AN INVENTORY OF CARBON STOCKS UNDER NATIVE VEGETATION AND FARM FIELDS IN SOUTH-CENTRAL MONTANA

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES CONTINUED

Table Page

LIST OF TABLES CONTINUED

LIST OF FIGURES

LIST OF FIGURES CONTINUED

ABSTRACT

Annually, carbon dioxide (CO_2) is emitted from the burning of fossil fuels, creating a CO_2 emission source. Vegetation and soils capture and store these emissions, however not nearly in the quantity being emitted. Disparity between sources and sinks of CO_2 emissions requires actions focused on reducing CO_2 emissions (CCSP, 2007). Cabin Creek Ranch, near Shepherd, MT offers a rich opportunity to understand the current carbon balance within various land cover types, and to determine the effect that cropping, grazing and concentrated feeding has on the potential for ranch soils to sequester additional carbon. Samples were collected from 30 soil and 16 vegetation locations, which were randomly chosen in a variety of cover types. Soil samples were taken every 15cm throughout the soil profile (down to 100cm, if possible). Four .25m^2 frames were used to collect herbaceous material 25 meters in each cardinal direction from soil pit center. Clay and land cover type were found to have a significant interaction on the organic carbon content in the soils ($p=0.021$). Additionally, dryland crop was found to be significantly different in organic carbon content compared to other cover types ($p<0.0001$). Therefore, management towards a specific land cover type could help mitigate CO_2 emissions. For example, revegetating dryland crop fields to a native grassland, sagebrush or forest, the landscape would be able to store 230%, 232% and 256% more organic carbon, respectively. Understanding the carbon balance on the landscape scale contributes to understanding the global carbon balance to help mitigate burning of fossil fuels.

WHY CONDUCT A CARBON INVENTORY?

In 2003, North America contributed 27% (1,856 million metric tons) to total global carbon dioxide (CO2) emissions, 85% of those emissions were from the United States (1578 million metric tons of CO2), 9% from Canada (167 million metric tons of CO2) and 6% from Mexico (111 million metric tons of CO2). The single largest contributor of these emissions in North America is the combustion of fossil fuels for commercial energy, accounting for 780 million metric tons of CO2 emissions in 2003. The second largest contributor in North America is transportation, accounting for 575 million metric tons of CO2 emissions in 2003 (CCSP, 2007). However, North America has globally important sinks as well. In 2003, North American vegetation removed 530 million tons of carbon per year and stored it as plant material and soil organic matter (CCSP, 2007; Derner and Schuman, 2007). This storage or sink removed 30% of the CO2 emissions from the atmosphere. The remaining 1,335 million metric tons of carbon per year means North America is a net source of atmospheric CO2. This disparity requires actions focused on reducing fossil fuel emissions, in which an array of policy instruments at local, regional, national and international levels will need to be implemented (CCSP, 2007).

The combustion of fossil fuels in the last century has created an imbalance in the cycling of carbon through the atmosphere, land, freshwater, and marine environments (CCSP, 2007). Land conversion from forests to agricultural fields, and other land-use changes, has also released stored carbon back to the atmosphere (Billings, 2006; CCSP, 2007; Elmore and Asner, 2006; Jones and Donnelly, 2004; Liao et al. 2006; Zhang et al.

2011; Davidson and Ackerman, 1993), affecting other ecosystem processes, such as water quality, nutrient cycling and ecosystem health (Derner and Schuman, 2007). Changes in land use also change soil structure (Chan et al 2003), affecting the carbon storage capacity of soils, potentially increasing the amount of CO2 emissions (Bronick and Lal, 2005). This change is important because soils can store twice as much carbon as the atmosphere, and 2.5 times as much as plants, making soils an important factor in the capture and storage of carbon on local as well as global scales.

Carbon capture and storage (CCS) by soils follows two general pathways; terrestrial and geologic. Geologic carbon is permanently stored in underground rock formations, preventing the release back to the atmosphere (CCSP, 2007). Terrestrial carbon is stored in forests and other vegetation or in the soils of farmland, cropland, rangeland and other organic soils (IPCC, 2000). Because geologic formations exist below soils, management has limited effect on the geologic carbon stocks. However, terrestrial carbon can be manipulated to enhance storage or to limit the release of CO2 back to the atmosphere. There are two approaches to storing carbon in terrestrial ecosystems: 1) protecting ecosystems that already store carbon in a way that stocks are maintained or increased and 2) managing soils and vegetation to increase CCS beyond current conditions. The terrestrial CCS processes represent approaches that land managers can manipulate to help mitigate rising atmosphere CO2 through ecosystem rather than hard engineering processes.

Understanding the basics of CCS is important, but being able to implement these management recommendations can be challenging. Management practices that limit the amount of disturbance can increase carbon storage within soils. However, soils and vegetation are variable across time and space, and not understanding the fundamental processes occurring while trying to capture and store carbon can be detrimental. Understanding the processes that influence the distribution of carbon across the landscape can allow us to ameliorate the consequences of anthropogenic disturbances to the carbon cycle and the feedback loop of global climate change (Jobbágy and Jackson, 2000; Throop et al., 2012; Zhang et al., 2011). One way of understanding the processes controlling carbon distribution is to look at the carbon balance on a landscape scale and determine the storage potential of certain landscapes.

Multiple studies have shown the distribution of soil organic carbon (SOC) through the soil column is a function of both climate and vegetation (Jobbágy and Jackson, 2000, 2001; Throop et al., 2012). Plant characteristics, such as, biomass cycling rates, above- and below-ground biomass distribution, root distribution and maximum rooting depth all play important roles in determining soil carbon profiles (Jobbágy and Jackson, 2001). Because these attributes differ among species, differences in vegetation community composition can dictate the distribution of soil organic carbon across the landscape (Hall et al., 2012; Jackson et al., 2002; Lal, 2005; Rau et al., 2011; Zhang et al., 2011). Therefore, it is important to understand the role that different types of vegetation play in incorporating carbon into the soils for long-term storage. Determining the amount of carbon that can be sequestered based on vegetation community provides managers an easier target for landscape management.

The purpose of this study was to determine the current inventory of carbon associated with various vegetation or land cover types on a ranch located in south central Montana. The current owner wants to use the property to mitigate CO2 emissions, so it is important to have an initial carbon inventory. This inventory will serve as a baseline for evaluating the effect management may have on future incorporation of carbon into the soil/vegetation system. Because of the perceived relationship between plant community and carbon distribution across the landscape, a clear picture of which vegetation communities can capture and store the most carbon will direct management practices that can offset CO2 emissions. With this guidance, management, in turn, would help mitigate the rising levels of atmospheric CO2.

TOTAL CARBON

Terrestrial Carbon Storage

Carbon stored in plant biomass, organism biomass or in soils is all considered part of the terrestrial carbon capture and storage (CCS) pathway. Carbon capture and storage pathways are different depending upon the type of carbon one is analyzing. Soil carbon is comprised of two forms: organic and inorganic. Inorganic carbon is isolated to arid and semi-arid regions of the world, whereas organic carbon is found in all global soils (Sanderman, 2012). Differentiation between these forms is important when trying to mitigate for the rise in atmospheric carbon dioxide levels because organic carbon is the most easily manipulated of the two and has been assigned monetary value in carbon banking programs. Therefore, knowing where on the landscape the different forms are sequestered and how each form moves through plant, soil and animal systems is extremely beneficial.

Organic Carbon

Organic compounds contain carbon-hydrogen bonds, and are derived from living organisms or their decomposition. The two main processes that incorporate organic carbon into the soil are: 1) root and shoot decomposition and 2) root exudates and other substances being released into the rhizosphere during plant growth (Kuzyakov and Domanski, 2000).

Cropping and grazing management practices are some of the most common practices that affect organic carbon stocks. Zhang et al (2011) found that as degradation of grasslands increased due to overgrazing, soil aggregate break-up increased, resulting in losses of carbon from the soil. Most of the loss is thought to be organic carbon, because organic carbon is highly concentrated in the top 30cm of the soil column where roots accumulate (Jobbágy and Jackson, 2000). On the other hand, it has been argued that carbon storage increases in grazed grasslands (Derner et al, 1997; Henderson, 2000; Schuman et al., 1999). In addition, Schuman et al (2002) state that well managed grazing stimulates growth of herbaceous species and improves nutrient cycling in grassland ecosystems.

Agricultural soils provide another way to sequester atmospheric carbon. Entry et al (2004) showed that the increased organic matter lead to organic acid synthesis that dissolves carbonates and inhibits carbonate formation. Because croplands are limited in the amount of organic matter incorporated into the soil, carbonates form easily, increasing the soil inorganic carbon stock. With this in mind, it is easy to understand that there will be less inorganic carbon found in areas that have a higher amount of organic matter in the soil profile (e.g. native grassland and sagebrush). However, agriculture has been proposed as a way to increase the amount of SOC and soil productivity (Olson et al, 2014) using cover crops. Olson et al. (2014) found that SOC stocks in the tillage zone, subsoil and rooting zone increased with cover crops. West and Marland (2002) examined the energy requirements and subsequent carbon emissions associated with current agricultural practices in the United States and found that changing from conventional tillage (168 kg C $ha^{-1}yr^{-1}$ released) to no-till farming can sequester up to 200 kg C $ha^{-1}yr^{-1}$. However, carbon sequestered in an agricultural setting can be negated by the fossil fuel emissions during planting and tilling (West and Marland, 2002). To date, most of the literature indicates that intensive cropping in conventional tilling systems may increase overall carbon emissions, hindering mitigation efforts.

Inorganic Carbon

Inorganic compounds do not contain the carbon-hydrogen bonds of the organic form because they are most often derived from geologic materials. Specifically, inorganic carbon refers to mineral carbonates (Bronick and Lal, 2005; Sanderman, 2012), occurring in two forms, lithogenic and pedogenic. Lithogenic or primary carbonates are defined as soil inorganic carbon that is inherited from calcareous parent material, whereas pedogenic carbonate is defined as inorganic carbon that has formed in situ by the precipitation of calcium carbonate ($CaCO_3$) within soils from the surface and upper horizons (Sanderman, 2012). In other words, pedogenic carbonates form when dissolved CO_2 combines with calcium and magnesium from outside the system, eventually precipitating as carbonate or bicarbonate (Bronick and Lal, 2005). In arid locations, bicarbonate cations, dissolved carbonates and CO_2 can react with other available cations to form these secondary coatings on soil particles (Bronick and Lal, 2005). However, it is difficult to differentiate between pedogenic and lithogenic carbon forms. According to West et al (1988), lithogenic carbonates arise from lithorelicts like indurated limestone bedrock and coarse limestone fragments; whereas pedogenic carbonates include thin laminar cappings on indurated limestone, and carbonate films and threads on soil ped faces. However, because inorganic carbonate tends to accumulate deeper in the soil profile than organic carbon, most analyses (chemical and physical) can easily differentiate between organic and inorganic forms by controlling for soil depth.

Little information is known about the interaction between SOC and pedogenic carbonate formation in arid and semi-arid regions of the world (Bronick and Lal, 2005). Nonetheless, Sanderman (2012) proposes three pathways to enhance the exchange of carbon dioxide between atmosphere and soils. The first is the process of silicate mineral weathering in which carbon dioxide in the atmospheric gaseous phase is converted to solid, bicarbonate. This bicarbonate is then stored in soils for 100s to 1000s of years. The second process is carbonate dissolution, in which the carbonate is dissolved in the upper soil profile to be re-precipitated deeper in the soil (Khokhlova et al, 1997**)**. This process is less clear because it depends on where the carbon dioxide originated; upper soil horizons, groundwater or the atmosphere. The third process is pedogenic carbonate formation, which is derived from the carbonate dissolution process and consumes bicarbonate while precipitating calcium carbonate and releasing carbon dioxide back into the atmosphere.

Inorganic carbon is very hard to manipulate with management practices. However, organic carbon is very sensitive to management practices, and can be easily manipulated in order to increase the soil organic carbon stocks. In addition, inorganic carbon takes thousands of years to form, whereas the organic carbon stocks fluctuate yearly. Management practices that affect both the soil organic carbon and aboveground carbon stocks are conservation of natural areas, grazing management, reforestation and cropping systems. Conservation of natural areas protects the surface horizons that store a large amount of organic carbon (Jobbágy and Jackson, 2000). Grazing management has different outcomes when it comes to carbon sequestration. Derner et al. (19997), along with others (Shuman et al, 1999; Henderson 2000) state that grazing increases the soil organic carbon stocks; whereas Zhang et al (2011) showed that grazing degraded the landscapes, decrease the soil carbon stocks. Reforestation and cropping systems are increasing the aboveground biomass, ultimately increasing the herbaceous carbon stock on the landscapes. These practices are just a few of the different management practices that can be implemented to increase carbon stocks.

