.81 (5.45)	2.47 (2.24)
TribuneEA5-10	20.7 (16.73)	4.24 (3.12)	52.64 (19.81)	14.07 (10.29)	8.57 (2.96)	3.98 (2.68)
TribuneEA10-15	5 (1.19)	2.47 (0.32)	62.59 (10.88)	24.34 (7.24)	12.84 (3.66)	7.87 (1.68)
TribuneEA15-40	3.36 (0.76)	2.46 (0.72)	32.32 (12.55)	42.37 (13.31)	17.89 (2.18)	8.16 (1.22)
TribuneEA40-75	2.41 (0.2)	1.53 (0.32)	8.68 (4.45)	32.51 (4.35)	12.8 (2.64)	4.65 (0.57)
TribuneEA75-100	1.23 (0.31)	0.71 (0.41)	2.31 (0.38)	8.24 (0.93)	3.68 (0.68)	1.51 (0.94)
TribuneIR0-5	48.96 (9.64)	8.08 (1.88)	41.44 (7.84)	68.99 (9.59)	36.51 (2.51)	23.04 (2.1)
TribuneIR5-10	2.19 (0.32)	1.59 (0.34)	9.54 (1.06)	32.32 (5.6)	11.08 (1.65)	10.63 (2.39)
TribuneIR10-15	1.58 (0.07)	0.84 (0.17)	2.9 (0.84)	18.09 (4.36)	5.78 (1.22)	8.18 (0.92)
TribuneIR15-30	0.76 (0.42)	0.48 (0.1)	1.55 (0.21)	6.63 (0.6)	2.55 (0.37)	4.15 (0.3)
TribuneIR30-50	0.46 (0.08)	0.45 (0.14)	1.16 (0.22)	4.64 (0.81)	1.61 (0.28)	2.5 (0.36)
TribuneIR50-85	0.45 (0.16)	0.25 (0.08)	0.58 (0.33)	2.45 (0.26)	0.92 (0.15)	1.03 (0.39)
TribuneIR85-100	0.29 (0.32)	0.28 (0.17)	0.18 (0.27)	1.92 (0.21)	0.74 (0.32)	0.62 (0.1)
TribuneNP0-5	26.8 (2.28)	16.37 (2.72)	179.82 (9.24)	82.73 (8.05)	52.32 (5.65)	52.99 (4.85)
TribuneNP5-10	15.84 (5.01)	9.48 (3.19)	136.85 (42.42)	43.85 (9.68)	19.49 (2.88)	19.15 (4.09)
TribuneNP10-15	12.27 (2.94)	6.5 (1.21)	100.5 (24.37)	45.49 (5.52)	21.41 (5.41)	23.93 (3.21)
TribuneNP15-40	6.5 (0.99)	4.61 (0.17)	50.93 (9.91)	56.18 (26.18)	18.41 (1.95)	21.46 (5.09)
TribuneNP40-75	4.16 (1.36)	2.63 (0.4)	12.22 (4.31)	40.14 (7.79)	11.85 (2)	11.16 (2.74)
TribuneNP75-100	1.77 (0.77)	1.02 (0.28)	3.96 (0.67)	9.99 (2.28)	5.22 (1.17)	3.58 (0.91)

Table C.1. Continued.

Sample Label	CO2 Respiration mg CO_2 g $soil^{-1}$	ACE Protein Content mg protein g $soil^{-1}$	POXC mg reactive C kg $soil^{-1}$	Total Microbial Biomass nmol g^{-1}	Gram (+) Bacteria nmol g^{-1}
TribuneAG0-5	0.38 (0.06)	4.62 (0.52)	1372 (22.31)	21.66 (13.79)	8.01 (4.01)
TribuneAG5-10	0.23 (0.07)	4.37 (0.81)	1375 (5.4)	15.2 (12.28)	5.58 (3.99)
TribuneAG10-15	0.13 (0.03)	1.62 (0.68)	1376 (10.71)	8.75 (4.12)	3.36 (1.44)
TribuneAG15-40	0.52 (0.08)	0.14 (0.04)	1378 (23.56)	20.79 (12.99)	7.87 (4.47)
TribuneAG40-75	0.33 (0.08)	0.01 (0.03)	1365 (16.08)	14.42 (12.28)	5.05 (4.28)
TribuneAG75-100	0.23 (0.08)	0 (0)	1370 (19.73)	14.21 (5.86)	5.49 (2.33)
TribuneEA0-5	1.23 (0.82)	6.46 (2.65)	1390 (25.21)	21.14 (9.03)	8.01 (3.33)
TribuneEA5-10	0.42 (0.28)	3.6 (1.29)	1375 (11.35)	18.89 (15.6)	6.89 (5.31)
TribuneEA10-15	0.43 (0.03)	2.06 (0.99)	1384 (14.53)	17.13 (9.14)	5.75 (3.93)
TribuneEA15-40	0.36 (0.08)	0.39 (0.29)	1377 (9.67)	23.12 (13.4)	7.39 (1.64)
TribuneEA40-75	0.31 (0.13)	0 (0)	1349 (11.5)	16.38 (10.48)	5.91 (3.48)
TribuneEA75-100	0.1 (0.06)	0 (0)	1349 (11.07)	12.05 (6.98)	4.51 (2.52)
TribuneIR0-5	2.36 (0.62)	3.18 (0.83)	1467 (7.97)	330.11 (44.12)	45.48 (5.24)
TribuneIR5-10	0.88 (0.12)	0.05 (0.06)	1482 (74.72)	77.75 (10.13)	11.54 (2.04)
TribuneIR10-15	0.41 (0.08)	0 (0)	1544 (110.99)	53.31 (12.21)	7.59 (2.17)
TribuneIR15-30	0.34 (0.03)	0 (0)	1366 (19.45)	50.4 (9.14)	6.66 (1.5)
TribuneIR30-50	0.24 (0.09)	0 (0)	1344 (9.68)	33.43 (2.1)	3.64 (0.44)
TribuneIR50-85	0.14 (0.03)	0 (0)	1338 (11.06)	21.19 (3.63)	1.84 (0.58)
TribuneIR85-100	0.14 (0.03)	0 (0)	1347 (14.06)	16.83 (3.98)	1.46 (0.57)
TribuneNP0-5	0.71 (0.16)	11.51 (1.57)	1431 (18.95)	47.89 (21.02)	15.28 (6.5)
TribuneNP5-10	0.34 (0.13)	5.08 (1.3)	1409 (7.39)	37.48 (39.47)	12.24 (11.18)
TribuneNP10-15	0.14 (0.06)	3.67 (0.83)	1379 (11.99)	17.12 (7.44)	5.65 (3.7)
TribuneNP15-40	0.11 (0.04)	1.81 (0.58)	1363 (60.6)	44.36 (21.47)	14.04 (5.45)
TribuneNP40-75	0.07 (0.02)	1.17 (0.29)	1367 (13.38)	26.69 (20.55)	10.12 (7.33)
TribuneNP75-100	0.05 (0.03)	0 (0)	1351 (8.47)	13.78 (11.31)	5.55 (4.38)

Table C.1. Continued.

Sample Label	Gram (-) Bacteria nmol g^{-1}	Actinomycete nmol g^{-1}	Arbuscular Mycorrhizal Fungi nmol g^{-1}	Saphrophytic fungi nmol g^{-1}	Fungi to Bacteria Ratio nmol g^{-1}
TribuneAG0-5	2.42 (1.49)	0.21 (0.06)	1.48 (0.28)	0.75 (0.85)	0.23 (0.08)
TribuneAG5-10	1.6 (1.43)	0.16 (0.11)	1.33 (0.24)	0.41 (0.47)	0.34 (0.19)
TribuneAG10-15	1.17 (0.76)	0.12 (0.06)	1.44 (0.17)	0.11 (0.08)	0.39 (0.17)
TribuneAG15-40	1.96 (1.27)	0.24 (0.09)	1.51 (0.14)	0.43 (0.4)	0.24 (0.14)
TribuneAG40-75	1.51 (1.53)	0.22 (0.15)	1.45 (0.35)	0.32 (0.44)	0.41 (0.23)
TribuneAG75-100	1.34 (0.83)	0.24 (0.11)	1.73 (0.24)	0.21 (0.17)	0.33 (0.17)
TribuneEA0-5	2.22 (1.1)	0.3 (0.07)	1.69 (0.17)	0.44 (0.42)	0.22 (0.07)
TribuneEA5-10	1.96 (1.79)	0.2 (0.11)	1.5 (0.34)	0.53 (0.79)	0.33 (0.2)
TribuneEA10-15	1.48 (1.21)	0.21 (0.15)	1.6 (0.25)	0.23 (0.2)	0.26 (0.19)
TribuneEA15-40	1.96 (0.51)	0.25 (0.04)	1.67 (0.15)	0.39 (0.31)	0.19 (0.08)
TribuneEA40-75	1.73 (1.48)	0.23 (0.09)	1.57 (0.06)	0.4 (0.4)	0.33 (0.17)
TribuneEA75-100	1.33 (1.24)	0.19 (0.14)	1.64 (0.26)	0.19 (0.13)	0.39 (0.19)
TribuneIR0-5	57.31 (8.34)	20.26 (2.01)	11.84 (1.78)	58.46 (11.26)	0.47 (0.05)
TribuneIR5-10	8.71 (0.56)	5.65 (1.21)	5.35 (0.46)	18.71 (2.87)	0.72 (0.04)
TribuneIR10-15	4.86 (1.35)	4.9 (1.42)	2.17 (0.95)	13.76 (2.83)	0.82 (0.18)
TribuneIR15-30	5.22 (1.48)	4.09 (0.82)	1.93 (0.32)	13.51 (1.5)	0.87 (0.16)
TribuneIR30-50	3.24 (0.37)	2.01 (0.27)	1.62 (0.28)	10.27 (0.69)	1.17 (0.15)
TribuneIR50-85	1.56 (0.33)	0.89 (0.22)	0.83 (0.19)	6.32 (0.84)	1.54 (0.4)
TribuneIR85-100	1.5 (0.64)	0.68 (0.32)	0.68 (0.55)	4.71 (0.34)	1.51 (0.7)
TribuneNP0-5	4.97 (2.02)	0.5 (0.1)	2.94 (1.9)	0.94 (0.37)	0.27 (0.15)
TribuneNP5-10	4.3 (4.55)	0.37 (0.25)	1.73 (0.37)	0.52 (0.49)	0.32 (0.17)
TribuneNP10-15	1.74 (1.4)	0.3 (0.15)	2.16 (0.9)	0.46 (0.35)	0.28 (0.12)
TribuneNP15-40	4.83 (2.08)	0.37 (0.15)	2.57 (1.48)	2.53 (2.11)	0.28 (0.14)
TribuneNP40-75	3 (2.33)	0.34 (0.23)	1.67 (0.17)	1.26 (1.34)	0.27 (0.1)
TribuneNP75-100	1.55 (1.56)	0.16 (0.19)	1.71 (0.49)	0.44 (0.43)	0.38 (0.15)

Supplemental Notes

Manhattan pedon description.

USDA - NATURAL RESOURCES CONSERVATION SERVICE

PEDON DESCRIPTION

Native prairie-Manhattan

Print Date: 06/04/2019

Description Date: 10/22/2018 12:00:00 AM

Describer: B. Nester, J. Anderson, J. Warner, C. Tecklenburg

User Site ID: S2018KS161102

User Pedon ID: S2018KS161102

Soil Name as Described/Sampled: Tully

Taxon Kind as Sampled: series Classification Type: sampled as

Sampled as Classification: Fine, mixed, superactive, mesic Pachic Argiustolls

Pedon Type: correlates to named soil

Pedon Purpose: research site

Lab Source ID: KSSL Lab Pedon #: 19N0203

Location Information:

Country: United States

State: Kansas

County: Riley

MLRA: 76 -- Bluestem Hills

Soil Survey Area: KS161 -- Riley County, Kansas

5-SAL -- Salina, Kansas

Map Unit: Reading SIL 1-3%

Quad Name: Swede Creek, Kansas

Location Description:

Legal Description: of Section 12, Township 11 S. , Range 7 E.

Latitude: 39 degrees 6 minutes 20.02 seconds north

Longitude: 96 degrees 36 minutes 36.14 seconds west

Datum: WGS84

UTM Zone: 14

UTM Easting: 706655 meters

UTM Northing: 4331214 meters

Physiographic Division: Interior Plains

Physiographic Province: Central Lowland Province

Physiographic Section: Osage plain

State Physiographic Area: Flint Hills Upland

Local Physiographic Area: Flint Hills Uplands

Geomorphic Setting: on footslope of base slope of hillslope

Upslope Shape: concave Cross Slope Shape: linear

Primary Earth Cover: Grass/herbaceous cover

Secondary Earth Cover: Grassland rangeland

Parent Material: alluvium over colluvium

Particle Size Control Section: 29 to 79 cm.