Currently, Cabin Creek Ranch has intact native grasslands, sagebrush and forests, with both the northern and southern boundaries comprised of cropland (irrigated and dryland). These different land cover types provide an opportunity to describe the amount of carbon stored in the soils under different management systems. Furthermore, grazing management on the ranch includes winter supplementation locations scattered through the native rangeland. It is not well understood whether these concentrated feeding areas increase the amount of organic matter entering the soil or have long-term negative effects on the amount of carbon being captured and stored. For example, the compaction of the soil during the feeding period could limit the infiltration of water, hindering the decomposition of added organic matter, and ultimately, slowing organic carbon accumulation. With all these different land uses, there is a rich opportunity to understand the current balance of carbon within the various land cover types at Cabin Creek Ranch, and to determine the effect that cropping, grazing and concentrated feeding sites may have on the potential for ranch soils to sequester additional carbon.

RANCH

Background

Cabin Creek Ranch is located near Shepherd, Montana about 23 miles northeast of Billings (Figure 1). The ranch is comprised of 20,000 acres, in which private and public lands are intermixed (Figure 2). The Bureau of Land Management has 3,500 acres checker boarded inside the ranch boundaries, along with 640 acres of State Land. The ranch landscape is broken into 16,000 acres of native rangeland/pasture, 3,000 acres of dry cropland and 900 acres of irrigation cropland. Pivots, fed from the Billings Bench Water Association (BBWA) diversion from the Yellowstone River, irrigate all of the cropland located in the southern portion of the ranch, whereas the dryland cropping occurs in the northern portion.

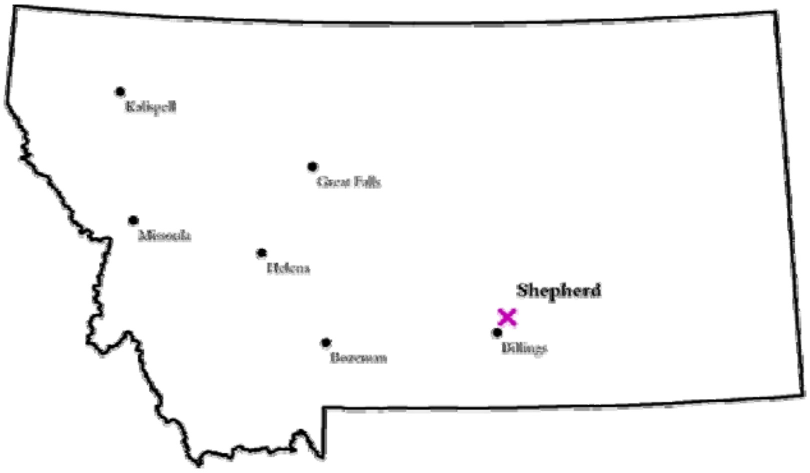

Figure 1. Cabin Creek Ranch located in south central Montana near the small rural community of Shepherd, Montana.

The Shelhamer family owned Cabin Creek ranch from 1962 to 2012. Their operation consisted of commercial Angus and Angus X cattle, dryland and irrigated farming. Crops included winter wheat, alfalfa hay, sugar beets, corn for silage and a small amount of barley. Most of the crop production is sold as a cash crop.

In May 2012, Mr. Rob Andy purchased Cabin Creek Ranch from the Shelhamer family. The ranch is still managed as the Shelhamer family did, with production of alfalfa hay, dryland wheat, sugar beets, corn and barley. In addition to cropping, the ranch runs purebred Angus cattle, 500 cow/calf pairs, 100 yearlings and 25-30 bulls. Mr. Andy bought the ranch to mitigate carbon output from multiple manufacturing companies in the US and overseas. Even though there is not a set protocol for carbon sequestration marketing in the United States, Mr. Andy wanted to be a leader in the trade of carbon credits not used by his company. Because security exchange standards require verification of the amount of carbon being sequestered, Mr. Andy needed a carbon baseline for his property before any monetary value could be assigned to tonnage of carbon sequestered. In order to determine a carbon baseline, all objects that are part of the carbon cycle (plants and soils) need to be analyzed to determine their contribution to the carbon baseline.

Landscape Assessment: Vegetation, Soils and Geology

Cabin Creek Ranch encompasses a wide range of vegetative communities (Figure 2, Table 1) and soils. This diversity provides a range of possibilities to offset carbon emissions. Cabin Creek Ranch rangelands are comprised of sagebrush and grasslands intermixed with deep drainages supporting ephemeral riparian communities. Because of additional water, these communities have greater species richness and biomass production than surrounding sagebrush and grassland. This is expected to increase organic carbon storage. Higher amounts of organic carbon in riparian areas would occur, because runoff from the surrounding uplands facilitates the breakdown and incorporation of organic matter (and organic carbon) into the floor of the drainage. In addition, areas that are water collection sites have an increase in fine particulate matter (clays), which binds organic carbon, further increasing the organic carbon content. However, there are also areas of the landscape in which cattle are fed supplements during the winter months. Animal concentration in confined areas degrades the vegetation community. A degraded rangeland exhibits a decrease in species diversity, potentially resulting in a decreased amount of carbon storage, in both the plants and the soils (Zhang et al., 2011; Houghton et al., 1999). However, other studies show an increase in carbon storage under grazing pressure when compared to ungrazed exclosures due to increased nutrient cycling and stimulated herbaceous growth in grassland ecosystems (Derner et al, 1997; Henderson, 2000; Schuman et al. 1999, 2002).

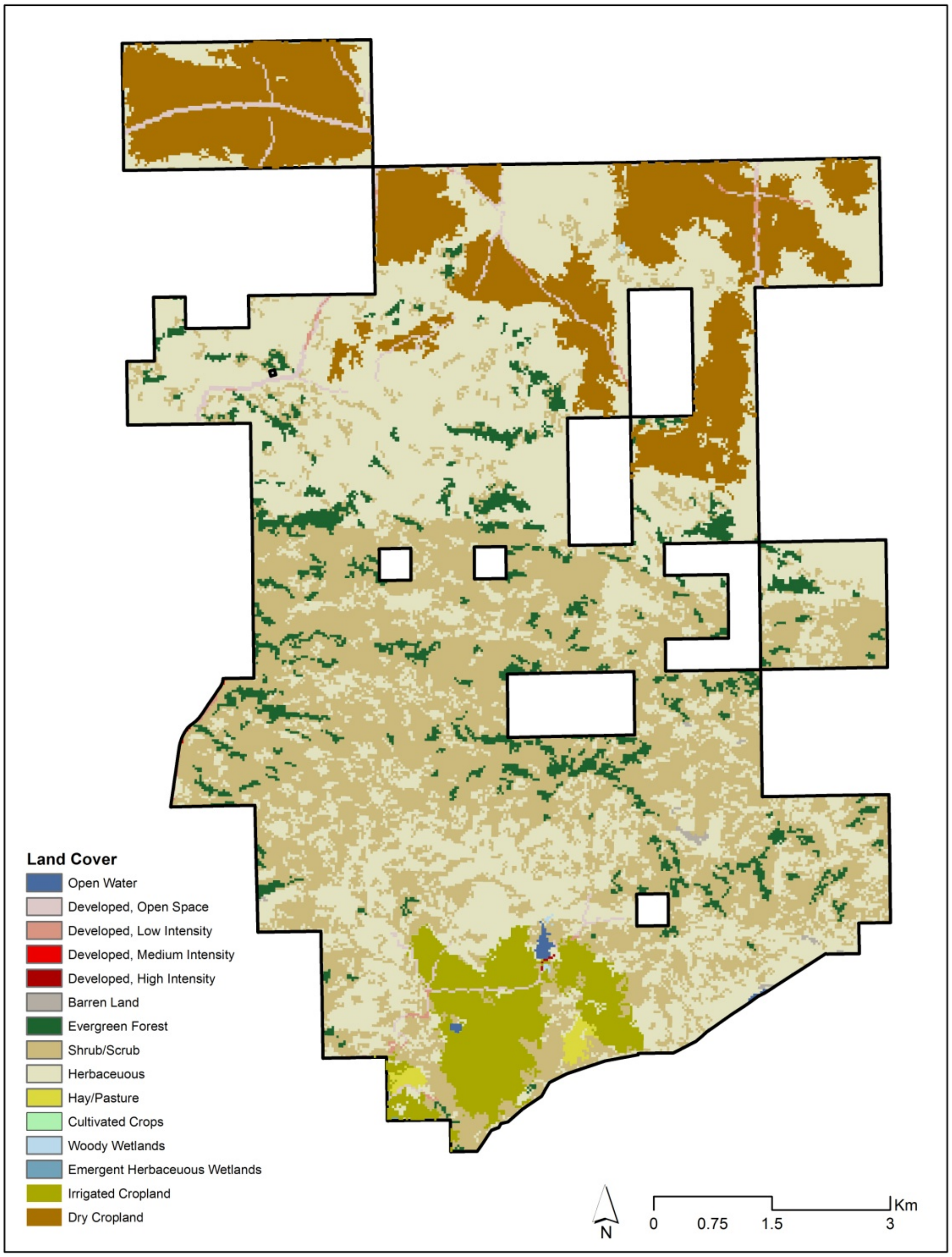

Figure 2. Cabin Creek Ranch land cover map. The north part of the ranch is comprised of dry cropland (brown polygons), whereas the south part of the ranch is comprised of irrigated croplands (moss green polygons) and perennial riparian locations (adjacent to the Yellowstone River). The rest of the ranch has native rangeland, comprised of forest, sagebrush shrublands and grassland (green, dark tan and light tan, respectively), with ephemeral riparian locations intermixed. Data was generated from the USDA Geospatial Data Gateway (accessed 2013).

Table 1. Acreage of land cover types on Cabin Creek Ranch Shepherd, Montana. Perennial riparian is not included, as the boundary of the ranch does not include this cover type. Acreage was calculated from the Figure 2 with the use of ArcMap.

Land Cover	Acreage (ac)
Forest	1,032
Sagebrush	6,679
Grassland	8,140
Irrigated Cropland	926
Dry Cropland	2,950
Ephemeral Riparian	273

These land cover types described by their dominant vegetative communities exist on a complex series of soils (Figure 3). The soil series are listed as suborders (Figure 4, Table 2) for easier discussion. Table 2 also displays the percentage of the ranch each series covers. To facilitate sampling, soils were stratified using NRCS soil survey maps accessed through the UC Davis web tools. This mapping service provided information on the expected soil depth, organic matter concentration and texture of various soil classes within the property boundary. In addition, this search indicated that the ranch is comprised of a variety of different soil complexes, all of which are similar in the textural category, with varying amounts of sand and clay.

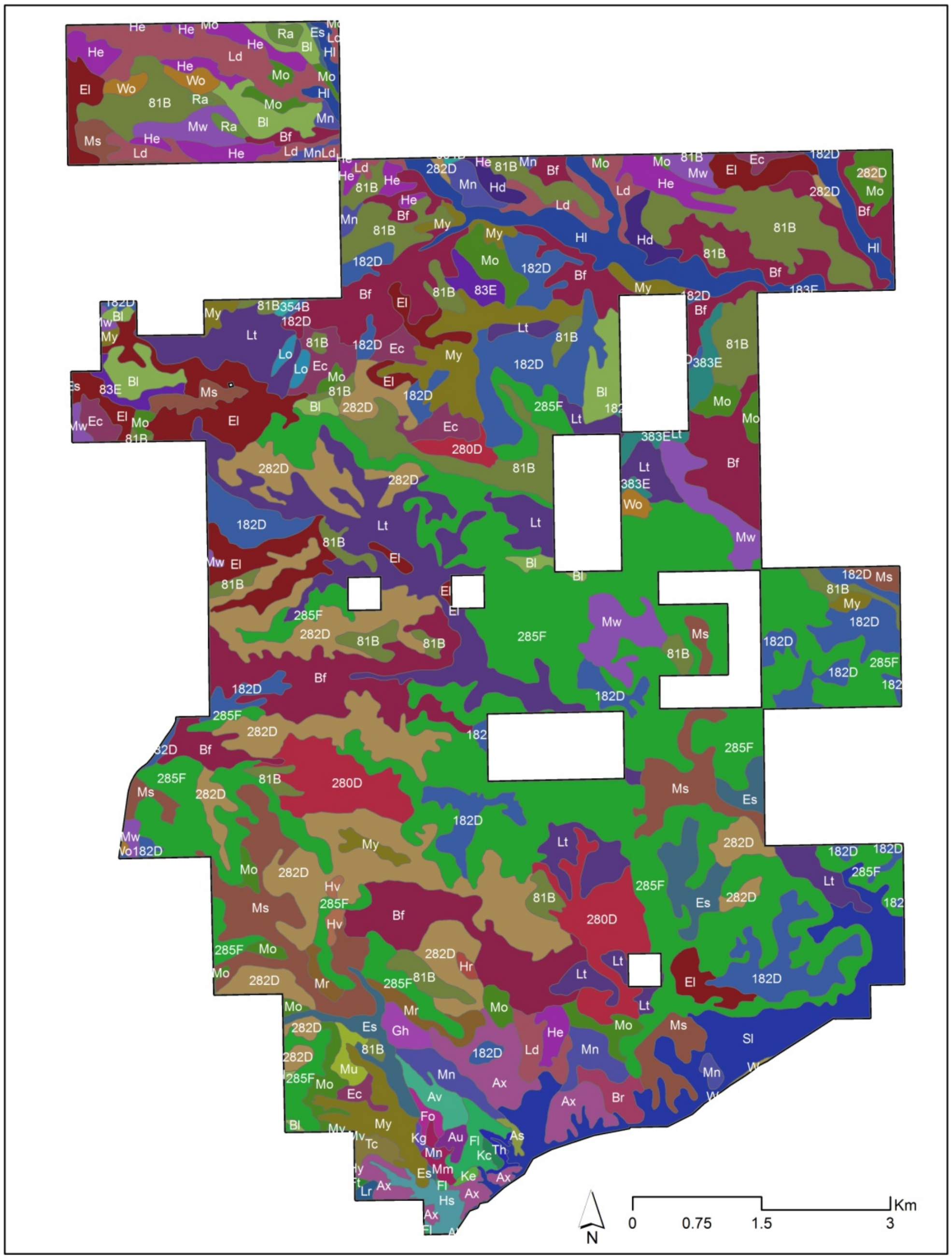

Figure 3. Mixed soil series on the Cabin Creek Ranch. The map was downloaded from the UC Davis soils application (http://casoilresource.lawr.ucdavis.edu/gmap/). Each color represents a different series, which are classified to suborders (Figure 4), and classified in Table 2. The UC Davis application was developed by the California Soil Resource Lab at UC Davis and UC-ANR in collaboration with the USDA Natural Resources Conservation Service.

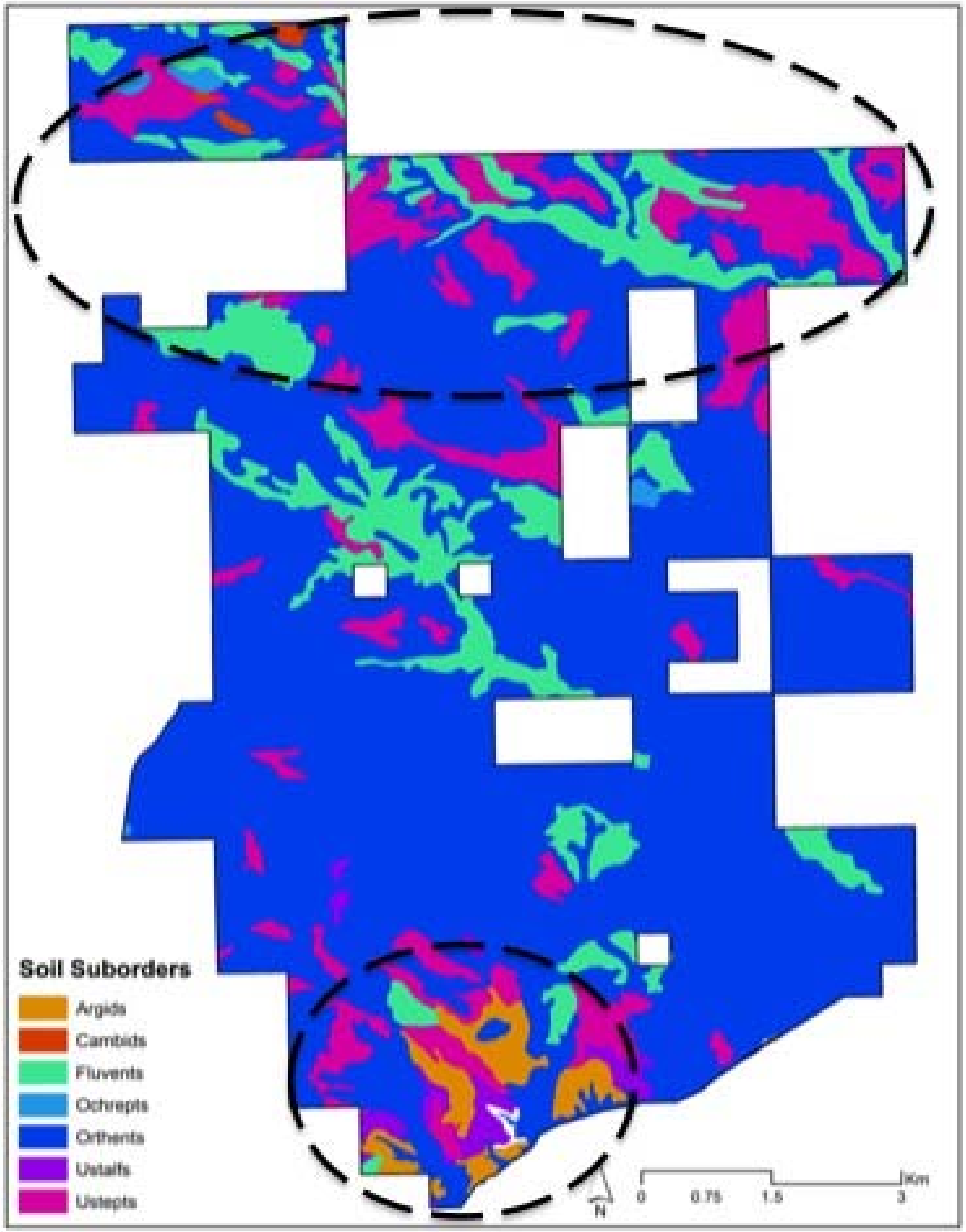

Figure 4. Cabin Creek Ranch soil suborder map. Soil series (figure 3) were classified in ArcMap by their suborders and were then merged into new suborder polygons. Those soil series that were classified into suborders are shown in table 2. Black ovals indicate locations of dryland (north) and irrigate (south) cropping systems.

Table 2. Compilation of Cabin Creek soils in terms of dominant taxonomic suborders and textural categories within map units, and the area of the ranch covered by each set of series and complexes. Each map unit may be comprised of multiple soil series because the scale of the mapping effort did not allow specific series to be mapped exactly. This information was drawn from the Billings and Rosebud county soil survey (Geospatial Data Gateway, 2013).

	Map Unit Symbol	**Map Unit Name**	**Acreage (ac)**
Argids			400
	Au	Arvada Clay Loam, 0 to 1 percent slopes	
	Av	Arvada Clay Loam, 1 to 4 percent slopes	
	Ax	Arvada-Bone Silty Clay Loams, 0 to 1 percent slopes	
Cambids			42
	Ra	Razor clay loam, 2 to 7 percent slopes	
Fluvents			2,420
	Al	Haverson Silt Clay Loam, 0 to 1 percent slopes	
	Gh	Glenberg fine sandy loam, 1 to 4 percent slopes	
	Hd	Haverson silty clay loam, 0 to 1 percent slopes	
	He	Haverson silty clay loam, 1 to 3 percent slopes	
	Hl	Haverson-and Lohmiller soils, 0 to 4 percent slopes	
	Hy	Hysham-Laurel silty clay loams, 0 to 2 percent slopes	
	Lo	Lohmiller silty clay, 3 to 7 percent slopes	
	Lr	Lohmiller silty clay, 0 to 1 percent slopes	
	Lt	Lohmiller – Elso complex, 4 to 15 percent slopes	
Ochrepts			79
	Wo	Worland fine sandy loam, 2 to 7 percent slopes	
Orthents			14,483
	182D	Cabbart-Delpoint Loams, 4 to 15 percent slopes	
	183E	Cabbart-Blacksheep, dry-Complex, 8 to 25 percent slopes	

Table 2. (Continued)

	Map Unit Symbol	Map Unit Name	Acreage (ac)
Orthents (Cont.)	280D	Blacksheep, dry-Cabbart, dry-Rock Outcrop Complex, 8 to 60 percent slopes	
	282D	Cabbart-Blacksheep complex, 4 to 15 percent slopes	
	285F	Blacksheep, dry-Cabbart, dry-Rock outcrop complex, 8 to 60 percent slopes	
	383E	Cabbart-Blacksheep complex, 8 to 25 percent slopes	
	As	Apron fine sand loam, 4 to 7 percent slopes	
	Bf	Bainville-Elso-Shale outcrop complex, 7 to 25 percent slopes	
	Bl	Bainville-Worland Complex, 4 to 7 percent slopes	
	Ec	Elso clay loam, 4 to 7 percent slopes	
	El	Elso clay loam, 7 to 15 percent slopes	
	Es	Elso-Lohmiller Complex, 15 to 35 percent slopes	
	Hs	Hilly, Gravelly Land	
	Ld	Lambert Soils, 7 to 35 percent slopes	
	Ms	McRae- Bainville Loams, 7 to 15 percent slopes	
	Mw	Midway-Razor clay loams, 4 to 7 percent slopes	
	My	Midway-Shale Outcrop Complex	
	Sl	Shale Outcrop	
Ustalfs			253
	354B	Bonfri-Cabbart Loams, 0 to 4 percent slopes	
	Br	Bew-Allentine Clays, 0 to 1 percent slopes	
	Tc	Thurlow Clay Loam, 4 to 7 percent slopes	
	Fl	Fort Collins – Arvada Clay Loams, 0 to 1 percent slopes	
	Fo	Fort Collins – Arvada Clay Loams, 1 to 4 percent slopes	
	Ft	Fort Collins and Thurlow Clay Loams, 1 to 4 percent slopes	
	Hr	Hesper silty clay loam, 1 to 4 percent slopes	
	Hv	Hydro-Allentine complex, 2 to 7 percent slopes	

Table 2. (Continued)

	Map Unit Symbol	**Map Unit Name**	**Acreage (ac)**
Ustalfs (Cont.)	Kc	Keiser Silty Clay Loam, 0 to 1 percent slopes	
	Ke	Keiser Silty Clay Loam, 1 to 4 percent slopes	
	Kg	Keiser Silty Clay Loam, 4 to 7 percent slopes	
Ustepts			2,324
	81B	Delpoint-Cabbart Loams, 2 to 8 percent slopes	
	Mm	McRae Loam, 0 to 1 percent slopes	
	Mn	McRae Loam, 1 to 4 percent slopes	
	Mo	McRae Loam, 4 to 7 percent slopes	
	Mr	McRae Loam, 7 to 15 percent slopes	
	Mu	McRae-Hysham loams, 1 to 3 percent slopes	
	Mv	Midway-Shale Outcrop Complex	

Further information on the physical parameters controlling carbon stores was obtained by downloading a geologic map of the ranch from Montana Bureau of Mines and Geology (MBMG). This aided in determination of the parent material of the soils (Figure 5). The acreage of each geologic formation underlying the ranch is shown in Table 3. The geological data was reviewed to determine if inorganic carbon (carbonates) was expected to be in the soils. The Fox Hills formation appears as gentle grass covered slopes at the base of steep hills and cliffs formed by the Lance Formation. It becomes clay rich and consists of thin layers of sand, silt and clay overlain by well-sorted, very fine to medium grained sandstone. The Lance formation is fine- to coarse- grained sandstone and supports sparse pine growth. It becomes interbedded with shale and clays between the sandstone layers. Where contact between the Lance and Fox Hill formations occur, calcareous sandstone and carbonaceous clay appear. The Bearpaw formation is a type of shale, which outcrops to form flat to gently rolling grass-covered topography. It contains few scattered limestone concretions and is interbedded with silt and sand when it abuts the base of the Fox Hills formation. This geologic/suborder information will direct later interpretation of both land cover types and soils on the landscape (ranch level) scale.

Table 3. Geologic formation and associated land cover classes on the Cabin Creek Ranch (Montana Bureau of Mines and Geology, Wilde and Porter, 2000). Alluvial flood plains and gravels will contain a mixture of vegetation, usually found in riparian locations.