Diagnostic Features: mollic epipedon 0 to 59 cm.

argillic horizon 29 to 200 cm.

secondary carbonates 86 to 179 cm.

redox concentrations 127 to 200 cm.

lithologic discontinuity 179 to 179 cm.

Top Depth (cm)	Bottom Depth (cm)	Restriction Kind	Restriction Hardness

Slope	Elevation	Aspect	MAAT	MSAT	MWAT	MAP	Frost-	Drainage	Slope	Upslope
							Free Days	Class	Length	Length
(%)	(meters)	(deg)	(C)	(C)	(C)	(mm)			(meters)	(meters)
4.0	334.0	236					well			

A1--0 to 15 centimeters; silty clay loam, very dark brown (10YR 2/2) interior, moist; 29 percent clay; moderate medium granular structure; friable, slightly hard, moderately sticky, moderately plastic; deformable; common fine roots throughout and many medium roots throughout; many fine dendritic tubular pores; noneffervescent, by HCl, 1 normal; clear smooth boundary. Lab sample # 19N01090

A2--15 to 29 centimeters; silty clay loam, black (10YR 2/1) interior, moist; 31 percent clay; moderate medium granular structure; friable, slightly hard, moderately sticky, moderately plastic; deformable; many fine roots throughout; common fine dendritic tubular pores; noneffervescent, by HCl, 1 normal; clear smooth boundary. Lab sample # 19N01091

Bt1--29 to 59 centimeters; silty clay loam, very dark grayish brown (10YR 3/2) interior, moist; 38 percent clay; weak medium prismatic structure parts to moderate medium subangular blocky structure; very firm, hard, moderately sticky, very plastic; semideformable; common very fine roots

throughout; common fine dendritic tubular pores; 25 percent prominent clay films on all faces of peds; noneffervescent, by HCl, 1 normal; clear smooth boundary. Lab sample # 19N01092

Bt2--59 to 86 centimeters; silty clay, brown (10YR 4/3) interior, moist; 43 percent clay; weak medium prismatic structure parts to moderate medium subangular blocky structure; very firm, very hard, very sticky, very plastic; semideformable; common very fine roots throughout; common fine dendritic tubular pores; 30 percent prominent clay films on all faces of peds; noneffervescent, by HCl, 1 normal; clear wavy boundary. Lab sample # 19N01093

Btk1--86 to 127 centimeters; silty clay, dark yellowish brown (10YR 4/4) interior, moist; 46 percent clay; weak medium prismatic structure parts to moderate medium subangular blocky structure; very firm, very hard, very sticky, very plastic; semideformable; common very fine roots throughout; common very fine dendritic tubular pores; 25 percent prominent clay films on all faces of peds; noneffervescent, by HCl, 1 normal; clear wavy boundary. Lab sample # 19N01094

Btk2--127 to 179 centimeters; silty clay loam, yellowish brown (10YR 5/4) interior, moist; 34 percent clay; weak medium prismatic structure parts to moderate medium subangular blocky structure; firm, hard, moderately sticky, moderately plastic; semideformable; common very fine roots throughout; common very fine dendritic tubular pores; 20 percent prominent clay films on all faces of peds; 2 percent fine spherical masses of oxidized iron with clear boundaries throughout; 35 percent coarse prominent irregular moderately cemented white (10YR 8/1), moist, carbonate concretions with sharp boundaries throughout; noneffervescent, by HCl, 1 normal; clear wavy

boundary. Lab sample # 19N01095

2Bt--179 to 200 centimeters; silty clay loam, brown (7.5YR 4/4) interior, moist; 31 percent clay; weak medium prismatic structure parts to moderate medium subangular blocky structure; friable, slightly hard, moderately sticky, moderately plastic; deformable; common very fine roots throughout; common very fine dendritic tubular pores; 25 percent prominent clay films on all faces of peds; 5 percent coarse spherical masses of oxidized iron with clear boundaries throughout; 15 percent coarse prominent irregular moderately cemented white (10YR 8/1), moist, carbonate concretions with sharp boundaries throughout; 2 percent nonflat subangular indurated 2 to 5 mm. chert fragments; noneffervescent, by HCl, 1 normal. Lab sample # 19N01096

USDA - NATURAL RESOURCES CONSERVATION SERVICE

PEDON DESCRIPTION

Conventional tillage-Manhattan

Print Date: 06/04/2019

Description Date: 10/23/2018 12:00:00 AM

Describer: B. Nester, J. Anderson, J. Warner, C. Tecklenburg, M. Stark

User Site ID: S2018KS161103

User Pedon ID: S2018KS161103

Soil Name as Described/Sampled: Reading

Taxon Kind as Sampled: taxadjunct Classification Type: sampled as

Sampled as Classification: Fine, mixed, superactive, mesic Pachic Vertic Argiudolls

Pedon Type: taxadjunct to the series

Pedon Purpose: research site

Lab Source ID: KSSL Lab Pedon #: 19N0204

Location Information:

Country: United States

State: Kansas

County: Riley

MLRA: 76 -- Bluestem Hills

Soil Survey Area: KS161 -- Riley County, Kansas

5-SAL -- Salina, Kansas

Map Unit: Reading Silt loam Rarely Flooded.

Quad Name: Swede Creek, Kansas

Location Description:

Legal Description: of Section 12, Township 11 S. , Range 7 E.

Latitude: 39 degrees 6 minutes 11.77 seconds north

Longitude: 96 degrees 36 minutes 15.34 seconds west

Datum: WGS84

UTM Zone: 14

UTM Easting: 707162 meters

UTM Northing: 4330973 meters

Physiographic Division: Interior Plains

Physiographic Province: Central Lowland Province

Physiographic Section: Osage plain

State Physiographic Area: Flint Hills Upland

Local Physiographic Area: Flint Hills Uplands

Geomorphic Setting: on tread of flood-plain step

Upslope Shape: linear Cross Slope Shape: linear

Primary Earth Cover: Grass/herbaceous cover

Secondary Earth Cover: Grassland rangeland

Parent Material: alluvium

Particle Size Control Section: 22 to 72 cm.

Diagnostic Features: mollic epipedon 0 to 200 cm.

argillic horizon 22 to 200 cm.

slickensides 68 to 175 cm.

secondary carbonates 135 to 200 cm.

free carbonates 175 to 200 cm.

gypsum accumulations 175 to 200 cm.

Top Depth (cm)	Bottom Depth (cm)	Restriction Kind	Restriction Hardness

Slope (%)	Elevation (meters)	Aspect (deg)	MAAT (C)	MSAT (C)	MWAT (C)	MAP (mm)	Frost-Free Days	Drainage Class	Slope Length (meters)	Upslope Length (meters)
2.0	335.0	10						well		

|_____|_____|_____|_____|_____|_____|_____|_____|_____|_____|_____|

Ap1--0 to 11 centimeters; black (10YR 2/1) interior silt loam; 26 percent clay; strong fine granular structure; very friable, soft, slightly sticky, slightly plastic; deformable; many fine roots throughout; noneffervescent, by HCl, 1 normal; abrupt smooth boundary. Lab sample # 19N01097

Ap2--11 to 22 centimeters; black (10YR 2/1) interior silty clay loam; 34 percent clay; moderate medium subangular blocky structure; friable, slightly hard, moderately sticky, moderately plastic; deformable; many fine roots throughout; noneffervescent, by HCl, 1 normal; clear smooth boundary. Lab sample # 19N01098

Bt--22 to 68 centimeters; black (10YR 2/1) interior silty clay; 41 percent clay; moderate medium prismatic structure parts to moderate medium subangular blocky structure; very firm, very hard, very sticky, very plastic; semideformable; common fine roots throughout; common fine dendritic tubular pores; 40 percent distinct clay films on all faces of peds; noneffervescent, by HCl, 1 normal; clear wavy boundary. Lab sample # 19N01099

Btss1--68 to 103 centimeters; black (10YR 2/1) interior silty clay; 54 percent clay; moderate medium prismatic structure parts to moderate medium subangular blocky structure; very firm, very hard, very sticky, very plastic; semideformable; common very fine roots throughout; common fine dendritic tubular pores; 35 percent prominent slickensides (pedogenic) on slickensides and 40

percent distinct clay films on all faces of peds; noneffervescent, by HCl, 1 normal; clear wavy boundary. Lab sample # 19N01100

Btss2--103 to 135 centimeters; very dark gray (10YR 3/1) interior silty clay; 52 percent clay; moderate medium prismatic structure parts to moderate medium angular blocky structure; very firm, very hard, very sticky, very plastic; semideformable; common very fine roots throughout; common fine dendritic tubular pores; 30 percent prominent slickensides (pedogenic) on slickensides and 50 percent distinct clay films on all faces of peds; noneffervescent, by HCl, 1 normal; clear wavy boundary. Lab sample # 19N01101

Btkss--135 to 175 centimeters; very dark grayish brown (10YR 3/2) interior silty clay; 43 percent clay; moderate medium prismatic structure parts to moderate medium angular blocky structure; very firm, very hard, very sticky, very plastic; semideformable; common very fine roots throughout; common fine dendritic tubular pores; 20 percent prominent slickensides (pedogenic) on slickensides and 40 percent distinct clay films on all faces of peds; 1 percent fine prominent irregular moderately cemented white (10YR 8/1), moist, carbonate nodules with sharp boundaries throughout and 3 percent very fine prominent irregular white (10YR 8/1), moist, carbonate masses with diffuse boundaries throughout; noneffervescent, by HCl, 1 normal; clear wavy boundary. Lab sample # 19N01102

2Btky--175 to 200 centimeters; very dark grayish brown (10YR 3/2) interior silty clay loam; 36 percent clay; moderate medium prismatic structure parts to moderate medium angular blocky structure; firm, moderately hard, very sticky, very plastic; semideformable; common fine dendritic

tubular pores; and 40 percent distinct clay films on all faces of peds; 5 percent fine prominent irregular white (10YR 8/1), moist, carbonate masses with diffuse boundaries throughout and 1 percent fine prominent irregular white (10YR 8/1), moist, gypsum masses with diffuse boundaries throughout; very slight effervescence, by HCl, 1 normal. Lab sample # 19N01103

Enhanced Agriculture-Manhattan

P-11 Reading

A. Morphology

Part A Score _____

HORIZONATION				BOUNDARY		TEXTURE			COLOR			STRUCTURE		MOIST CONSIST.	SOIL FEATURES			SCORE
Prefix	Master	Sub.	No	Depth (cm)	Dist.	Rock Frag. Mod.	Class	Clay (%)	Hue	Value	Chroma	Grade	Type		RMF Conc. (Y/-)	RMF Depl. (Y/-)	Matrix Conc. (Type)	
(2)	(4)	(2)	(2)	(2)	(2)	(2)	(4)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(40)
-	A	p	1	12	A	-	SIL	24	10YR	2	2	2	PL	FR	-	-	-	
-	A	p	2	23	A	-	SIL or SICL	28	10YR	2	1	2	PL	FR	-	-	-	
-	BA	-	-	53	C	-	SICL	31	10YR	2	1	2	SBK	FI	-	-	-	
-	B	t	1	78	C	-	SICL	37	10YR	2	1	2	PR	FI	Y	-	FE-MN	
-	B	tss	1	109	C	-	SIC or SICL	40	10YR	2	1	2	PR	FI	Y	-	FE-MN	
-	B	tss	2	128	G	-	SICL	37	10YR	3	2	2	ABK	VFI	Y	-	FE-MN	
-	B	tss	3	150+	-	-	SICL	35	10YR	3	2	2	ABK	VFI	Y	-	FE-MN	

Btk at 150 cm (not judged)

1.) Btss horizons are in different layer of alluvium
2.) Slickensides are weakly expressed.