	Geologic Formation	**Associated Land Cover**	**Acreage (ac)**
Kb	Bearpaw Formation	Grassland	1,889
Kfh	Fox Hills Formation	Grassland/Sagebrush	144
Kl	Lance Formation	Pinyon-juniper Forest	9,956
Qal	Alluvium of Modern Flood Plains and Channels	-	448
Qat3	Alluvial gravel, terrace level 3	-	383
Tfle	Tongue River Member of Fort Union Formation	Sagebrush or Pinyon-juniper forest	365
Tft	Tullock Member of Fort Union Formation	Sagebrush or Pinyon-juniper forest	6,876

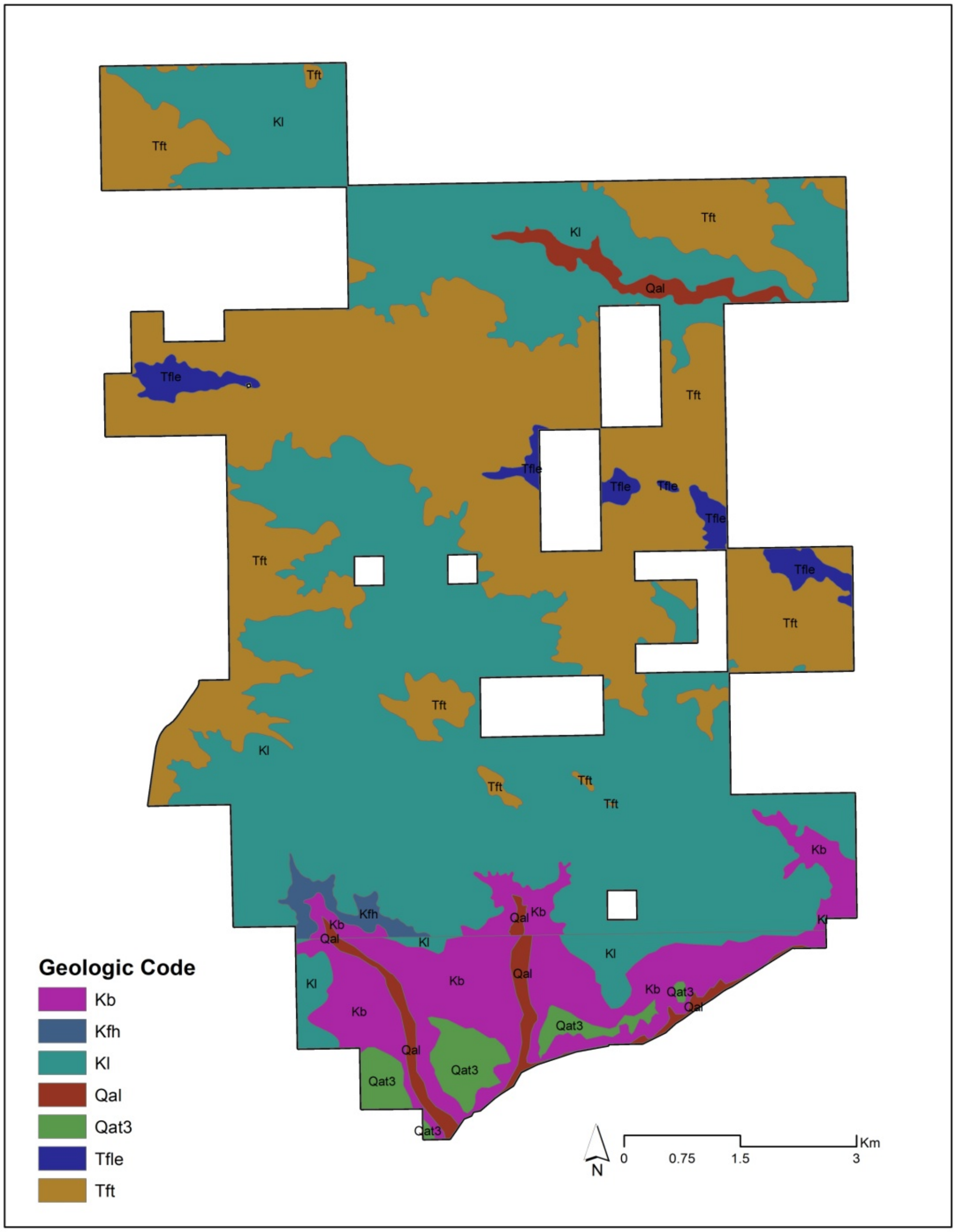

Figure 5. Cabin Creek Ranch geologic map. Kb is the Bearpaw Formation (shale dominated), Kfh is the Fox Hills Formation, Kl is the Lance Formation, Qal is Alluvium of modern flood plains and terraces, Qat3 represents alluvial gravel and terrace level 3, Tfle is the Tongue River member of the Fort Union formation and Tft represents the Tullock member of the Fort Union formation. These parent materials vary from sand to clay texture and determine the textural composition of the soil and in combination with topography help to evaluate age and residence time of soils. Data was collected for the Billings and Rosebud counties from the Geospatial data Gateway (accessed 2013).

Study Design

Field Data Acquisition

Soil pits were randomly selected within the seven different landscape cover types, as well as the concentrated winter-feeding areas (Table 4) during the summer of 2013 and 2014. A minimum of two soil pits in each land cover type was excavated to have replication during analysis. Pit locations were determined by randomly locating different land cover types when driving around the ranch, in which selected locations were assumed representative of the ranch's landscape. Each pit was dug to 1 meter or until bedrock was encountered. The soil column was classified according to the NRCS taxonomic classification system using standard field description techniques (Schoenberger et al, 2012). Each soil pit had pH, CO_3 effervescences strength, and percent coarse material, color, and texture recorded to further on-site soil classification. Because of weak horizon development, samples were collected at 15cm intervals to the bottom of the pit using a metal cylinder extraction approach. A 15cm incremental collection depth was used to maintain consistency across the landscape because of variable soil depths within the ranch landscape and it is a standard technique of sampling soil (Jobbágy and Jackson, 2001). These samples were also used to determine the bulk density.

Table 4. Soil pit locations on Cabin Creek Ranch by land cover type. A minimum of two (2) pits were excavated (excluding perennial riparian, as it falls outside of the ranch boundaries) in order to get a representative measure of soil conditions at the site. The range in depth is the range of the soil profile depths within each plant community type (e.g. one forest pit was 18cm in depth while another was 72cm in depth, the remaining pit depths fell between the two extremes).

Plant Community Type	# of pits	Range of depth (cm)
Forest	5	18-72
Grassland	6	25-89
Sagebrush	12	32-80
Dryland Crop	3	36-100
Irrigated Cropland	2	63/72
Ephemeral Riparian	2	80/95
Perennial Riparian	1	97
Concentrated	7	28-100

Vegetation samples were collected from a random subset of the soil pits (16 out of 30) during the spring/summer of 2013 and 2014. Soil data characterization sheets from previous trips to the ranch were put into a pile, classified by plant community type, and three to four soil pit locations were chosen from that pile in order to randomly chose where vegetation samples were collected. At the forest locations, trees that fell within the 25 meter radius, from the center of the soil pit, were measured and a subset of branches, leaves (needles) and trunk biomass was collected. Herbaceous material was harvested in each of the four cardinal directions, 25 meters out from the center of the soil pit, using a $0.25m^2$ frame (Figure 6). This allowed us to calculate herbaceous biomass on a square meter basis. Tree biomass was collected within a 25-meter radius circle from the soil pit, similar to the herbaceous harvest (Figure 6). Tree biomass was calculated based on species, using a diameter at breast height (dbh) equation (Jenkins et al, 2004). Trees needed to be larger than 2.5 dbh (classified as mature) in order to be used in the equation.

Therefore, trees that were classified as 'small' were considered to have a dbh of 2.5 for the purpose of the equation.

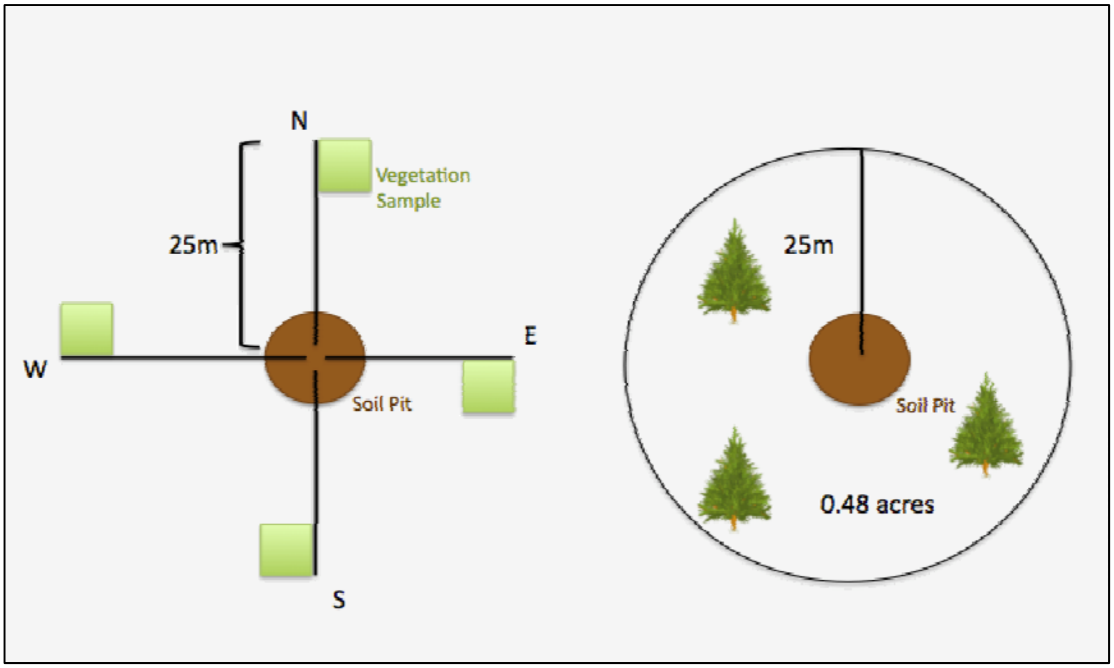

Figure 6. Soil and vegetation sampling design. Vegetation was clipped within $0.25m^2$ sampling frames, 25 meters from the center of the soil pit (left) in each of the four cardinal directions (July, 2014). Trees occurring within a 50-meter diameter circle (right) where identified to species and then a subsample of branches, leaves (needles) and trunk biomass was collected (July, 2013).

Harvested herbaceous material was separated into functional groups (e.g. C_3 grasses, C_4 grasses, annual grass, annual forbs, perennial forbs, carex, ½ shrub and shrub). Shrubs were either Wyoming big sagebrush (*Artemisia tridentata* subsp. w*yomingensis)* or skunkbrush sumac (*Rhus trilobata*). All shrub canopy intercepted by the 25m lines was measured following procedures described by Miller et al (2003). All forest locations had herbaceous understory material collected; with three out of five forested locations having woody material collected. In addition, the perennial riparian and one of the ephemeral riparian locations had tree biomass harvested from the sites. Trees were separated into two size classes (Figure 7), mature and small. Tree biomass was collected in a 50-meter diameter circle (25 meter radius out from the center of the soil pit), equaling 0.48 acres. Biomass and organic carbon content is reported as a ratio to the acreage calculation to determine the tree contribution to total biomass and total organic carbon content for the forested locations on Cabin Creek Ranch.

Figure 7. Ponderosa pine (left) and juniper (right) individuals showing examples of the smaller size class classification. Trees with a dbh smaller than 2.5cm were grouped with the small class size when determining biomass production; measured dbh for trees larger than 2.5cm were used in biomass calculation.

Lab Data Acquisition

All soil and vegetation samples were analyzed for total carbon by combustion with either a TruSpec Micro CN machine Leco Corporation; or Elemental Combustion System 4010, Costech Analytical Technologies (herein Costech). Vegetation samples were dried at 60°C for 6 hours, while soils were dried at 105°C for 12 hours to achieve uniform moisture content during analysis.

Soils were sieved to 2mm before being milled using a roller mill (R. Engel, custom design). Organic content of the soils was initially estimated using the UC Davis Soil Web description for organic matter content in each soil group at the ranch. Soil organic carbon content can be estimated by multiplying the amount of organic matter in a particular soil by 0.50 (Pribyl, 2010). Bulk density measurements were collected using a steel ring (90.4cm^3 in volume) driven into the side of the soil pit, within each of the 15cm depth increments. Dry bulk density was determined and corrected for coarse fragments through equations 1 and 2, and assuming a density of 2.7 g cm^{-3} for coarse material. Bulk density was necessary for the calculation of the total amount of organic carbon that occurs within each soil pit as mass per area (kg carbon per square meter).

$$\text{Volume \% coarse material} * 2.7\ \text{g cm}^{-3} = \text{g coarse material cm}^{-3}\ \text{soil} \qquad \text{Eq. [1]}$$

$$[\text{g soil cm}^{-3}\ \text{soil}] - [\text{g coarse material cm}^{-3}\ \text{soil}] = \text{g fines cm}^{-3}\ \text{soil} \qquad \text{Eq. [2]}$$

Inorganic carbon was removed from a subset of soil samples by fumigation (Harris et al., 2001), either directly in the capsule used for combustion analysis, or in a larger container before subsampling. Organic carbon could then be determined by difference between unfumigated and fumigated samples. In addition, inorganic carbon was quantified from the change in pressure following reaction of a known mass of a soil (Sherrod et al. 2002). This indirect measure of inorganic carbon was used to determine if complete carbonate conversion occurred during the fumigation process. Because inorganic carbon stocks may exceed organic carbon stocks in arid soils, this assessment was essential for quantitative evaluation of organic carbon storage.

We wanted to test the idea that soil texture might control soil organic carbon storage, so in addition to hand texturing, texture was determined using a hydrometer (Gee and Bauder, 1986) on soils from vegetation collection sites. This aided assessment of the difference in soil composition between the land cover types and confirmed results from field hand texturing.

Data Analysis

In order to control for heterogeneity of soil depth across the landscape, (Table 4) analyses were only conducted on the 0 to 45cm depths across all the sites. Furthermore, exploratory statistical analyses early in the study indicated variability in soil depth throughout the land cover types overwhelmed all other comparisons (Figures A1 and A2; shows two land cover types out of eight). Sites that contained only one depth (7 out of 38) were not included in the analysis to avoid skewing the data with missing values. With organic carbon content (kg C m^{-2}) as the response variable, an exponential decline of organic carbon with increasing depth in the soil profile was expected (Amundson 2001). Not surprisingly, the exponential decline of organic carbon with depth created a right skewed residual plot (when checking for normal distribution of organic carbon residuals through the use of a qq-plot) so the response was log transformed (natural log (ln)) to linearize the relationship for statistical analyses. Once transformed, a linear mixed model was used to compare organic carbon levels among land cover types to determine the factors influencing organic carbon content in soils. This model allows a test of fixed effects while controlling for observations that are correlated because samples come from the same pit. Land cover, depth and clay were the fixed effects driving the response variable (organic carbon), and pit were the random effect. Simple regression and one-way ANOVA analyses were not used because these models would not control for the correlation among observations within the same soil pit. Clay was selected for additional analysis because it is listed as a factor influencing organic carbon. Jobbágy and Jackson (2000) showed that soil organic carbon increased as clay content increased with depth. In addition, these authors reported that soil organic carbon had a negative relationship with sand content, indicating that soil texture is important when determining the soil organic carbon balance.

Bulk density was analyzed using a one-way ANOVA to test for differences between land cover types. Because there was one factor (land cover type) influencing the response (bulk density), a one-way ANOVA was used instead of other analysis. This was done with both field data and bulk densities reported (NRCS) for a limited set of soil series occurring on the ranch. Analysis with both sets of bulk density measures was necessary because of uncharacteristically low bulk density estimates from some of the field samples.

Aboveground herbaceous material was compared to the production estimates reported by the NRCS in their web soil survey for each soil series where biomass production was measured. The published levels for three different precipitation years (drought, normal, above normal) were compared to the clipped biomass production for the same soil series. This comparison provided an accuracy check for the Cabin Creek biomass production measures. Tree values were not included because the NRCS does not include tree or shrub biomass in their annual production estimates.

BROAD RESULTS

Aboveground Biomass

Forest locations were characterized by an overstory of ponderosa pine (*Pinus ponderosa*) and Rocky Mountain juniper (*Juniperus scopulorum*), with an understory of, western wheatgrass (*Pascopyrum smithii*), threadleaf sedge (*Carex filifolia*) and Japanese brome (*Bromus japonicus*). The perennial riparian area was characterized by an overstory of peach leaf willow (*Salix amygdaloides*), plains cottonwood (*Populus deltoides*) and Russian olive (*Elaeagnus angustifolia*), with an understory of native grasses and forbs and a dense stand of reed canary grass (*Phalaris arundinacea*). The ephemeral riparian locations had a higher amount of native grasses and forbs than the perennial site, with one of the ephemeral locations supporting an over-aged plains cottonwood (*Populus deltoides*). Species composition and corresponding scientific names for biomass harvested in the various landforms are shown in Table A1, Appendix A.

Biomass from each location was compared to the NRCS estimates for the same soil series. The average biomass clipped for each land cover, along with the average production biomass from the NRCS is shown in Table 5 (and graphically in Figure 8). For the natural rangeland sites (forest, grassland and sagebrush), the 2014 biomass production fell within the normal range listed by the NRCS (Cabin Creek 300 – 600lbs/ac; NRCS 350 – 700lbs/ac). The perennial riparian, ephemeral riparian and concentrated sites have higher biomass than estimated by the NRCS, probably because they have a constant disturbance regime allowing invasive species to take over the site. Most of the native perennial grasses (C_3 and C_4) and forbs expected to occur in riparian areas (Natural Resource Conservation Service, 2013), were not present in the Cabin Creek perennial riparian area, as the site was dominated by reed canary grass (Table A2, Appendix A). The concentrated sites had higher proportions of annual grasses and forbs compared to grassland and sagebrush. The biomass harvested in 2014 in the concentrated, perennial riparian and ephemeral riparian areas were higher than what would be expected by the NRCS estimate. Even though the NRCS records did not contain values for perennial riparian, concentrated, and ephemeral riparian cover types, agency estimates were based on reported production for soils that were present under these cover types.

Table 5. Comparison of average 2014 herbaceous biomass and NRCS estimate for different precipitation years (in kg m^{-2}). The 2014 herbaceous biomass was harvested within each land cover type and the NRCS production based on soil series for the same land cover types. The three precipitation years the NRCS used to estimate biomass was below normal (drought), normal and above normal (favorable).

	Grass-land	**Forest**	**Sage-brush**	**Concentrated**	**Perennial Riparian**	**Ephemeral Riparian**
Drought	0.089	0.066	0.076	0.100	0.070	0.073
Normal	0.121	0.085	0.103	0.140	0.094	0.105
Favorable	0.150	0.104	0.133	0.177	0.112	0.127
2014 Clip	0.110	0.070	0.077	0.270	0.484	0.139

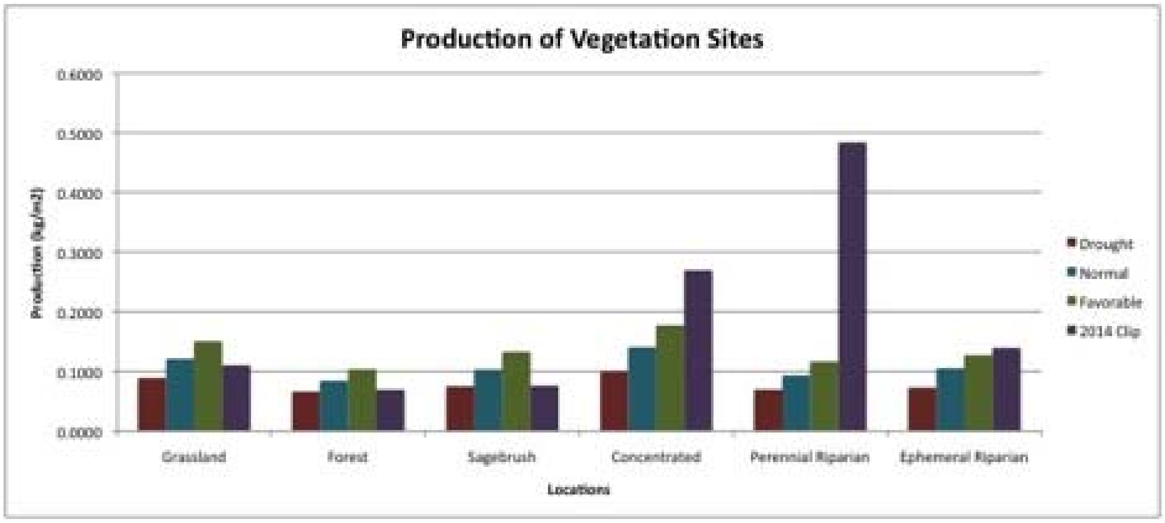

Figure 8. Production of vegetation clipped in 2014 compared to expected production based on the accompanying NRCS soil series. This information came from the NRCS web soil survey data, in which soil series were used to determine the expected biomass based on above normal precipitation (favorable), normal precipitation (normal) and below normal precipitation (drought).

Vegetation carbon content is shown in table 6. Surprisingly, there was little difference in the percentage of organic carbon between the functional groups.

Table 6. Percent carbon for each functional group determined through combustion analysis. The percent carbon for the trees incorporates all the branches, leaves, and trunk cores into a single number.

	Percent Carbon	**Average Percent Carbon**
Annual Grass	43	43
Annual Forb	46, 43, 44	44
C3	43, 45, 43	44
C4	41, 43, 43	42
Perennial Forb	44, 43, 40	42
Carex	43, 41, 43	42
½ Shrub	45, 47, 44	45
Reed Canary Grass	42	42
Trees	50, 46, 48, 46, 44	47

Soil Description

Field observations indicated little horizination throughout the soil profile, consistent with limited soil development given arid conditions. However, there was a large amount of calcium carbonate, which could be seen in the white carbonate accumulation in some of the pits, indicating formation of diagnostic Calcic horizons (Figure 9, Keys to Soil Taxonomy). These observations suggest that the soils sampled on Cabin Creek could be placed in the taxonomic orders of Aridisols, Inceptisols or Entisols, generally consistent with soil mapping for this area (Table 2, Figure 4).

Figure 9. Photo depicting the carbonate formation in one of the soils pits located in a grassland system on Cabin Creek Ranch. The arrow designates the zone of carbonate accumulation.

Table 7 shows the average bulk density for each of the three depth increments (0-15cm, 15-30cm, and 30-45cm) for each land cover type collected in spring/summer of 2013 and 2014. There was no significant difference (P>0.92, P>0.75 and P/0.39) between land cover types for each depth increment (0-15cm, 15-30cm, and 30-45cm), respectively. The ANOVA table with degrees of freedom, sum of squares, etc. appears in Appendix A, Table A3. Only three Cabin Creek pedons fell within NRCS described soils, specifically Hesper, Lambert, and Allentine. Table 8 shows the average bulk density from NRCS for Lambert, Hesper, and Allentine soil series. This limited data only changed the bulk densities of three pits when the bulk densities were swapped in the second bulk density ANOVA run (Table A4). Two of the pits that used NRCS bulk density data were concentrated locations, while the third pit was an irrigated crop field (Table A4). Even when using NRCS reported bulk densities for three of the Cabin Creek soil units, no significant difference (P>0.92, P>0.74, and P>0.22 for 0-15cm, 15-30cm, and 30-45cm, respectively) between soil depths, within the sampling sites, was detected. Because there was no different in bulk density among the various land cover types and the fact that over 90% of the sampled pits had no corresponding NRCS lab data for bulk densities, the Cabin Creek field data was used to calculate organic carbon content.

Table 7. The average bulk density (g/cm^3) for each depth (0-15cm, 15-30cm, and 30-45cm) across all vegetative communities for samples collected in spring/summer of 2013 and 2014.

	0-15cm	**15-30cm**	**30-45cm**
Dryland Crop	1.12	0.98	0.87
Concentrated	1.02	1.11	1.15
Ephemeral Riparian	1.15	1.03	0.95
Grassland	1.06	1.05	0.96
Irrigated Crop	1.01	0.82	0.98
Forest	0.99	1.03	0.95
Sagebrush	1.13	0.98	1.11

Table 8. The average bulk density (g/cm^3) for each depth (0-15cm, 15-30cm, and 30-45cm) from the NRCS web soil data mart for the Lambert, Hesper, and Allentine soil series. This information was substituted in for three Cabin Creek Ranch locations, in which no statistical significant difference was observed (Table A4, Appendix A).

	0-15cm	**15-30cm**	**30-45cm**
Lambert	1.33	1.34	1.36
Hesper	1.37	1.38	1.41
Allentine	1.24	1.38	1.43

Soil Inorganic Carbon

On the Cabin Creek Ranch, inorganic carbon increased with soil depth in comparison to organic carbon stocks. This was expected because organic carbon declines with depth (Jobbágy and Jackson, 2000). A graphical representation of this organic carbon decay with depth is shown in Figure 10. The average amount of carbon by each land cover type within the 45cm profile is shown in table 9. The results from the combustion analysis combined with bulk density measures (giving the total amount of carbon by land area) for each land cover location (includes all locations and all depths) are shown at a landscape level scale in table A5 (Appendix A).

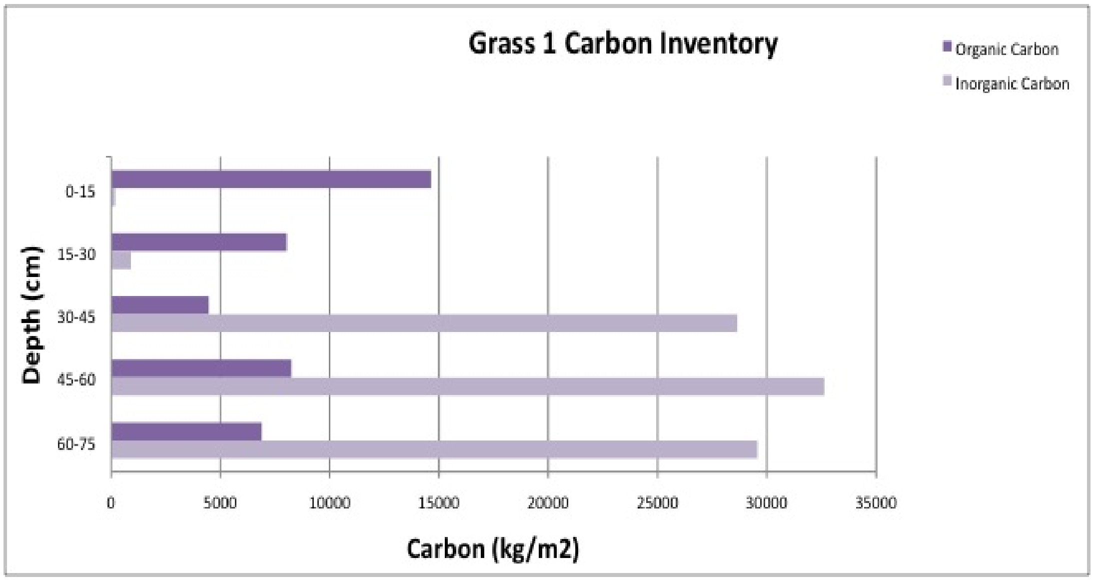

Figure 10. Distribution of soil organic and inorganic carbon with depth in a grassland location on Cabin Creek Ranch, Shepherd, MT.