B. Soil Hydrology and Profile Characteris-tics

Part B Score _____

Hydraulic Conductivity (3-5-3)		Effective Soil Depth (5)	Water Retention Diff. (5)	Soil Wetness Class (5)	TOTAL SCORE
Surface Layer	Limiting Layer	cm	cm	cm	
____ Very High	_____ Very High	__x__ Very Deep (> 150)	_____ Very Low (< 7.5)	__x__ Class 1 (> 150)	**Part A** _____
____ High	_____ High	_____ Deep (100.1- 150)	_____ Low (7.5-15)	_____ Class 2 (100.1-150)	**Part B** _____
_x__ Mod High	_____ Mod High	_____ Mod. Deep (50.1- 100)	_____ Medium (15.1-22.5)	_____ Class 3 (50.1 – 100)	**Part C** _____
____ Mod Low	__x___ Mod Low	_____ Shallow (25-50)	__x__ High (> 22.5)	_____ Class 4 (25- 50)	**Part D** _____
____ Low	_____ Low or	_____ Very Shallow (< 25)		_____ Class 5 (< 25)	**Part E** _____
____ Very Low	__x__ Very Low				**Total** _____

C. Site Characteristics

P-11 Reading

Part C Score _____

Landform (5)	Parent Material (5*)	Slope (5)	Hillslope Profile Position (5)	Surface Runoff (5)
_____ Upland _____ Upland depression _____ Alluvial fan __x__ Stream terrace _____ Floodplain _____ Footslope _____ Dunes/Interdunes	__x__ Alluvium _____ Colluvium/Pedisediment _____ Eolian Sand/Eolian loam _____ Loess _____ Residuum _____ Glacial Till/Sediments	__x_ 0 to 2% ____ 2 to 6% ____ 6 to 9% ____ 9 to 15% ____ 15 to 25% ____ >25% 1%	____ Summit ____ Shoulder ____ Backslope ____ Footslope ____ Toeslope __x_ None (gradient <2%)	____ Negligible/Ponded __x_ Very Low ____ Low ____ Medium ____ High ____ Very High

D. Soil Classification

Part D Score _____

Epipedon (5)	Diagnostic Subsurface Horizons and Features (5*)	Order (5)	Suborder (5)	Great Group (5)		Family Particle-Size Class (5)
__x_ Mollic ____ Ochric ____ Umbric ____ None	____ Albic ____ None _x__ Argillic ____ Natric ____ Cambic ____ Calcic ____ Lithic Contact ____ Paralithic Contact __x_ Slickensides ____ Abrupt Textural Change ____ Albic materials ____ Lamellae ____ Lithologic Discontinuities ____ Aquic Conditions	____ Vertisols __x_ Mollisols ____ Alfisols ____ Inceptisols ____ Entisols	____ Aquerts ____ Usterts ____ Albolls ____ Aquolls _x__ Ustolls ____ Aqualfs ____ Ustalfs ____ Aquepts ____ Ustepts ____ Aquents ____ Psamments ____ Fluvents ____ Orthents	____ Epiaquerts ____ Endoaquerts ____ Calciusterts ____ Haplusterts ____ Argialbolls ____ Calciaquolls ____ Argiaquolls ____ Epiaquolls ____ Endoaquolls ____ Natrustolls ____ Calciustolls ____ Paleustolls __x_ Argiustolls ____ Haplustolls	____ Albaqualfs ____ Epiaqualfs ____ Endoaqualfs ____ Paleustalfs ____ Haplustalfs ____ Epiaquepts ____ Endoaquepts ____ Calciustepts ____ Haplustepts ____ Fluvaquents ____ Endoaquents ____ Ustipsamments ____ Ustifluvents ____ Ustorthents	____ Sandy ____ Loamy ____ Clayey ____ Coarse-loamy ____ Fine-loamy ____ Coarse-silty ____ Fine-silty __x_ Fine ____ Very-fine ____ Sandy-skeletal ____ Loamy-skeletal ____ Clayey-skeletal ____ Loamy-skeletal over clayey

Depth of Particle Size Control Section (5)

_____ 0 cm to root limiting layer (<36 cm)
_____ 25 to 100 cm
_____ 25 cm to root limiting layer (between 36-100 cm)
__x__ Upper 50 cm of argillic
_____ Upper boundary of argillic to 100 cm (contrasting particle size)
_____ All of the argillic or natric where it is <50 cm thick

E. Site Interpretations

Part E Score _____

Septic Tank Absorption Fields (5)	Rangeland Ecological Site (5)	Dwellings without Basements (5)
_x__ Suitable ____ Provisionally Suitable or → __x_ Unsuitable	____ Claypan ____ Loamy Upland ____ Shallow Limestone Hills ____ Clayey Upland __x_ Loamy Lowland ____Choppy Sands ____ Upland Hills ____ Gravelly Flint Hills ____ Other	____ Slight _x__ Moderate _x__ Severe SICL or SIC

USDA United States Department of Agriculture

1

Hays pedon description

USDA - NATURAL RESOURCES CONSERVATION SERVICE

PEDON DESCRIPTION

Native prairie-Hays

Print Date: 06/04/2019

Description Date: 8/22/2018 12:00:00 AM

Describer: L. Bricknell, R. Still

User Site ID: S2018KS051002

Site Note: native range; Pit is approximately 50 feet from the edge of a Harney-Carlson silt loams, 1 to 3 percent slopes polygon.

User Pedon ID: S2018KS051002

Pedon Note: Particle Size Control Section clay: 33 percent; This soil is a taxajunct to Harney. This soil is pachic and does not fit the critieria for a fine particle size class.

Soil Name as Described/Sampled: Harney

Taxon Kind as Sampled: series Classification Type: sampled as correlated

Sampled as Classification: Fine, smectitic, mesic Typic Argiustolls

Soil Name as Correlated: Harney

Taxon Kind as Correlated: taxadjunct

Correlated Classification: Fine-silty, smectitic, mesic Pachic Argiustolls

Pedon Type: taxadjunct to the series

Pedon Purpose: research site

Lab Source ID: KSSL Lab Pedon #: 19N0201

Location Information:

State: Kansas

County: Ellis

MLRA: 73 -- Rolling Plains and Breaks

Soil Survey Area: KS051 -- Ellis County, Kansas

Map Unit: 2612 -- Harney silt loam, 0 to 1 percent slopes

Quad Name: Hays South, Kansas

Location Description: One mile south of Hays, KS in native range.

Legal Description: 1,115 feet west and 2,357 feet south of the NE corner of Section 15, Township 14, Range 18

Latitude: 38 degrees 50 minutes 7.70 seconds north

Longitude: 99 degrees 18 minutes 12.20 seconds west

Datum: WGS84

UTM Zone: 14

UTM Easting: 473670 meters

UTM Northing: 4298562 meters

Physiographic Division: Interior Plains

Physiographic Province: Great Plains Province

Physiographic Section: Plains border

State Physiographic Area:

Local Physiographic Area:

Geomorphic Setting: on summit of interfluve of hillslope

Upslope Shape: linear Cross Slope Shape: linear

Primary Earth Cover: Grass/herbaceous cover

Parent Material: loess

Particle Size Control Section: 58 to 108 cm.

Diagnostic Features: mollic epipedon 0 to 92 cm.

argillic horizon 58 to 206 cm.

secondary carbonates 92 to 206 cm.

free carbonates 192 to 206 cm.

Top Depth (cm)	Bottom Depth (cm)	Restriction Kind	Restriction Hardness

Slope (%)	Elevation (meters)	Aspect (deg)	MAAT (C)	MSAT (C)	MWAT (C)	MAP (mm)	Frost-Free Days	Drainage Class	Slope Length (meters)	Upslope Length (meters)

1.0	611.0										

A--0 to 39 centimeters; very dark grayish brown (10YR 3/2) broken face silt loam, very dark brown (10YR 2/2) broken face, moist; 26 percent clay; moderate fine granular structure; friable, slightly hard; common fine roots throughout and common very fine roots throughout; noneffervescent; clear smooth boundary. Lab sample # 19N01073

BA--39 to 58 centimeters; dark grayish brown (10YR 4/2) broken face silty clay loam, very dark grayish brown (10YR 3/2) broken face, moist; 30 percent clay; moderate medium subangular blocky structure parts to moderate fine granular structure; firm, hard; common fine roots throughout and common very fine roots throughout; common very fine pores; noneffervescent; clear smooth boundary. Lab sample # 19N01074

Bt--58 to 92 centimeters; dark grayish brown (10YR 4/2) broken face silty clay loam, very dark grayish brown (10YR 3/2) broken face, moist; 32 percent clay; strong fine subangular blocky structure parts to weak medium prismatic structure; firm, hard; common very fine roots throughout; common very fine pores; 65 percent clay films on all faces of peds; noneffervescent; clear smooth boundary. Lab sample # 19N01075

Btk1--92 to 112 centimeters; grayish brown (10YR 5/2) broken face silty clay loam, dark grayish

brown (10YR 4/2) broken face, moist; 34 percent clay; weak medium prismatic structure parts to strong medium prismatic structure; firm, hard; common very fine roots throughout; common fine and common very fine pores; 70 percent clay films on vertical faces of peds; 5 percent fine threadlike carbonate masses throughout; noneffervescent; clear smooth boundary. Lab sample # 19N01076

Btk2--112 to 134 centimeters; brown (10YR 5/3) broken face silty clay loam, brown (10YR 4/3) broken face, moist; 38 percent clay; weak coarse prismatic structure parts to strong medium prismatic structure; firm, hard; common very fine roots throughout; common very fine pores; 80 percent clay films on all faces of peds; 5 percent fine threadlike carbonate masses throughout and 2 percent medium spherical weakly cemented carbonate concretions throughout; noneffervescent; clear smooth boundary. Lab sample # 19N01077

Btk3--134 to 174 centimeters; light yellowish brown (10YR 6/4) broken face silty clay loam, brown (10YR 5/3) broken face, moist; 34 percent clay; moderate coarse prismatic structure parts to moderate medium prismatic structure; firm, hard; common very fine pores; 70 percent clay films on all faces of peds; 3 percent fine threadlike carbonate masses throughout and 5 percent medium spherical weakly cemented carbonate concretions throughout; noneffervescent; clear smooth boundary. Lab sample # 19N01078

Btk4--174 to 192 centimeters; brown (7.5YR 5/4) broken face silty clay loam, brown (7.5YR 4/4) broken face, moist; 31 percent clay; moderate coarse prismatic structure parts to moderate medium prismatic structure; firm, hard; common very fine pores; 2 percent carbonate coats on all faces of

peds and 50 percent clay films on all faces of peds; 2 percent fine threadlike carbonate masses throughout and 5 percent medium irregular carbonate masses throughout and 2 percent medium spherical weakly cemented carbonate concretions throughout; noneffervescent; clear smooth boundary. Lab sample # 19N01079

Btk5--192 to 206 centimeters; light brown (7.5YR 6/4) broken face silt loam, brown (7.5YR 5/4) broken face, moist; 25 percent clay; weak very coarse prismatic structure parts to moderate medium prismatic structure; friable, slightly hard; common fine and common very fine pores; 3 percent clay films on all faces of peds and 10 percent carbonate coats on all faces of peds; 2 percent fine threadlike carbonate masses throughout and 4 percent medium irregular weakly cemented carbonate nodules throughout; strong effervescence; abrupt smooth boundary. Lab sample # 19N01080

USDA - NATURAL RESOURCES CONSERVATION SERVICE

PEDON DESCRIPTION

Conventional tillage-Hays

Print Date: 06/04/2019

Description Date: 8/22/2018 12:00:00 AM

Describer: L. Bricknell, R. Still

User Site ID: S2018KS051003

Site Note: Pit is approximately 150 feet from the edge of a Harney-Carlson silt loams, 1 to 3 percent slopes polygon.; cropland

User Pedon ID: S2018KS051003

Pedon Note: Particle Size Control Section clay: 35 percent; Cropland

Soil Name as Described/Sampled: Harney

Taxon Kind as Sampled: series Classification Type: sampled as

Sampled as Classification: Fine, smectitic, mesic Typic Argiustolls

Pedon Type: correlates to named soil

Pedon Purpose: research site

Lab Source ID: KSSL Lab Pedon #: 19N0202

Location Information:

State: Kansas

County: Ellis

MLRA: 73 -- Rolling Plains and Breaks

Soil Survey Area: KS051 -- Ellis County, Kansas

Map Unit: 2612 -- Harney silt loam, 0 to 1 percent slopes
Quad Name: Hays South, Kansas
Location Description: One mile south of Hays, KS in cropland
Legal Description: 945 feet east and 314 feet north of the SW corner of Section 10, Township 14, Range 18
Latitude: 38 degrees 50 minutes 34.10 seconds north
Longitude: 99 degrees 18 minutes 52.90 seconds west
Datum: WGS84
UTM Zone: 14
UTM Easting: 472691 meters
UTM Northing: 4299380 meters
Physiographic Division: Interior Plains
Physiographic Province: Great Plains Province
Physiographic Section: Plains border
Geomorphic Setting: on summit of interfluve of hillslope
Upslope Shape: linear Cross Slope Shape: linear
Primary Earth Cover: Crop cover
Parent Material: loess
Surface Fragments: None
Particle Size Control Section: 24 to 74 cm.
Diagnostic Features: mollic epipedon 0 to 24 cm.
argillic horizon 24 to 210 cm.

secondary carbonates 64 to 210 cm.

free carbonates 75 to 210 cm.