Table 9. Average carbon amounts (kg m^{-2}) to a depth of 45cm for landscape cover types on the Cabin Creek Ranch, Shepherd, MT in 2014. E. Riparian is ephemeral riparian and P. Riparian is perennial riparian. All carbon amounts were calculated by taking the percentage of carbon from the Costech (total and organic carbon) or from the direct measurement of pressure (Sherrod et al 2002) and multiplying by the respective bulk density measurements for each cover type. All land cover types had at least two replicates, except for perennial riparian. TC – total carbon; OC – organic carbon; IC – inorganic carbon.

	TC	**TC Std. Dev.**	**OC**	**OC Std. Dev.**	**IC**	**IC Std. Dev.**
Dryland Crop	15.5	6.6	4.4	4.7	11.1	3.2
Concentrated	7.1	1.7	3.6	1.3	3.5	2.0
E. Riparian	10.0	3.4	1.9	1.1	8.1	4.5
Grass	7.4	1.4	3.2	1.6	4.2	1.5
Irrigated Crop	12.9	10.9	5.0	3.6	7.9	7.3
Forest	10.7	0.7	4.0	2.2	6.7	1.5
Sagebrush	11.9	2.7	3.7	2.0	8.2	3.0
P. Riparian [a]	9.4	-	7.0	-	2.4	-

[a] only one site so standard error could not be calculated

Soil Organic Carbon

When determining normal distribution of organic carbon, the residual plot showed a right skewed distribution (Figure 11a), which was expected with the exponential decline of organic carbon with depth. Consequently, the response was log transformed (Figure 11b) for statistical analyses. In order to answer the question of ‘what factors influence organic carbon content in soils’ a full interaction model (linear mixed model analysis) was used. This incorporated the three factors (depth, land cover type, and clay percentage) and any interactions that would occur among them (depth*land cover, depth*clay percentage, land cover *clay percentage, and depth*land cover*clay percentage). Results from the full interaction model are shown in table A6 in Appendix A. A three-way interaction model was used to determine statistical significance of the three factors on the amount of soil organic carbon. The outcome indicates no statistically significant interaction occurring among the three variables (land cover (treatment), depth of the profile and clay percentage of the soil). It is important to note, however, that the sample size (n=31) is small which may explain the lack of statistically significance interaction among the listed terms.

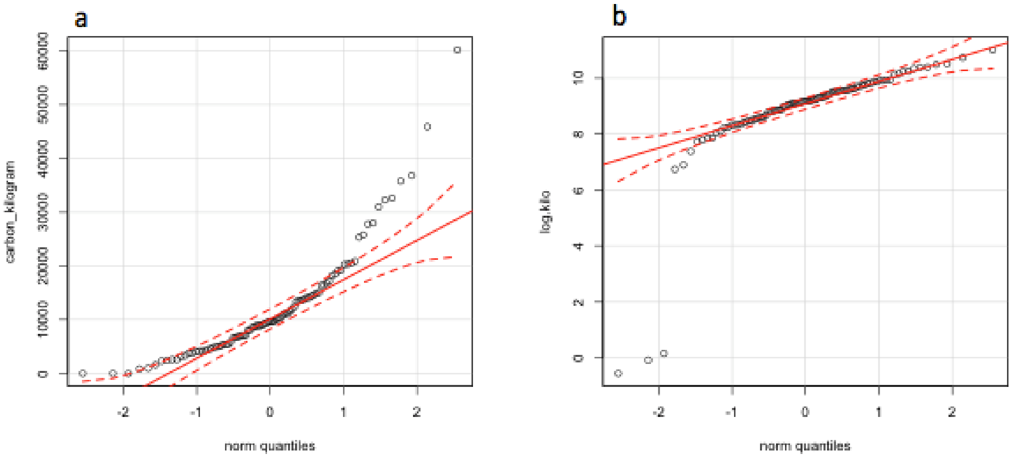

Figure 11. Organic carbon residual data from Cabin Creek Ranch, before transformation (a) and after log transformation (b) to meet the normality assumption associated with using a linear mixed model.

Since a statistically significance interaction was not obtained, the three-way interaction was removed and a reduced model, with two-way interactions, was run. The reduced model examines factors that could affect the organic carbon composition by comparing two factors for a statistically significant interaction. The results show, once again, that the interaction between land cover and depth, and depth and clay percentage are not statistically different (table A7, Appendix A). The lack of an interaction between clay percentage and depth confirmed the interpretation of poor or limited horizon formation in these soils. There was, however, a statistically significant interaction (P=0.02, table A7, Appendix A) between land cover type and the clay percentage. This means that the amount of organic carbon is influenced by the clay percentage within the sampled land cover type. Table A8 (Appendix A) shows the estimates that are associated with the reduced interaction model, indicating that concentrated and ephemeral riparian locations are statistically significantly different, in clay percentage, when compared to dryland crop ($P<0.08$ and $P<0.004$, respectively). Holding soil depth constant to control for the wide variation in soil depths across the ranch landscape caused no statistical significance that might have been expected (Table A8, $P>0.72$).

Following up on the interaction outcomes, a one-way ANOVA was run to determine if there was a difference in organic carbon content between the different land cover types. Because of the high levels of biomass and soil depth in the perennial riparian area, two analyses were performed, one with the perennial riparian measures in the model (Table A9, Appendix A) and one without perennial riparian measures (Table A10, Appendix A). Both of the one-way ANOVAs showed that thee was a statistically significant difference in organic carbon between the different land cover types. Additionally, there was only one perennial riparian site and it fell outside of the ranch boundaries. Therefore, perennial riparian will not be included in further discussion because ranch management objectives would not apply to this location.

Table 10 shows the average soil organic carbon (kg/ha^{-1}) for each land cover type. Dryland crop was statistically significantly different than other land covers (Table A11, Appendix A). Table A12 (Appendix A) shows the back transformed estimate of the average organic carbon content for each of the land cover types. All the p-values indicate a difference in the organic carbon stock between dryland crop and the other land cover types. According to Table A12, dryland crop has less organic carbon than the other land cover types, because the other estimates are positive. Mean separation of these estimates is shown in Figure 12, in which Cis were obtained using the Tukey-Kramer method. The

Tukey test corrects for experiment-wise error rates and was set for a 90% family-wise confidence interval.

Table 10. Average soil organic carbon (SOC) content (kg/ha^{-1}) for each land cover type collected during the spring/summer of 2013/2014 at Cabin Creek Ranch, Shepherd, MT. Superscripts represent statistically significant differences between land cover types (A11, Appendix A).

	Dryland Crop	**Irrigated Crop**	**Concentrated**	**Ephemeral Riparian**	**Grassland**	**Forest**	**Sagebrush**
SOC (kg/ha^{-1})	21,729^{a}	57,349^{b}	42,660^{b}	23,249^{b}	37,189^{b}	43,873^{b}	37,223^{b}

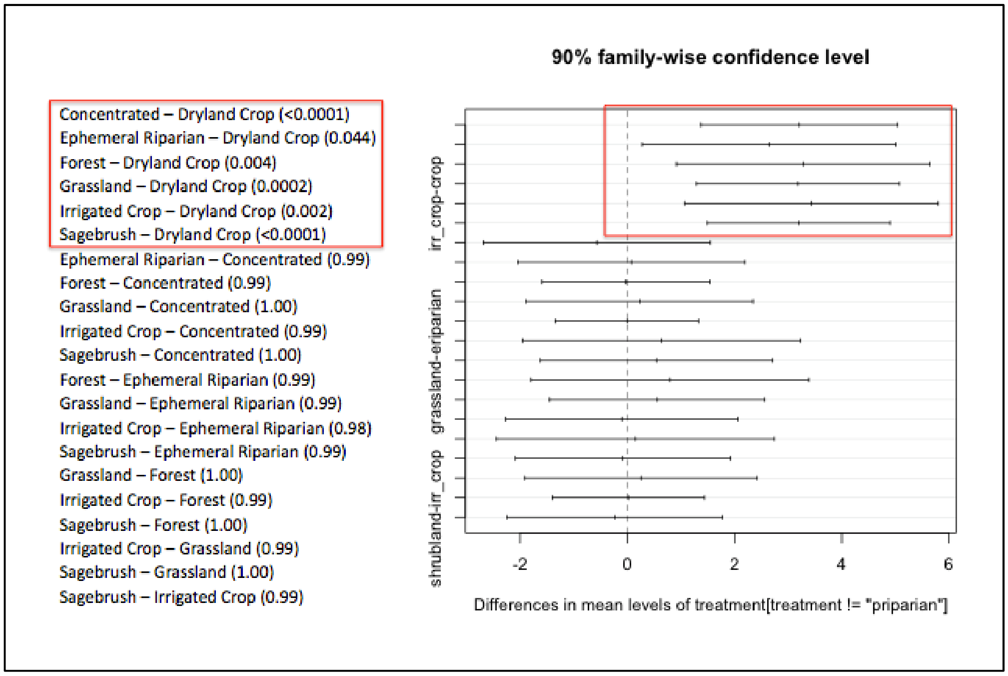

Figure 12. Tukey pairwise comparisons of soil organic carbon levels in the 0 to 45cm depth of the different vegetative communities found at Cabin Creek Ranch, Shepherd, MT. Values are considered significantly different if the bar does not cross "0". For example, dryland crop has statistically significantly lower organic carbon than concentrated. This comparison is excluding perennial riparian locations (x-axis labeling [treatment!="priprian"]). Each line is comparing the amount of organic carbon between two land cover types to one-another.

Because the interaction between land cover types and clay percentage was statistically significant, another one-way ANOVA was performed to test for differences between the vegetative communities based on clay percentages (Table A13; Table A14 shows estimates). Clay percentage was not log transformed as the qq-plot of the residuals was normally distributed. Therefore, Table A14 (Appendix A) indicates that the average for dryland crop locations is 36% clay; considerably more than in the other land cover types. The percentage of clay for the other land cover types, can be estimated by subtracting the individual land cover type from the 36.33g cm^{-3} for dryland crop (concentrated feeding areas will have ~10% clay; (36.33 (dryland crop) -26.55 (concentrated) = 9.78).

Figure 13 uses information from Table A14 to display clay percentage for the various land cover types on the ranch. This comparison, once again, shows dryland crop has the highest amount of clay, followed by irrigated crop, then grassland. It is important to note that besides every cover type being statistically different from dryland crop, several of the other cover types are also statistically significantly different from one another (Figure 14). Dryland crop has the most amount of clay, with the forest locations having the least amount of clay. This makes sense as the forest locations were located on outcrops, and many of these locations had little soil development. Irrigated crop has the second highest clay percentage, possibly due to losses of topsoil through erosion or changes in soil characterization due to mixing through tillage.

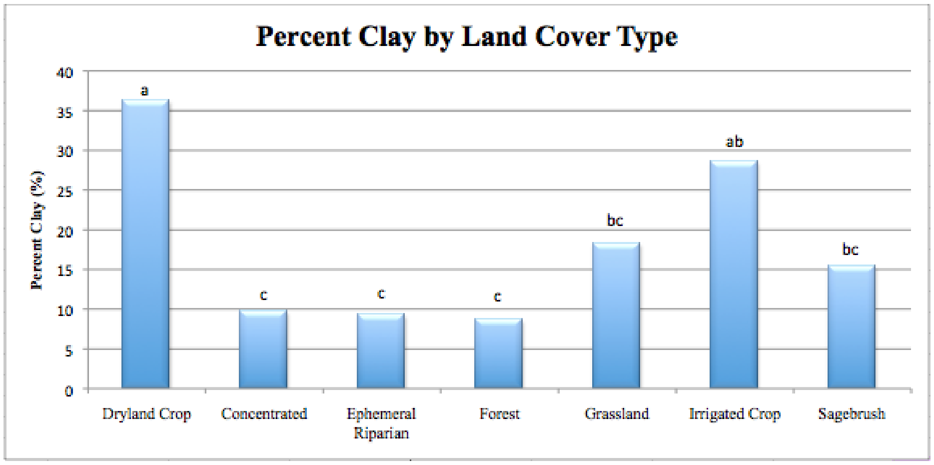

Figure 13. Average clay percentage for the land cover types surveyed on the Cabin Creek Ranch during 2013/2014. This is a graphical representation of Table A14 (Appendix A; estimates from one-way ANOVA), where dryland crop has the highest amount of clay and the forest locations has the lowest. Superscripts denote statistically significant differences at the P=0.10.

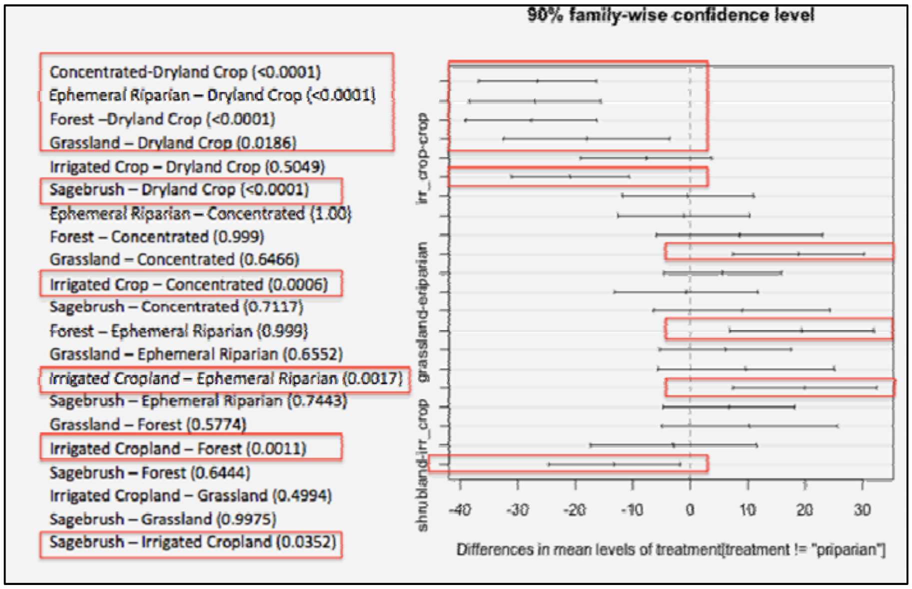

Figure 14. Tukey output from the one-way ANOVA evaluating clay content between land cover types. Comparisons that do not cross “0” are statistically different in percent clay. Those highlighted by red boxes are statistically different from each other. When comparing Treatment A – Treatment B, lines that fall to the left of 0 indicate ‘A’ has less clay than ‘B’, and vice-versa for lines falling to the right of 0. For example, concentrated has less clay than the dryland crop, while irrigated crop has more clay that then ephemeral riparian location.

The last part of this inventory effort was to determine the total carbon content for each of the land cover types. Table 11 shows the acreage (hectares) for each land cover type, the total soil organic carbon (kilograms), the total aboveground carbon (kilograms), and the cumulative organic carbon (soil organic carbon and aboveground carbon, in tonnes). Irrigated and dryland crop locations were not clipped, and the aboveground carbon numbers are estimated from the 2014 Agricultural Statistics for Montana (USDA, 2014). Irrigated cropland aboveground carbon content used alfalfa hay, with 3 harvests per year, whereas dryland crop was a one harvest per year of other hay. Land cover types that have a large acreage associated with them seem to be the front-runner for the amount of carbon that can be stored. However, for this very reason, the one-way ANOVA to determine if thee was a different in organic carbon content between land cover types was preformed (Table A12 and Figure 12), and it was shown that the only statistically significant difference in land cover types was that all land cover types are better than dryland crop. In addition, native areas were shown to the greater stores of carbon.

Table 11. Cabin Creek Ranch soil organic carbon (SOC) in kilograms and total aboveground carbon (AC) in kilograms for each cover type based on total acres within the ranch. An aboveground carbon value of 44% was used as an average across all sites. No samples of crop yield were obtained in 2013 and 2014; therefore, the asterisk denotes the estimated aboveground carbon content from 2014 Montana Agricultural Statistics for 2013 harvest. Cumulative organic carbon (COC) is the SOC and AC together, in tons.

Land Cover	**Acreage (ha)**	**Soil Organic Carbon (kg)**	**Aboveground Carbon (kg)**	**Cumulative Organic Carbon (tons)**
Forest	418	43,873	308	18,469
Sagebrush	2,702	37,223	339	101,492
Grassland	3,282	37,189	484	123,681
Irrigated Cropland	375	57,349	6,510*	23,947
Dryland Crop	1,194	21,729	1,480*	27,711
Ephemeral Riparian	110	23,249	2,130	2,791
Concentrated	13	42,660	1,188	570

Table 11 is very important, as it is the basis for the entire study. This table is the baseline of the amount of carbon that is on Cabin Creek Ranch. It is important to note that this table shows a snapshot of the amount of carbon that was on the ranch when the samples were taken (spring/summer of 2013/2014), and does not explain the amount of carbon that the ranch could sequester in the future. That type of information still needs to be studied.

DISSCUSSION / MANAGEMENT IMPLICATIONS

Quantification of current and potential carbon stocks in soils is critical for carbon credit assessment and forecasting. Soils offer a spatially extensive means of storing carbon, with substantial collateral benefits, such as soil health, improved water quality and nutrient cycling (Derner and Schuman, 2007). Furthermore, soils store twice as much carbon as the atmosphere and 2.5 times as much as vegetation (Karhu et al., 2014). The wide variety of soils (Table 2, Figure 4) that comprise Cabin Creek Ranch produce diverse vegetative communities, and as a result, suggest a range of opportunities to capture and store carbon. The variation of carbon that has been captured and stored (Table 11) is largely driven by the area (hectares) of each vegetation or land use class that occurs within the ranch boundaries. The two main sources of carbon stocks include those soil/plant complexes that have been anthropogenically altered (irrigated cropland, dryland crop, and concentrated), and native communities (sagebrush, grassland, and forest).

Soil carbon stocks at Cabin Creek Ranch are typical of semi-arid grassland and riparian settings (Table A5). Cumulative soil organic carbon inventories were 0.8 to 10.9 kg m^{-2}, whereas cumulative inorganic carbon inventories were 1.4 to 21.4kg m^{-2}. It should be noted that while soil organic carbon differed amount these land cover types (e.g. sagebrush organic carbon ranged from 1.5 to 9.0kg m^{-2} while irrigated cropland organic carbon ranged from 3.0 to 8.5kg m^{-2}) only dryland cropland differed significantly from the other land use classes (Table A11). Jobbágy and Jackson (2000) found a range of 5.1 to 22.9kg m^{-2} for organic carbon inventories (grassland to forest), whereas soils at Cabin Creek Ranch fall below these ranges (2.3 to 6.8 and 1.3 to 8.1 kg m^{-2}, grassland

and forest, respectively; Table A5). However, this difference could result from the broad set of ecological conditions Jobbágy and Jackson used in their metadata analysis. The metadata set used by Jobbágy and Jackson (2000) included tropical grasslands and savannas as well as semi-arid grasslands, like those at Cabin Creek. In higher rainfall areas with higher amounts of soil water, decomposition increases, allowing a greater fraction of organic carbon to be leached deeper into the soil profile. Compared to the wide range in precipitation values associated with different world biomes, Cabin Creek Ranch would fall at the drier end of the published values so our values are not unreasonable.

The importance that rainfall has on organic carbon capture is also shown on Cabin Creek Ranch by comparing the organic carbon content of the irrigated and dryland crop locations. Irrigated crop has a higher amount of soil organic carbon than dryland crop. If the irrigation (simulated rainfall) were removed from those fields, it would be reasonable to assume that the irrigated cropland would have the same amount of organic carbon as the dryland cropland, since they occur on the same relative type of soils (Figure 4). Jobbágy and Jackson (2000) found a similar relationship between organic carbon content and clay, in which soil organic carbon increased with increasing clay content. The only other difference between the two locations is the type of vegetative cover that is being harvested. Irrigated cropland is used from growth of alfalfa, and is harvested three times a year, producing 14,795kg biomass ha^{-1} (Table 11). Dryland crop locations are used for growth of wheat (other hay; USDA, 2014), with only one harvest a year; producing 3,363 kg biomass ha^{-1} (Table 11). The difference in these land cover types is not seen in the organic carbon being captured in the soil profile, due to the harvest of the biomass (Table 10). Therefore, the comparison of organic carbon between irrigated and dryland crop locations can be directly related to the amount of moisture each site receives. However, despite their higher clay content, cropping systems that remove high amounts of vegetation biomass and regularly expose soils to wind and water erosion have lower organic carbon levels than soils of surrounding native plant communities.

Our results are not conclusive on the effect that depth, land cover type or soil composition had on the organic carbon inventories of the semi-arid forest, sagebrush, and grassland soils. However, an interaction was found between clay percentage and the corresponding land cover type suggesting that vegetation communities respond to the amount of clay in the ranch's soils. This can be seen most clearly between the two categories previously described (anthropogenically altered and natural). Irrigated and cry cropland locations have a high amount of clay in the soil profile (28 and 36 percent clay, respectively; Table A14), whereas the natural locations have closer to 9 percent clay (grassland, forest, sagebrush, and concentrated). The concentrated site, which falls around the 9 percent clay, is a good bridge between the anthropogenically altered sites to the natural sites, since the only influence humans had on these sites was to increase the amount of time cattle spent here during the winter season. The break-up of the soil column could be one cause of the increase in clay percentage in those sites that were anthropogenically altered (through tillage). However, it is more likely that the irrigated and dryland cropping locations were originally located on sites that were naturally high in clay.

The irrigated crop location is comprised of soils classified as Argids, Orthents, Ustalfs, and Ustepts (Figure 4), which range in clay percentage of 5 to 60. However, the lower end of the clay percentage range for these soils make up a very small amount of the total soil suborder (Figure 3, Table 2). Dryland crop locations are comprised of soils classified as Ustepts, Fluvents, Ochrepts, and Orthents. These soils range in clay percentage from 5 to 50. Most of the ranch is comprised of the soil suborder Orthents, which is where the lower end of the clay range comes from (5 to 18% clay in the Apron series). Therefore, it would make sense that those areas that are being anthropogenically altered have a higher amount of clay than the natural areas, the resulting cropland locations occur on areas that are relatively flat as compared to grassland, sagebrush, and other land classes. Even though these locations are on benches, compared to other surrounding locations (the Yellowstone River), there are higher topographic features that surround them, making the farm fields the perfect locations for long-term deposition. The resulting depositional locations are comprised of soils that have a finer texture, indicating an increase in fine sediment (e.g. silt and clay). This increase in fine sediments affects the bulk density of the soils, in which finer-textured soils have lower bulk densities than coarser-textured soils.

Bulk densities were not statistically significantly different between cover types, even when NRCS data was substituted for specific pedons. Bulk densities ranged from 0.61g cm^{-3} to 1.46g cm^{-3} throughout the ranch. While the bulk densities less than 1.0 g cm3 appeared suspect, the NRCS database bulk density information for Cabin Creek Ranch was too limited to provide a better comparison. In support of our values, Murphy et al (2004) found bulk densities in northeastern Kansas's grasslands that ranged from 0.9 on Conservation Reserve Program (CRP) to 0.67g cm^{-3} under warm-season (C_4) native grass. In addition, Derner and Briske (2001) found a fine earth fraction of soils to be 0.75 to 1.13 g cm^{-3}, when looking at the difference between grazed and ungrazed locations in short-grass and tall-grass prairies in north-central Colorado. Cabin Creek Ranch soils had bulk densities that ranged from 0.61 to 1.46 g cm^{-3} in concentrated areas, whereas grassland bulk densities ranged from 0.61 to 1.27 g cm^{-3}. Similar to what Derner and Briske (2001) found, the higher bulk densities were found in areas that were grazed. This points out the importance of measuring the bulk density under a variety of different land cover types or management systems, to better understand the implications that management has on soil conditions that influence organic carbon content. In addition, bulk density can give some insight to historical land uses, as in the study by Murphy et al. (2004), where they reported soils with higher erosion potential under CRP and cool-season (C_3) grasses or soils that had previously been under cultivation.