Top Depth (cm)	Bottom Depth (cm)	Restriction Kind	Restriction Hardness

Slope (%)	Elevation (meters)	Aspect (deg)	MAAT (C)	MSAT (C)	MWAT (C)	MAP (mm)	Frost-Free Days	Drainage Class	Slope Length (meters)	Upslope Length (meters)
1.0	609.0									

Ap--0 to 17 centimeters; very dark gray (10YR 3/1) broken face silt loam, black (10YR 2/1) broken face, moist; 26 percent clay; weak medium subangular blocky structure parts to moderate fine granular structure; friable, slightly hard; common fine roots throughout and common very fine roots throughout; noneffervescent; abrupt smooth boundary. Lab sample # 19N01081

BA--17 to 24 centimeters; dark grayish brown (10YR 4/2) broken face silty clay loam, very dark grayish brown (10YR 3/2) broken face, moist; 31 percent clay; moderate medium subangular blocky structure parts to moderate fine granular structure; firm, hard; common fine roots throughout and common very fine roots throughout; common fine pores; noneffervescent; abrupt smooth boundary. Lab sample # 19N01082

Bt1--24 to 46 centimeters; grayish brown (10YR 5/2) broken face silty clay loam, dark grayish brown (10YR 4/2) broken face, moist; 34 percent clay; moderate medium subangular blocky structure; firm, hard; common very fine roots throughout; common fine and common very fine pores; 30 percent clay films on all faces of peds; noneffervescent; gradual smooth boundary. Lab sample # 19N01083

Bt2--46 to 64 centimeters; brown (10YR 5/3) broken face silty clay loam, brown (10YR 4/3) broken face, moist; 38 percent clay; weak medium prismatic structure parts to strong medium subangular blocky structure; firm, hard; common very fine roots throughout; common very fine pores; 60 percent clay films on all faces of peds; noneffervescent; clear smooth boundary. Lab sample # 19N01084

Btk1--64 to 75 centimeters; light brown (7.5YR 6/4) broken face silty clay loam, brown (7.5YR 5/4)

broken face, moist; 31 percent clay; weak medium prismatic structure parts to moderate medium subangular blocky structure; firm, hard; common very fine roots throughout; common fine and common very fine pores; 45 percent clay films on all faces of peds; 1 percent fine threadlike carbonate masses throughout; noneffervescent; abrupt wavy boundary. Lab sample # 19N01085

Btk2--75 to 92 centimeters; very pale brown (10YR 7/4) broken face silt loam, light yellowish brown (10YR 6/4) broken face, moist; 26 percent clay; weak coarse prismatic structure parts to moderate medium prismatic structure; friable, slightly hard; common very fine roots throughout; common fine and common very fine pores; 5 percent carbonate coats on vertical faces of peds and 30 percent clay films on all faces of peds; 2 percent medium irregular carbonate masses throughout and 5 percent medium spherical weakly cemented carbonate concretions throughout; strong effervescence; clear smooth boundary. Lab sample # 19N01086

Btk3--92 to 130 centimeters; light yellowish brown (10YR 6/4) broken face silt loam, yellowish brown (10YR 5/4) broken face, moist; 24 percent clay; weak coarse prismatic structure parts to moderate medium prismatic structure; friable, slightly hard; common fine and common very fine pores; 3 percent carbonate coats on all faces of peds and 4 percent clay films on all faces of peds; 4 percent fine irregular weakly cemented carbonate nodules throughout and 3 percent medium irregular carbonate masses throughout; strong effervescence; gradual smooth boundary. Lab sample # 19N01087

Btk4--130 to 180 centimeters; very pale brown (10YR 7/4) broken face silt loam, light yellowish

brown (10YR 6/4) broken face, moist; 20 percent clay; weak coarse prismatic structure parts to weak medium prismatic structure; friable, slightly hard; common fine and common very fine pores; 4 percent clay films on all faces of peds; 1 percent fine irregular carbonate masses throughout and 2 percent fine threadlike carbonate masses throughout and 2 percent medium irregular weakly cemented carbonate nodules throughout; strong effervescence; gradual smooth boundary. Lab sample # 19N01088

Btk5--180 to 210 centimeters; light yellowish brown (10YR 6/4) broken face silt loam, yellowish brown (10YR 5/4) broken face, moist; 18 percent clay; weak very coarse prismatic structure parts to moderate medium prismatic structure; friable, slightly hard; many very fine pores; 2 percent clay films on all faces of peds; 2 percent medium threadlike carbonate masses throughout; strong effervescence. Lab sample # 19N01089

Tribune pedon description.

USDA - NATURAL RESOURCES CONSERVATION SERVICE

PEDON DESCRIPTION

No-till irrigation-Tribune

Print Date: 11/05/2020

Description Date: 11/4/2019

Describer: B. Nester, L. Bricknell, J. Anderson, M. Stark, C. Tecklenburg

User Site ID: S2019KS071001

User Pedon ID: S2019KS071001

Soil Name as Described/Sampled: Richfield

Taxon Kind as Sampled: taxadjunct

Sampled as Classification: Fine-loamy, mixed, superactive, mesic Aridic Argiustolls

Pedon Type: taxadjunct to the series

Pedon Purpose: research site

Lab Source ID: KSSL Lab Pedon #: 20N0157

Location Information:

Country: United States

State: Kansas

County: Greeley

MLRA: 72 -- Central High Tableland
Soil Survey Area:
Map Unit: 1761 Richfield SiL 0-1%
Quad Name: Tribune

Location Description:
Legal Description: of Section 16, Township 17 S. , Range 40 W.

Latitude: 38 degrees 34 minutes 47.10 seconds north
Longitude: 101 degrees 44 minutes 48.01 seconds west
Datum: WGS84
UTM Zone: 14
UTM Easting: 260740 meters
UTM Northing: 4273726 meters

Physiographic Division: Interior Plains
Physiographic Province: Great Plains Province
Physiographic Section: High Plains
State Physiographic Area: High Plains
Local Physiographic Area:
Geomorphic Setting: plain on tableland
Upslope Shape: linear Cross Slope Shape: linear

Primary Earth Cover: Crop cover
Secondary Earth Cover: Row crop
Parent Material: calcareous loess

Particle Size Control Section: 17 to 50 cm.
Diagnostic Features: mollic epipedon 0 to 28 cm.
argillic horizon 17 to 50 cm.
secondary carbonates 28 to 200 cm.
free carbonates 28 to 200 cm.

Slope	Elevation	Aspect	Drainage
2.0 %	1,107 M	210°	well

Ap--0 to 17 centimeters; very dark grayish brown (10YR 3/2) interior silt loam, very dark brown (10YR 2/2) interior, moist; 26 percent clay; moderate medium platy structure; friable, slightly hard, moderately sticky, moderately plastic; deformable; common very fine roots throughout; common fine dendritic tubular pores; noneffervescent, by HCl, 1 normal; ; abrupt wavy boundary. Lab sample # 20N00538

Bt--17 to 28 centimeters; brown (10YR 4/3) interior silty clay loam, very dark grayish brown (10YR 3/2) interior, moist; 33 percent clay; moderate medium subangular blocky structure; firm, hard, moderately sticky, moderately plastic; semideformable; common very fine roots throughout; common very fine dendritic tubular pores; 4 percent clay films on all faces of peds; noneffervescent, by HCl, 1 normal; ; abrupt wavy boundary. Lab sample # 20N00539

Btk--28 to 50 centimeters; pale brown (10YR 6/3) interior silty clay loam, brown (10YR 4/3) interior, moist; 28 percent clay; weak medium subangular blocky structure; firm, hard, moderately sticky, moderately plastic; semideformable; common very fine roots throughout; common very fine dendritic tubular pores; 2 percent clay films on surfaces along root channels; 1 percent very fine prominent threadlike white (10YR 8/1), moist, carbonate masses in matrix; strong effervescence, by HCl, 1 normal; ; clear wavy boundary. Lab sample # 20N00540

Bk1--50 to 84 centimeters; pale brown (10YR 6/3) interior silt loam, brown (10YR 5/3) interior, moist; 26 percent clay; moderate medium prismatic structure; very friable, slightly hard, moderately sticky, moderately plastic; deformable; common very fine roots throughout; common fine dendritic tubular and common medium dendritic tubular and common very fine dendritic tubular pores; 1 percent coarse distinct white (10YR 8/1), moist, carbonate concretions in matrix and 1 percent very fine distinct threadlike white (10YR 8/1), moist, carbonate masses in matrix; violent effervescence, by HCl, 1 normal; ; gradual smooth boundary. Lab sample # 20N00541

Bk2--84 to 131 centimeters; very pale brown (10YR 7/3) interior silt loam, yellowish brown (10YR 5/4) interior, moist; 25 percent clay; weak very coarse prismatic structure parts to moderate medium prismatic structure; very friable, slightly hard, moderately sticky, moderately plastic; deformable; common very fine roots throughout; common fine dendritic tubular and common medium dendritic tubular and common very fine dendritic tubular pores; 2 percent fine distinct threadlike white (10YR 8/1), moist, carbonate masses in matrix; violent effervescence, by HCl, 1 normal; ; gradual smooth boundary. Lab sample # 20N00542

Bk3--131 to 170 centimeters; pale yellow (2.5Y 7/3) interior silt loam, light olive brown (2.5Y 5/3) interior, moist; 23 percent clay; moderate coarse prismatic structure; very friable, slightly hard, moderately sticky, moderately plastic; deformable; common very fine roots throughout; common fine dendritic tubular and common very fine dendritic tubular pores; 1 percent very coarse prominent white (10YR 8/1), moist, carbonate concretions in matrix and 1 percent very fine prominent threadlike white (10YR 8/1), moist, carbonate masses in matrix; violent effervescence, by HCl, 1 normal; ; gradual smooth boundary. Lab sample # 20N00543

Bk4--170 to 200 centimeters; silt loam, light olive brown (2.5Y 5/4) interior, moist; 20 percent clay; weak very coarse prismatic structure; very friable, slightly hard, moderately sticky, moderately plastic; deformable; common very fine roots throughout; common fine dendritic tubular and common very fine dendritic tubular pores; 1 percent very coarse prominent white (10YR 8/1), moist, carbonate concretions in matrix and 1 percent very fine prominent threadlike white (10YR 8/1), moist, carbonate masses in matrix; strong effervescence, by HCl, 1 normal; . Lab sample #

20N00544

USDA - NATURAL RESOURCES CONSERVATION SERVICE

PEDON DESCRIPTION

Conventional tillage-Tribune

Print Date: 11/05/2020

Description Date: 11/5/2019

Describer: B. Nester, L. Bricknell, J. Anderson, M. Stark, C. Tecklenburg

User Site ID: S2019KS071003

User Pedon ID: S2019KS071003

Soil Name as Described/Sampled: Richfield

Taxon Kind as Sampled: taxadjunct

Sampled as Classification: Fine-loamy, mixed, superactive, mesic Pachic Argiustolls

Pedon Type: taxadjunct to the series

Pedon Purpose: research site

Lab Source ID: KSSL Lab Pedon #: 20N0159

Location Information:

Country: United States

State: Kansas

County: Greeley
MLRA: 72 -- Central High Tableland
Soil Survey Area:
Map Unit: 1761 Richfield Sil 0-1%
Quad Name: Tribune, Kansas
Location Description:
Legal Description: of Section 19, Township 18 S. , Range 40 W.
Latitude: 38 degrees 28 minutes 4.46 seconds north
Longitude: 101 degrees 46 minutes 59.59 seconds west
Datum: WGS84
UTM Zone: 14
UTM Easting: 257180 meters
UTM Northing: 4261409 meters
Physiographic Division: Interior Plains
Physiographic Province: Great Plains Province
Physiographic Section: High Plains
State Physiographic Area: High Plains
Local Physiographic Area:
Geomorphic Setting: plain on tableland
Upslope Shape: linear Cross Slope Shape: linear
Primary Earth Cover: Crop cover
Secondary Earth Cover: Close-grown crop

Parent Material: calcareous loess
Particle Size Control Section: 25 to 75 cm.
Diagnostic Features: mollic epipedon 0 to 75 cm.
argillic horizon 25 to 200 cm.
secondary carbonates 75 to 200 cm.

Slope	Elevation	Aspect	Drainage
1.0 %	1,108.0 M	20°	well

Ap--0 to 13 centimeters; silt loam, very dark grayish brown (10YR 3/2) interior, moist; 22 percent clay; weak thick platy structure; very friable, slightly hard, moderately sticky, moderately plastic; deformable, by HCl, 1 normal; ; abrupt wavy boundary. Lab sample # 20N00553

AB--13 to 25 centimeters; silt loam, very dark brown (10YR 2/2) interior, moist; 25 percent clay; weak thick platy structure parts to moderate medium subangular blocky structure; very friable, slightly hard, moderately sticky, moderately plastic; deformable; 2 percent pressure faces on all faces of peds, by HCl, 1 normal; ; abrupt wavy boundary. Lab sample # 20N00554

Bt1--25 to 49 centimeters; silty clay loam, black (10YR 2/1) interior, moist; 32 percent clay; moderate medium subangular blocky structure; firm, hard, moderately sticky, moderately plastic; semideformable; common very fine roots throughout; common very fine dendritic tubular pores; 5 percent clay films on all faces of peds, by HCl, 1 normal; ; clear smooth boundary. Lab sample # 20N00555

Bt2--49 to 75 centimeters; silty clay loam, very dark grayish brown (10YR 3/2) interior, moist; 34 percent clay; moderate medium prismatic structure parts to weak medium subangular blocky structure; firm, hard, moderately sticky, moderately plastic; semideformable; common very fine roots throughout; common very fine dendritic tubular pores; 15 percent clay films on all faces of peds, by HCl, 1 normal; ; clear smooth boundary. Lab sample # 20N00556

Btk1--75 to 113 centimeters; silty clay loam, brown (10YR 4/3) interior, moist; 32 percent clay; moderate medium prismatic structure; firm, hard, moderately sticky, moderately plastic; semideformable; common very fine roots throughout; common fine dendritic tubular and common very fine dendritic tubular pores; 10 percent clay films on all faces of peds; 5 percent very fine prominent threadlike white (10YR 8/1), moist, carbonate masses in matrix; 10 percent nonflat subrounded indurated 2- to 5-millimeter quartzite fragments, by HCl, 1 normal; ; clear wavy boundary. Lab sample # 20N00557

Btk2--113 to 150 centimeters; silt loam, brown (10YR 5/3) interior, moist; 20 percent sand; 54 percent silt; 26 percent clay; moderate coarse prismatic structure; friable, slightly hard, moderately sticky, moderately plastic; deformable; common very fine roots throughout; common very fine dendritic tubular pores; 3 percent clay films on surfaces along root channels; 1 percent fine distinct irregular white (10YR 8/1), moist, carbonate masses in matrix; 2 percent nonflat subrounded indurated 2- to 5-millimeter quartzite fragments, by HCl, 1 normal; ; gradual wavy boundary. Lab sample # 20N00558

Btk3--150 to 200 centimeters; silt loam, yellowish brown (10YR 5/4) interior, moist; 20 percent sand; 56 percent silt; 24 percent clay; weak coarse prismatic structure; very friable, slightly hard, moderately sticky, moderately plastic; deformable; common very fine roots throughout; common fine dendritic tubular and common very fine dendritic tubular pores; 1 percent clay films on vertical faces of peds; 1 percent fine distinct irregular white (10YR 8/1), moist, carbonate masses in matrix and 1 percent very coarse distinct white (10YR 8/1), moist, carbonate concretions in matrix; 2 percent nonflat subrounded indurated 2- to 5-millimeter quartzite fragments, by HCl, 1 normal; . Lab sample # 20N00559

USDA - NATURAL RESOURCES CONSERVATION SERVICE

PEDON DESCRIPTION

Native prairie-Tribune

Print Date: 11/05/2020

Description Date: 11/5/2019

Describer: B. Nester, L. Bricknell, J. Anderson, M. Stark, C. Tecklenburg

User Site ID: S2019KS071004

User Pedon ID: S2019KS071004

Soil Name as Described/Sampled: Richfield

Taxon Kind as Sampled: series

Sampled as Classification: Fine, smectitic, mesic Aridic Argiustolls

Pedon Type: correlates to named soil

Pedon Purpose: research site

Lab Source ID: KSSL Lab Pedon #: 20N0160

Location Information:

Country: United States

State: Kansas

County: Greeley

MLRA: 72 -- Central High Tableland

Soil Survey Area:

Map Unit: 1761 Richfield SiL 0-1%

Quad Name: Tribune, Kansas

Location Description:

Legal Description: of Section 19, Township 18 S. , Range 40 W.

Latitude: 38 degrees 28 minutes 15.26 seconds north

Longitude: 101 degrees 46 minutes 43.39 seconds west

Datum: WGS84

UTM Zone: 14

UTM Easting: 257583 meters

UTM Northing: 4261730 meters

Physiographic Division: Interior Plains

Physiographic Province: Great Plains Province

Physiographic Section: High Plains

State Physiographic Area: High Plains

Local Physiographic Area:

Geomorphic Setting: plain on tableland

Upslope Shape: linear Cross Slope Shape: linear

Primary Earth Cover: Grass/herbaceous cover

Secondary Earth Cover: Other grass/herbaceous cover

Parent Material: calcareous loess

Particle Size Control Section: 20 to 35 cm.

Diagnostic Features: mollic epipedon 0 to 35 cm.

argillic horizon 20 to 35 cm.

free carbonates 35 to 51 cm.
secondary carbonates 35 to 160 cm.
free carbonates 80 to 200 cm.
lithologic discontinuity 160 to 160 cm.
secondary carbonates 193 to 200 cm.
lithologic discontinuity 193 to 193 cm.

Slope	Elevation	Aspect	Drainage
1.0%	1,107.0 M	325°	well

Ap--0 to 20 centimeters; very dark brown (10YR 2/2) interior silt loam, very dark grayish brown (10YR 3/2) interior, moist; 24 percent clay; moderate thick platy structure parts to weak medium subangular blocky structure; very friable, slightly hard, moderately sticky, moderately plastic; deformable; noneffervescent, by HCl, 1 normal; ; clear smooth boundary. Lab sample # 20N00560

Bt--20 to 35 centimeters; brown (10YR 5/3) interior silty clay loam, dark brown (10YR 3/3) interior, moist; 38 percent clay; moderate medium prismatic structure parts to strong fine prismatic structure; very firm, hard, very sticky, very plastic; semideformable; common fine roots throughout and common very fine roots throughout; common very fine dendritic tubular pores; 35 percent clay films on all faces of peds; noneffervescent, by HCl, 1 normal; ; abrupt smooth boundary. Lab sample # 20N00561

Bk1--35 to 51 centimeters; pale brown (10YR 6/3) interior silty clay loam, brown (10YR 5/3) interior, moist; 28 percent clay; moderate medium prismatic structure parts to moderate medium subangular blocky structure; firm, hard, moderately sticky, moderately plastic; semideformable; common very fine roots throughout; common fine dendritic tubular and common very fine dendritic tubular pores; 1 percent fine prominent irregular white (10YR 8/1), moist, carbonate nodules in matrix; violent effervescence, by HCl, 1 normal; ; clear wavy boundary. Lab sample # 20N00562

Bk2--51 to 80 centimeters; very pale brown (10YR 7/3) interior silt loam, pale brown (10YR 6/3) interior, moist; 26 percent clay; moderate medium prismatic structure parts to moderate medium subangular blocky structure; friable, slightly hard, moderately sticky, moderately plastic; deformable; common fine dendritic tubular and common very fine dendritic tubular pores; 4 percent fine distinct irregular white (10YR 8/1), moist, carbonate masses in matrix; noneffervescent, by HCl, 1 normal; ; clear wavy boundary. Lab sample # 20N00563

Bk3--80 to 107 centimeters; very pale brown (10YR 7/4) interior silt loam, light yellowish brown (10YR 6/4) interior, moist; 24 percent clay; weak medium prismatic structure; friable, slightly hard, moderately sticky, moderately plastic; deformable; common very fine roots throughout; common very fine dendritic tubular pores; 1 percent medium distinct irregular white (10YR 8/1), moist, carbonate masses in matrix; violent effervescence, by HCl, 1 normal; ; clear wavy boundary. Lab sample # 20N00564

Bk4--107 to 160 centimeters; light yellowish brown (10YR 6/4) interior loam, yellowish brown (10YR 5/4) interior, moist; 20 percent clay; weak coarse prismatic structure; very friable, slightly hard, moderately sticky, moderately plastic; deformable; common very fine roots throughout; common very fine dendritic tubular pores; violent effervescence, by HCl, 1 normal; ; clear smooth boundary. Lab sample # 20N00565

2C--160 to 193 centimeters; very pale brown (10YR 7/3) interior stratified sand to loamy sand, brown (7.5YR 5/4) interior, moist; 4 percent clay; weak very coarse prismatic structure; nonsticky, nonplastic; common medium dendritic tubular pores; violent effervescence, by HCl, 1 normal; ; Krotivina present in horizon from 129cm - 132cm.; abrupt smooth boundary. Lab sample # 20N00566

3Bkb--193 to 200 centimeters; very pale brown (10YR 7/4) interior loam, yellowish brown (10YR 5/4) interior, moist; 18 percent clay; weak coarse prismatic structure; very friable, slightly hard, slightly sticky, slightly plastic; deformable; 1 percent very fine distinct irregular white (10YR 8/1), moist, carbonate nodules in matrix; strong effervescence, by HCl, 1 normal; . Lab sample # 20N00567

Figures

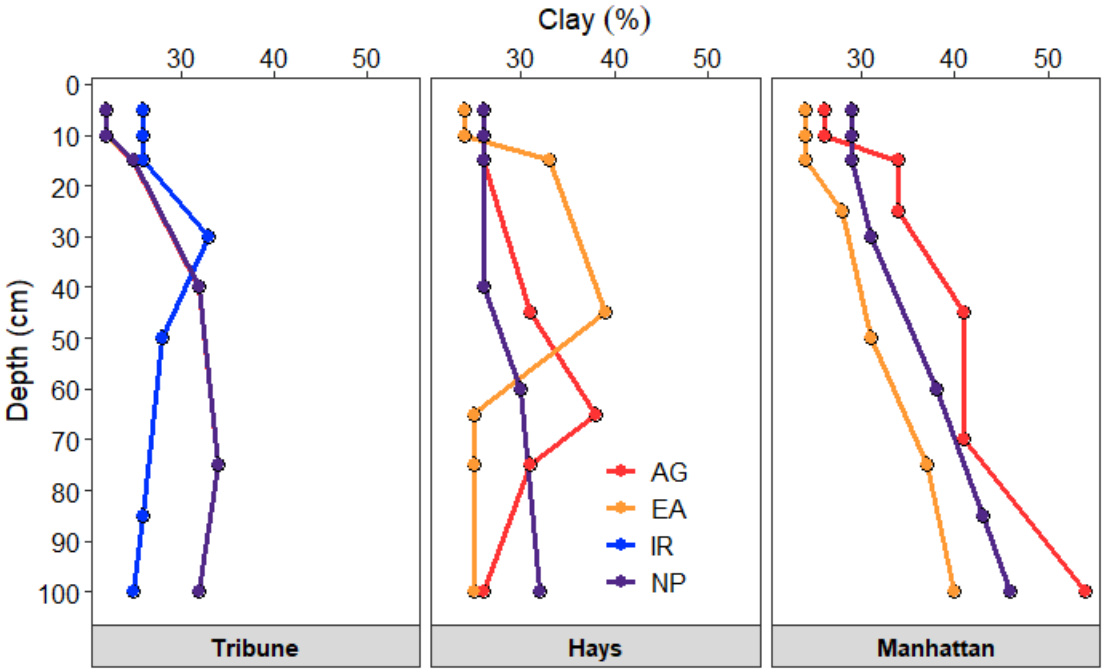

Figure C. 1. Clay by depth for different land uses and locations down to a 100 cm depth. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP). Clay for AG and EA is the same as NP at Tribune.

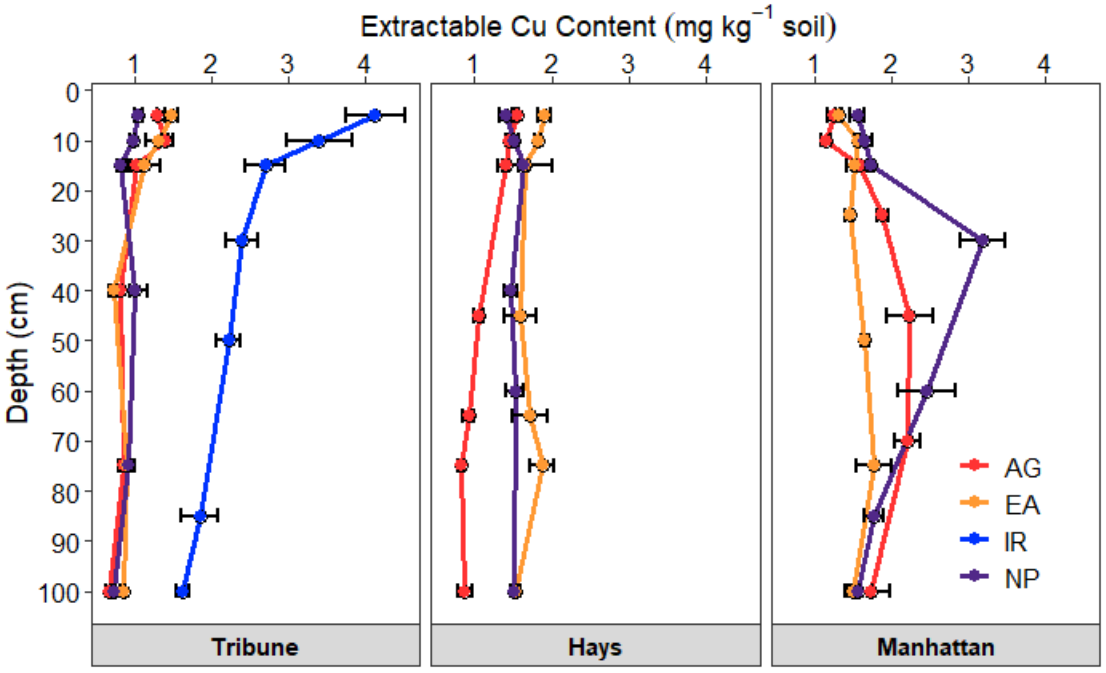

Figure C. 2. Copper by depth for different land uses and locations down to a 100 cm depth. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

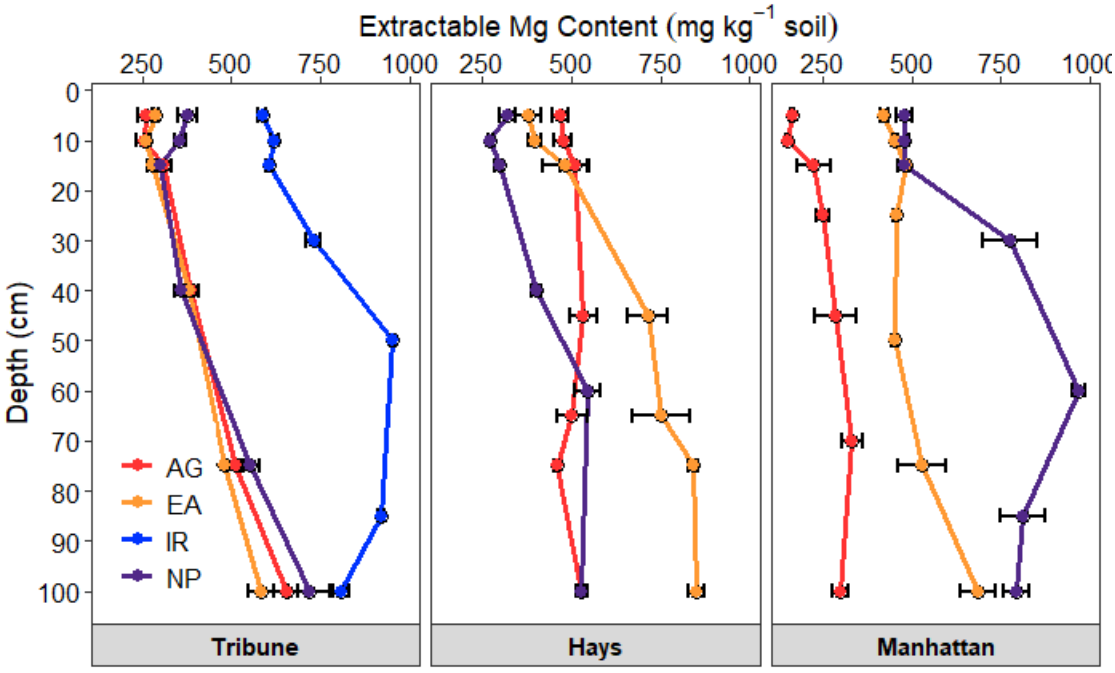

Figure C. 3. Magnesium by depth for different land uses and locations down to a 100 cm depth. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

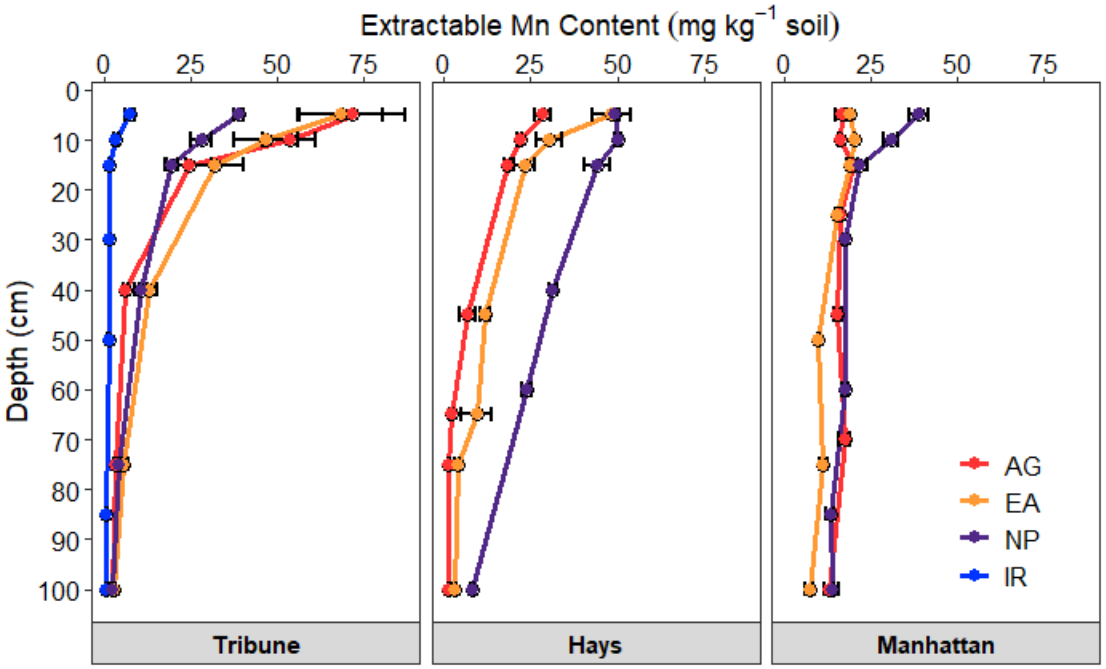

Figure C. 4. Manganese by depth for different land uses and locations down to a 100 cm depth. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

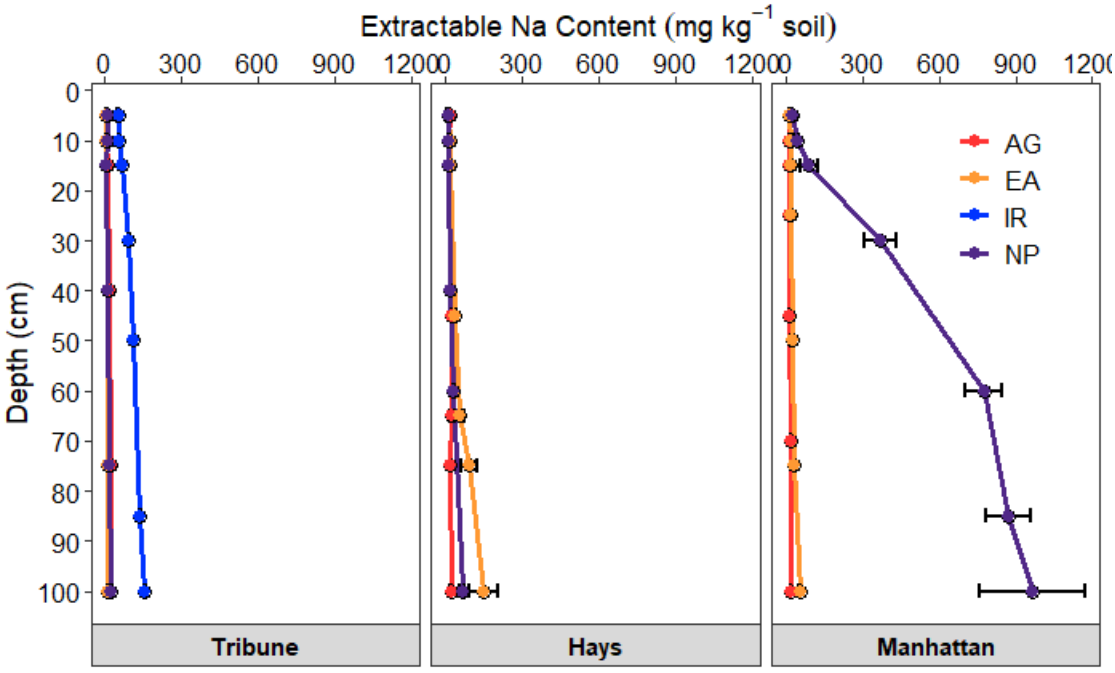

Figure C. 5. Sodium by depth for different land uses and locations down to a 100 cm depth. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

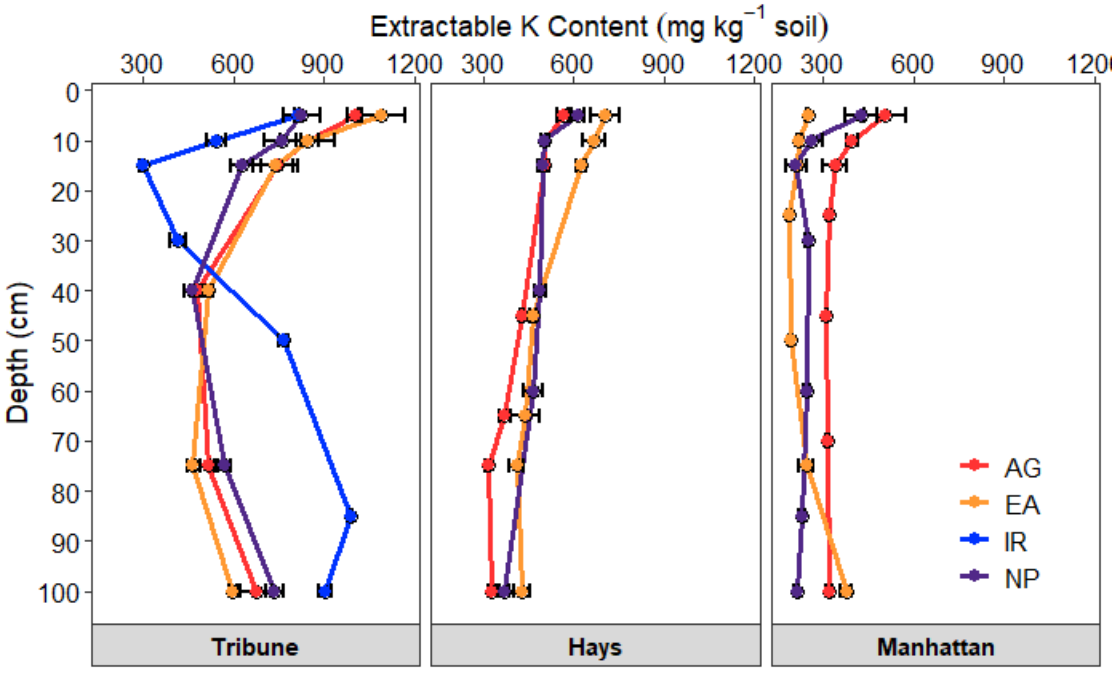

Figure C. 6. Potassium by depth for different land uses and locations down to a 100 cm depth. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

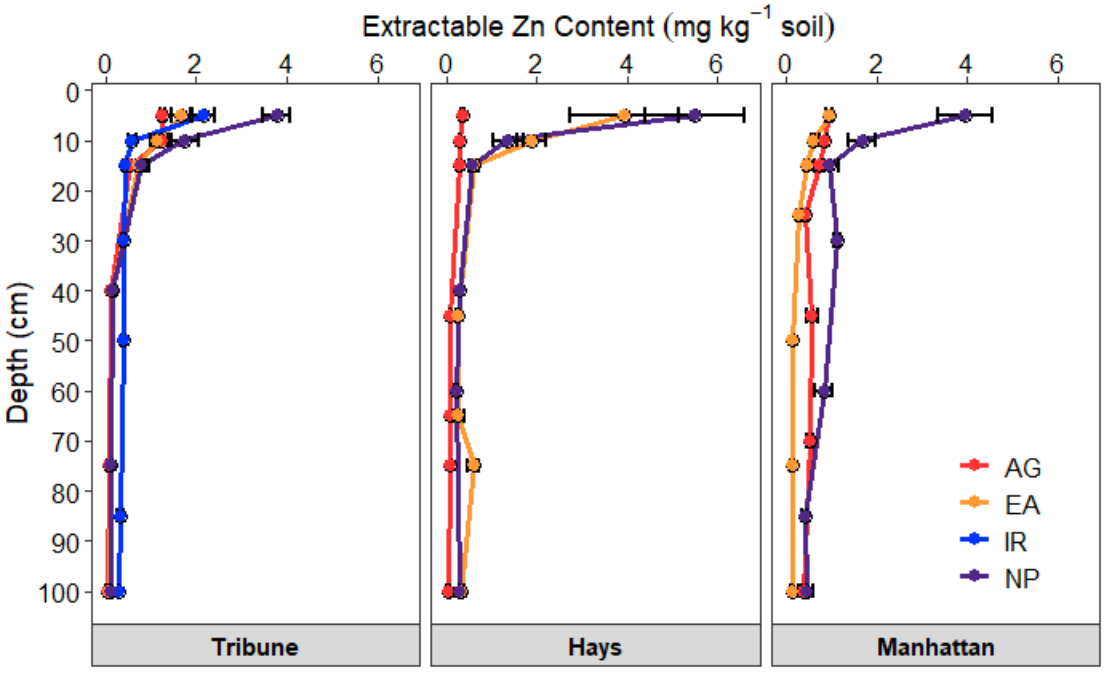

Figure C. 7. Zinc by depth for different land uses and locations down to a 100 cm depth. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

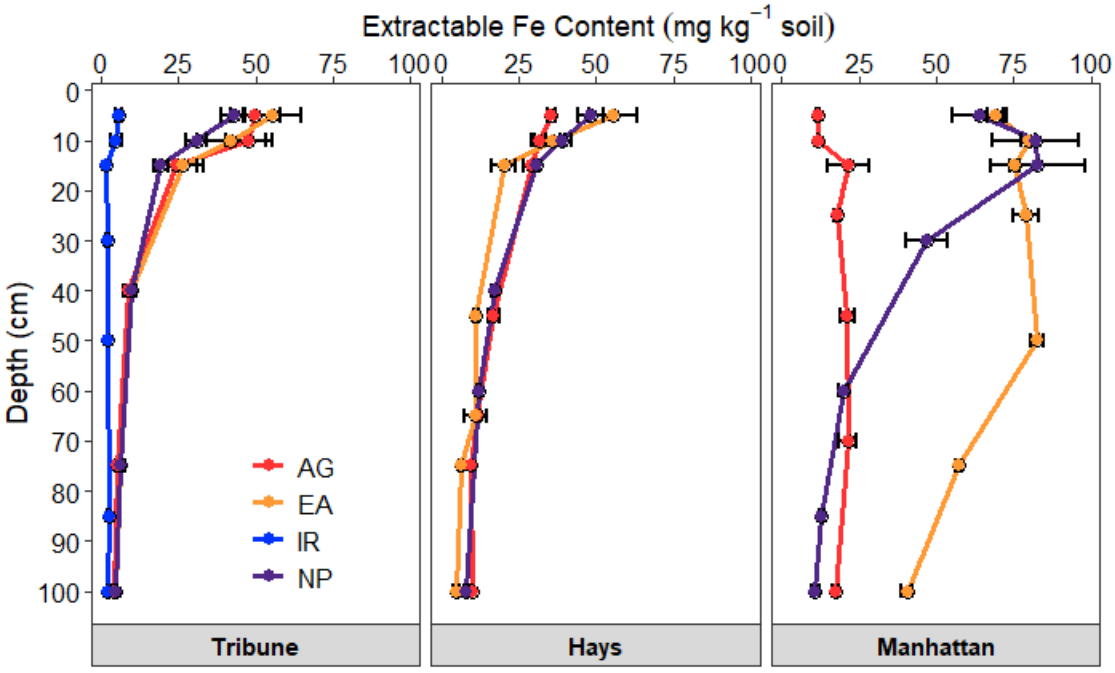

Figure C. 8. Iron by depth for different land uses and locations down to a 100 cm depth. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

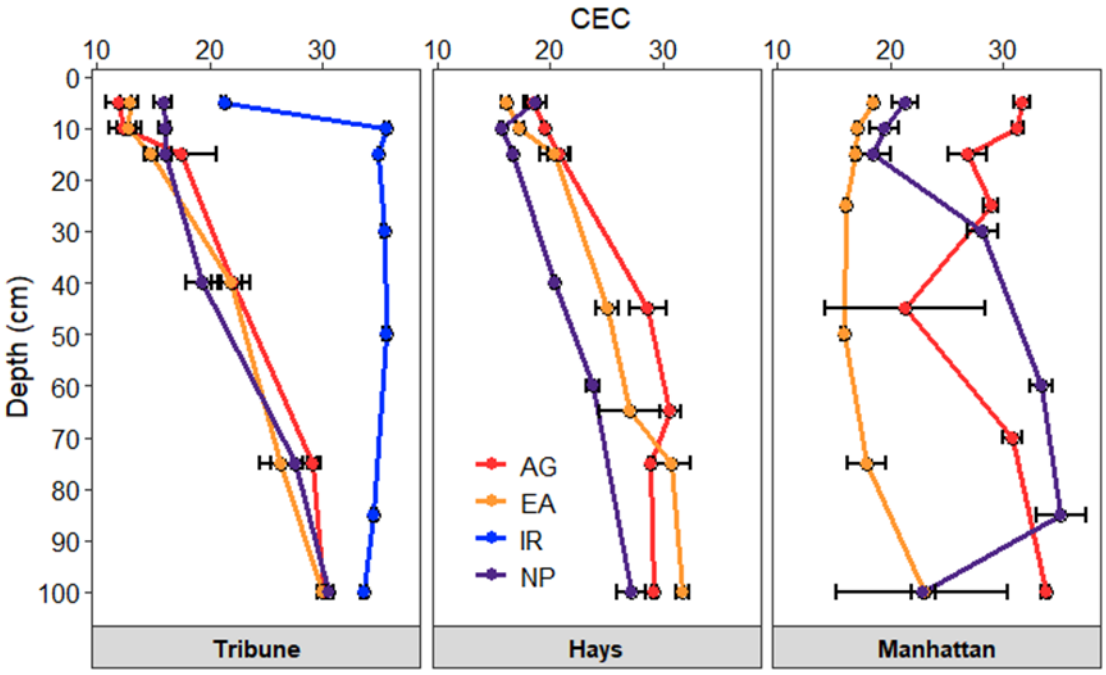

Figure C. 9. CEC by depth for different land uses and locations down to a 100 cm depth. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

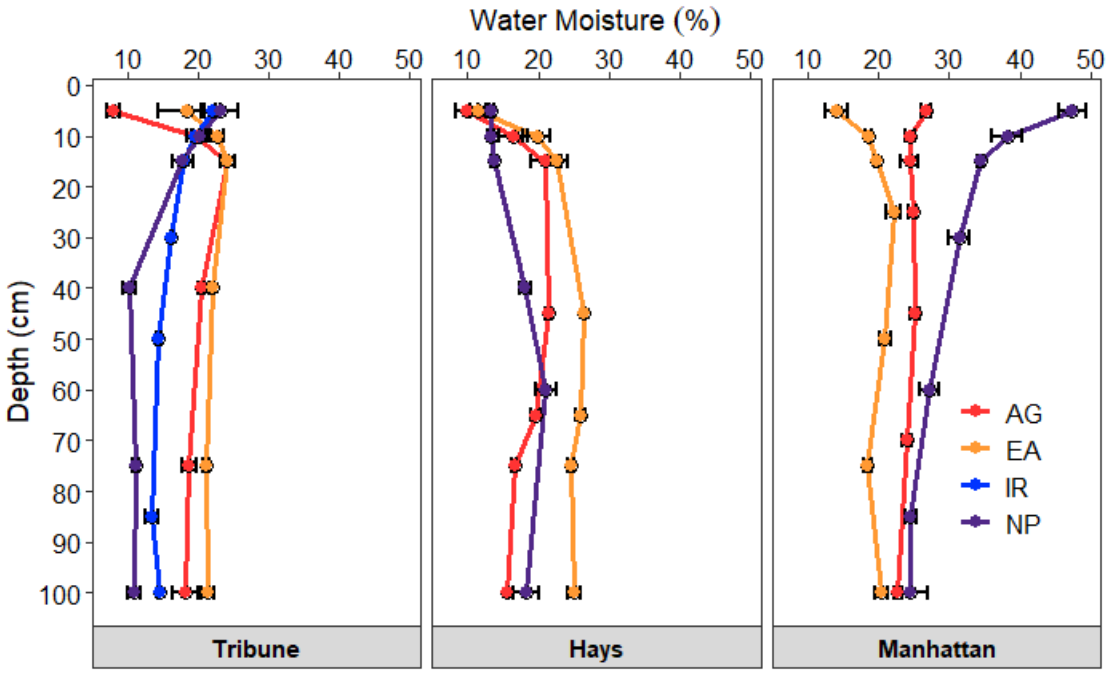

Figure C. 10. Soil water moisture by depth for different land uses and locations down to a 100 cm depth. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

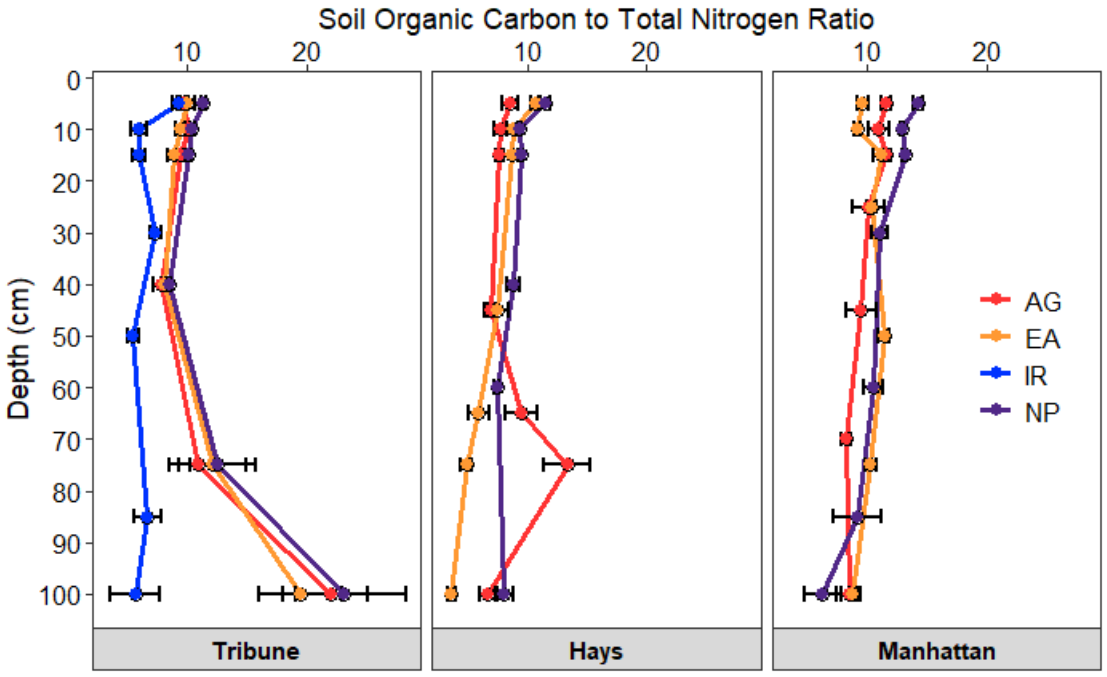

Figure C. 11. Soil organic carbon to total nitrogen by depth for different land uses and locations down to a 100 cm depth. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

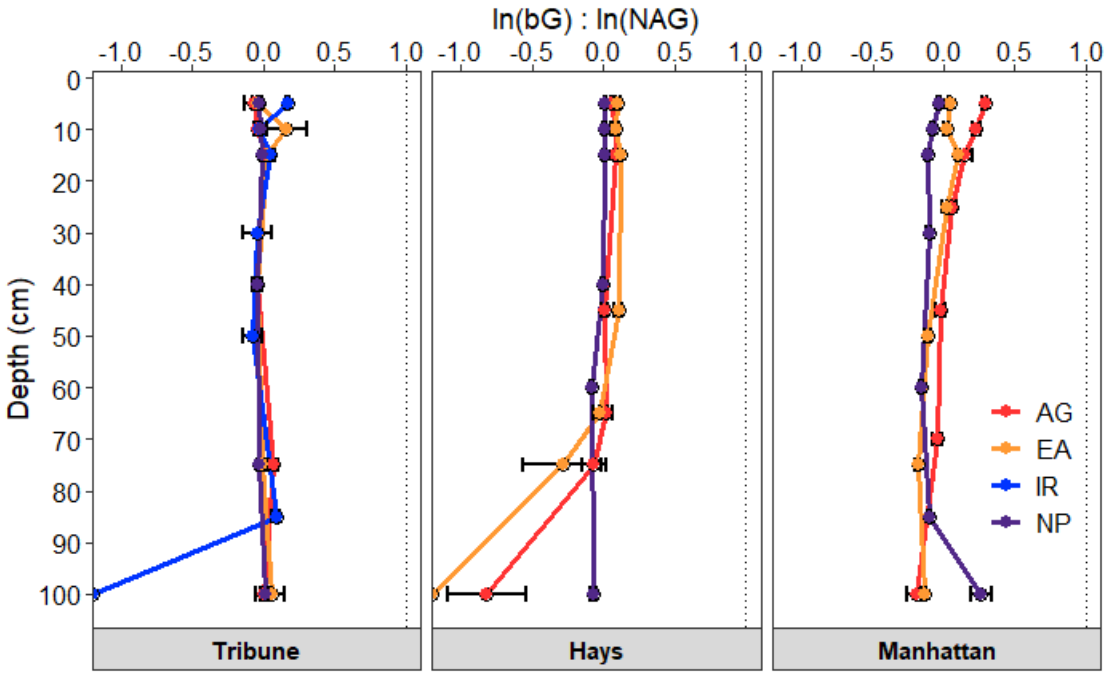

Figure C. 12. Differences in C-acquiring to N-acquiring enzyme activities by depth for different land uses and locations down to a 100 cm depth. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

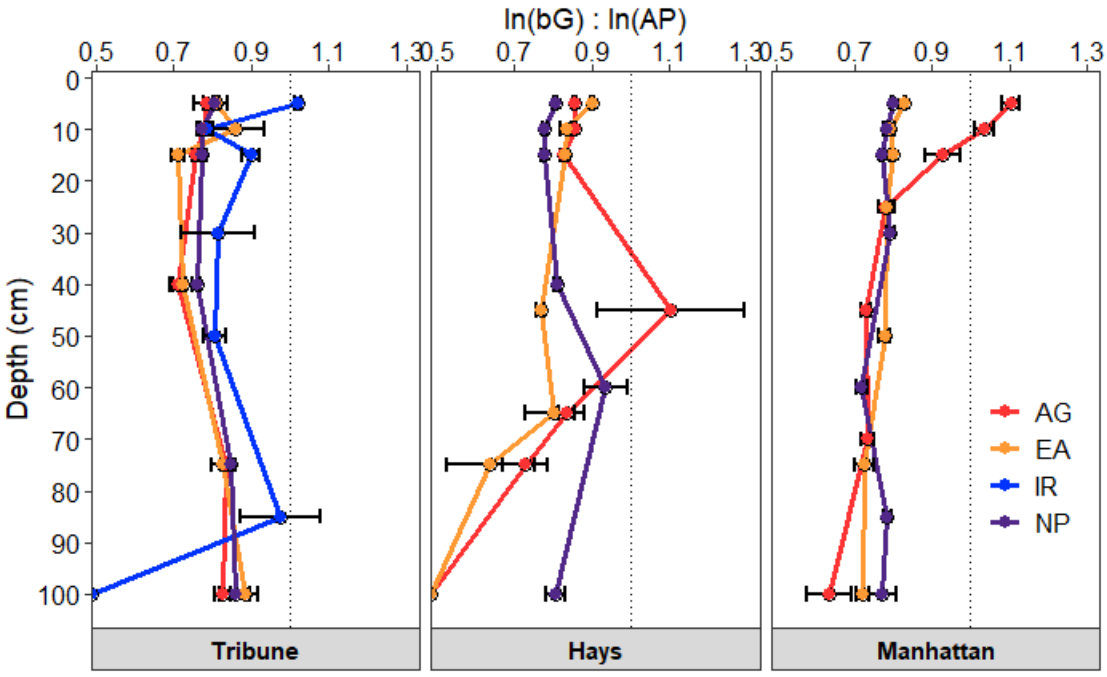

Figure C. 13. Differences in C-acquiring to lower pH P-acquiring enzyme activities by depth for different land uses and locations down to a 100 cm depth. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

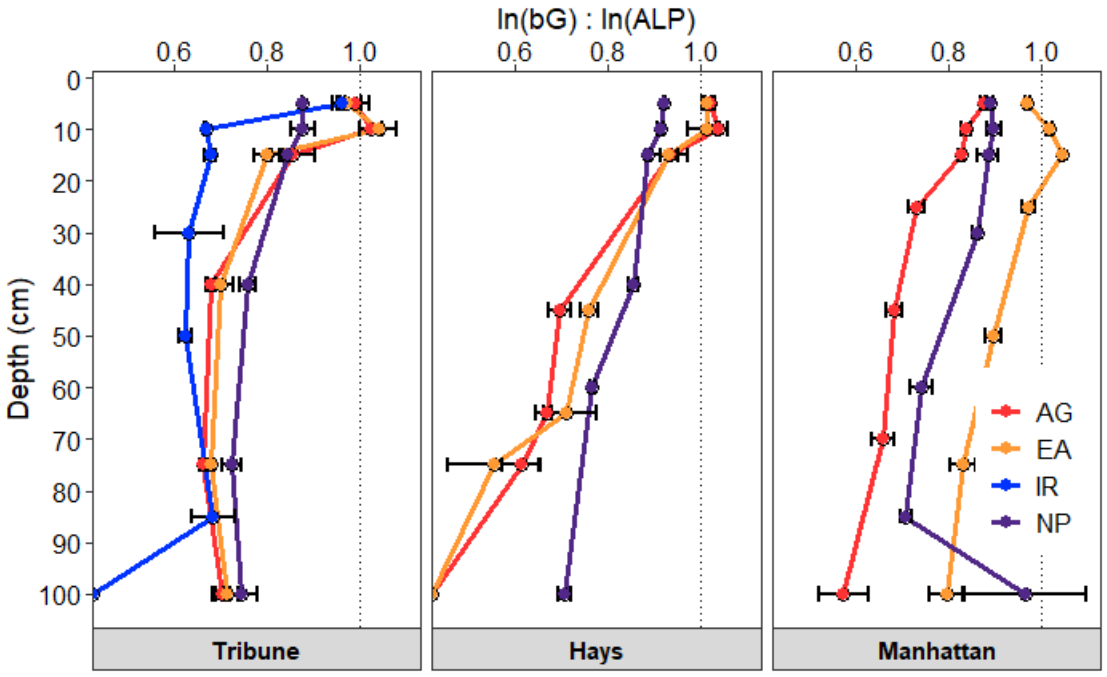

Figure C. 14. Differences in C-acquiring to higher pH P-acquiring enzyme activities by depth for different land uses and locations down to a 100 cm depth. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

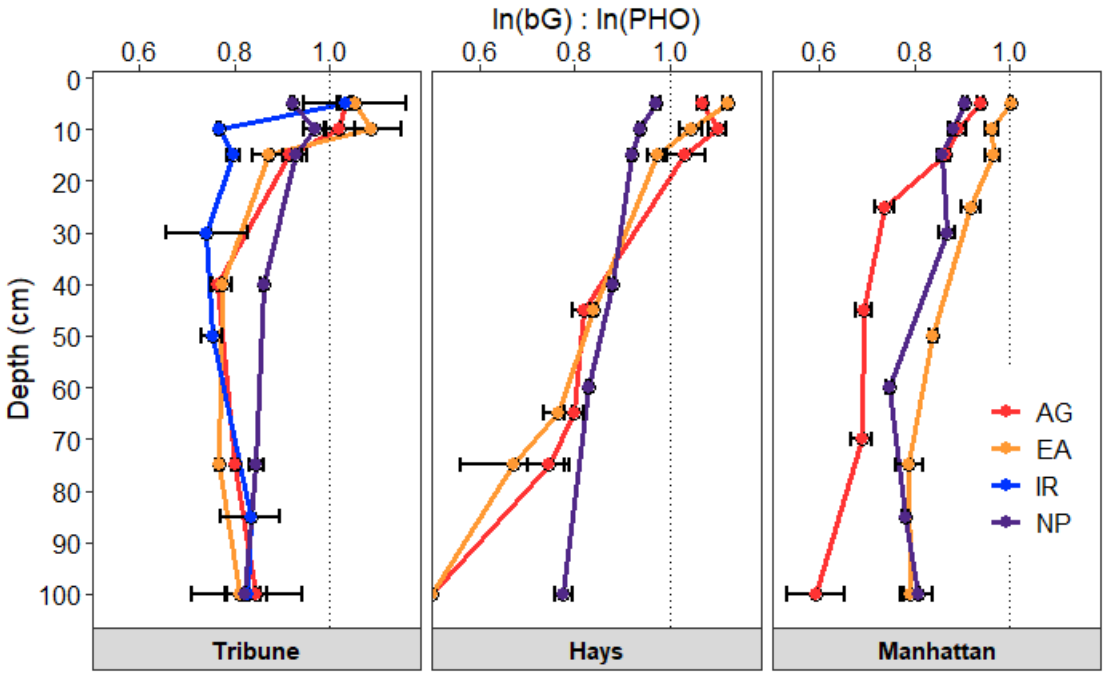

Figure C. 15. Differences in C-acquiring to P-acquiring enzyme activities by depth for different land uses and locations down to a 100 cm depth. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

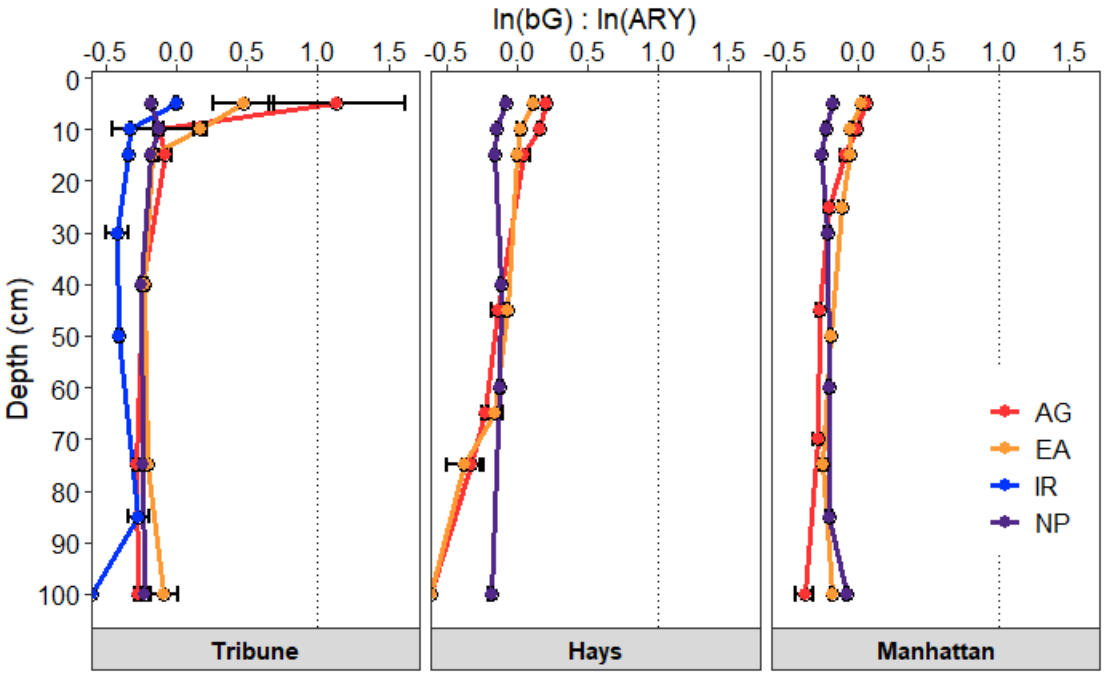

Figure C. 16. Differences in C-acquiring to S-acquiring enzyme activities by depth for different land uses and locations down to a 100 cm depth. Land use is labeled as conventional tillage (AG), no-till (EA), irrigation (IR), and native prairie (NP).

Appendix D - Custom-written R scripts

Chapter 2- Aggregate method

- https://rpubs.com/nilsemaj/chapter2aggregategraphs
- https://rpubs.com/nilsemaj/chapter2aggregatecode

Chapter 3- Topsoil

- https://rpubs.com/nilsemaj/chapter3graphs
- https://rpubs.com/nilsemaj/chapter3graphsandcode

- https://rpubs.com/nilsemaj/chapter3pcatopsoil
- https://rpubs.com/nilsemaj/chapter3pcatopsoilcode

Chapter 4- Depth

- https://rpubs.com/nilsemaj/chapter4depthgraph
- https://rpubs.com/nilsemaj/chapter4depthgraphcode

- https://rpubs.com/nilsemaj/chapter4correlationgraph
- https://rpubs.com/nilsemaj/chapter4correlationcode

- https://rpubs.com/nilsemaj/chapter4biplot
- https://rpubs.com/nilsemaj/chapter4biplotcode

Chapter 5- Infiltration

- https://rpubs.com/nilsemaj/chapter5infiltrationgraph
- https://rpubs.com/nilsemaj/chapter5infitlrationcode

R codes and datasets

https://drive.google.com/drive/folders/174kDUDoc-R9tSYOOLubOlRqXbHkoicxt?usp=sharing