Vegetation changes associated with climatic shifts and anthropogenic disturbance can have significant impacts on soil biogeochemical cycling (Rau et al., 2011). In parallel, there has been a considerable debate as to what vegetative functional group should be used to increase carbon storage. For example, woody vegetation stores carbon in tree trunks and canopies, in quantities based on age, productivity and density of the forest stand (Jackson et al, 2002; Nowak and Crane, 2002; Stephenson et al., 2014). In the semi-arid environment of the Cabin Creek Ranch, forested sites had the lowest amount of aboveground biomass (including trunk and canopy) out of the non-disturbed locations (forest, grassland, and sagebrush), leading to a lower amount of CO_2 being sequestered at these locations. This land cover type also stores the lowest organic carbon in the soil profile. One reason for this might be that the forest locations occur on shoulder locations (topographically), which has limited soil development due to constant soil erosion downslope. In addition, the limited amount of water received in the area limits the amount of large woody debris that can be sustained, resulting in lower amounts of CO_2 being captured in the biomass. Therefore, management should not be to increase forested acreage without substantial increases in irrigation.

Being able to take information from a study, even if it is a snapshot in time, and use that information allows managers to manipulate different landscapes to offset CO_2 emissions. For example, at Cabin Creek Ranch, dryland crop acreage is sequestering a lower amount of organic carbon than its potential based on soil clay content. Since no statistically significant difference between the dryland crop and native land cover types in their current carbon stores were observed, we wanted to know what would happen if the dryland cropping areas were converted back into a native plant community. One way of determining this is to take the average SOC (kg/ha^{-1}) of the land cover type you would return to native vegetation and subtract the SOC content of the dryland crop to get the percent increase in SOC. For example, to know the increase in percent SOC of going from dryland crop to grassland, we would take (37,189-21,729)/21,729 to arrive at a 71% increase in SOC when returning the area to permanent grassland. Doing the same calculation with the forest cover type yields a 101% increase in SOC when dryland cropping areas are returned to forest. However, we do not know how quickly the calculated SOC levels will recover following rehabilitation. Therefore, the most logical and successful approach would be to retain current sagebrush and grassland cover types.

Carbon inventories are an important factor to consider when reviewing the landscape carbon balance. Most of the organic carbon is in the top 15cm of the soil profile (Figure 10). Therefore, management practices that protect the soil surface are important when trying to mitigate for CO_2 emissions. Several management opportunities are to improve soil sequestration. First, is to manage the plant communities to protect the soil surface. By keeping a higher proportion of vegetation on the soil, soil erosion decreases, ultimately keeping the soil organic carbon stocks intact. On Cabin Creek Ranch, this could be accomplished by decreasing the amount of acreage devoted to bunk feeders that concentrate cattle in specific locations. This action will make currently degraded sites less vulnerable to long term erosion. Overused sagebrush and grassland cover types are less likely to sequester more carbon because a degraded rangeland exhibits a decreased amount of carbon stored and captured, in both plants and soils (Zhang et al, 2011; Houghton et al, 1999). Second, because this study represents a baseline inventory only, there is no information on how long soil organic carbon levels will remain high under irrigation if all the aboveground biomass is continually removed. The removal of crop residue decreases the amount of organic carbon that would be incorporated back into the soil column through decomposition. However, in order to determine how much aboveground biomass can be removed before damaging carbon storage at these locations additional research will be necessary. Lastly, returning those sites that are degraded or in a cropland situation to vegetation cover classes that can incorporate organic material back into the soil column over long periods could increase the amount of carbon being captured and stored. Ultimately, maintaining native cover types in higher ecological condition on Cabin Creek Ranch appears to be the best way to mitigate rising CO_2 emissions on the landscape scale.

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APPENDIX A

SUPPLEMENTAL DATA

Table A1. Species classified by functional group that were found in all of the vegetative clipped plots during 2013 and 2014 on the Cabin Creek Ranch, Shepherd, Montana.

Category	Common Name	Scientific Name
Annual Grass	Japanese Brome	*Bromus japonicus*
	Sixweeks Fescue	*Festuca octoflora*
	Cheatgrass	*Bromus tectorum*
	Annual Wheatgrass	*Eremopyrum triticeum*
	Little Barley	*Hordeum pusilla*
	Wild Oats	*Avena fatua*
Annual Forb	Salsify	*Tragopogon dubis*
	Dandelion	*Taraxacum*
	Prickly Lettuce	*Lactuca serriola*
	Mustard	*Brassica*
	Little Stickseed	*Hackelia*
	Knotweed	*Polygonum*
	Burning Bush	*Kochia scoparia*
	Russian Thistle	*Kalitragus*
	Lambs Quarters	*Chenopodium album*
	Western Tansy Mustard	*Descurainia pinnata*
Perennial Grass - C3	Western Wheatgrass	*Pascopyrum smithii*
	Sandberg Bluegrass	*Poa secunda*
	Needle and Thread Grass	*Stipa comata*
	Crested Wheatgrass	*Agropyron cristatum*
	Prairie Junegrass	*Koeleria macrantha*
	Green Needle Grass	*Nassella viridula*
	Bluebunch Wheatgrass	*Pseudoroegneria spicata*
	Streambank Wheatgrass	*Elymus lanceolatus*
	Foxtail	*Alopecurus*
Perennial Grass - C4	Blue Gramma	*Bouteloua gracilis*
	Inland Saltgrass	*Distichlis spicata*
	Prairie Sandreed	*Calamovilfa longifolia*
Perennial Forb	Scarlet Globemallow	*Sphaeralcea coccinea*
	Evening Primrose	*Gaura coccinea*
	Milvetch	*Astragalus*
	Slimflower Scurfpea	*Psoralidum tenuiflorum*
	Mountain Dandelion	*Agoseris*
	Fleabane	*Erigeron*
	Douglas Knotweed	*Polygonum douglasii*
	Scorpion tail	*Heliotropium angiospermum*
	Gumweed	*Grindelia squarrosa*
	Prairie Coneflower	*Ratibida*
	Bedstraw	*Gallium*
	Miners Candle	*Cryptantha scoporia*
Carex	Threadleaf Sedge	*Carex filifolia*
	Winterfat	*Krascheninnikovia arborescens*
	Broom Snakeweed	*Gutierrezia sarothrae*
	Fringed Sagewort	*Artemisia frigida*
½ Shrub	LA Sagewort	*Artemisia ludoriciana*

Table A2. Herbaceous biomass (kg m^{-2}) harvested within each land cover type and the NRCS production data based on soil series for each land cover type. A. Grass represents annual grasses, A. Forb represents annual forbs and P. Grasses represents perennial forbs. E. Riparian is ephemeral riparian, while P. Riparian is perennial riparian.

	A. Grass	**A. Forb**	**C3**	**C4**	**P. Forb**	**Carex**	**½ Shrub**	**Reed Canary Grass**
Forest 2	30.61	70.70	40.65	-	1.59	0.44	7.27	-
Forest 3	-	-	35.25	8.17	6.76	11.82	-	-
Forest 4	5.44	0.24	58.13	3.03	0.38	1.69	-	-
Forest 5	4.52	2.58	38.14	1.77	3.47	-	5.26	-
Forest 6	-	0.01	9.75	0.18	-	1.11	-	-
Grass 1	2.77	2.62	65.59	11.72	5.30	-	0.58	-
Grass 2	17.66	4.09	90.56	1.28	1.64	2.15	14.68	-
Sagebrush 1	0.96	2.65	1.60	14.65	0.27	-	1.11	-
Sagebrush 2	5.32	1.89	42.55	14.30	1.08	12.01	-	-
Sagebrush 3	17.36	-	73.30	19.21	18.91	1.77	0.45	-
E. Riparian	7.52	2.10	55.31	-	65.51	-	8.68	-
P. Riparian	0.01	76.59	62.16	-	-	-	-	344.93
Concentrated 2	63.17	482.51	3.71	-	-	-	-	-
Concentrated 4	54.40	158.98	2.81	-	-	-	-	-
Concentrated 5	76.20	10.00	24.36	1.06	6.64	-	-	-
Concentrated 6	50.90	25.99	116.86	-	1.82	0.14	-	-

Table A3. Results from a one-way ANOVA for soil bulk density for sampled depth increments across land cover types on the Cabin Creek Ranch during spring and summer of 2013 and 2014.

	Df	**Sum Sq.**	**Mean Sq.**	**F value**	**Pr(>F)**
Treatment (0-15cm)	6	0.07719	0.012865	0.3198	0.9189
Residuals	20	0.80459	0.040230		
Treatment (15-30cm)	6	0.1127	0.08545	0.5379	0.7465
Residuals	20	0.64633	0.032316		
Treatment (30-45cm)	6	0.22744	0.037907	1.1143	0.3926
Residuals	18	0.61236	0.034020		

Table A4. Results from a one-way ANOVA for bulk density for each depth increment across land cover types with a hybridized data set containing collected information from the spring/summer of 2013/2014 and bulk densities from the NRCS web soil data mart for the Lambert, Hesper and Allentine series.

	Df	**Sum Sq.**	**Mean Sq.**	**F value**	**Pr(>F)**
Treatment (0-15cm)	6	0.06432	0.010720	0.3101	0.9246
Residuals	21	0.72589	0.034566		
Treatment (15-30cm)	6	0.14493	0.024115	0.5887	0.7356
Residuals	21	0.86161	0.041029		
Treatment (30-45cm)	6	0.33265	0.055441	1.5197	0.2251
Residuals	19	0.69316	0.036482		

Table A5. Total, organic and inorganic carbon for each pit at Cabin Creek Ranch. Taking percentage of total carbon and multiplying by bulk density and land area gave total carbon for each location. The same measurement was done for the organic carbon and inorganic carbon components. Inorganic carbon was determined by subtracting organic carbon from total carbon or from direct measurement of gas.

	Total Carbon ($kg\ m^{-2}$)	**Organic Carbon ($kg\ m^{-2}$)**	**Inorganic Carbon ($kg\ m^{-2}$)**
Dryland Crop 1	22.9	9.7	13.2
Dryland Crop 2	19.4	0.8	18.8
Dryland Crop 3	23.6	3.6	20.0
Concentrated 1	10.0	5.4	4.6
Concentrated 2	16.6	4.9	11.7
Concentrated 3	14.0	9.5	4.5
Concentrated 4	13.9	2.2	11.7
Concentrated 5	3.2	1.5	1.5
Concentrated 6	8.2	3.2	0.0
Concentrated 7	11.3	3.1	8.2
Ephemeral Riparian 1	17.7	1.4	16.5
Ephemeral Riparian 2	13.0	3.2	9.8
Grass 1	9.5	2.5	7.0
Grass 2	14.3	6.8	7.5
Grass 3	13.4	4.2	9.2
Grass 4	10.9	2.3	8.7
Grass 5	9.7	3.8	4.9
Grass 6	22.3	2.7	19.7
Irrigated Crop 1	29.9	8.5	21.4
Irrigated Crop 2	13.1	3.0	10.1
Perennial Riparian	16.6	10.9	5.7
Forest 2	9.4	2.5	6.9
Forest 3	18.9	7.6	11.4
Forest 4	10.2	2.5	7.8
Forest 5	4.1	1.3	2.8
Forest 6	9.5	8.1	1.4
Sagebrush 1	14.2	4.3	10.1
Sagebrush 2	23.1	9.0	14.2
Sagebrush 3	16.0	2.1	10.2
Sagebrush 4	13.3	4.1	9.1
Sagebrush 5	13.8	1.5	12.3
Sagebrush 6	12.7	4.1	8.7
Sagebrush 7	10.5	4.0	6.5
Sagebrush 8	11.3	2.4	8.9
Sagebrush 9	15.1	3.3	11.6
Sagebrush 10	20.9	4.7	16.2
Sagebrush 11	11.5	3.2	8.3
Sagebrush 12	10.6	1.8	8.5

Table A6. Linear mixed model – *full interaction model*. Response is log transformed. This ANOVA table is the output from the model and shows three different order terms: high (land cover * depth * clay), moderate (land cover * depth; depth *clay; and clay *land cover), and low (land cover, depth and clay). The highest order term, or the three-way interaction is not statistically significant (p=0.485), and therefore can be removed from the model. This allows a reduced model to be performed.

	Sum Sq.	**Mean Sq.**	**Num DF**	**Den DF**	**F. Value**	**Pr(>F)**
Land Cover	9.825	1.965	7	16.58	0.8988	0.5046
Depth	0.081	0.081	1	15.20	0.0371	0.8499
Clay	3.259	3.259	1	15.78	1.4907	0.2401
Land Cover: Depth	9.877	1.975	7	15.74	0.9036	0.5030
Land Cover: Clay	19.534	3.256	7	16.32	1.4892	0.2428
Depth: Clay	1.020	1.020	1	15.37	0.4665	0.5048
Land Cover: Depth: Clay	10.211	2.042	5	16.01	0.9342	**0.4850**

Table A7. Linear mixed model – *reduced interaction model*. Response is log transformed. This ANOVA output shows the different interactions, or higher order terms (land cover * depth; depth * clay; and land cover * depth), along with lower order terms (land cover, depth and clay). Lower order terms are not interpretable because of the strong interaction within the higher order terms; the land cover and clay interaction is statistically significant (p=0.02).

	Sum Sq.	**Mean Sq.**	**Num DF**	**Den DF**	**F. Value**	**Pr(>F)**
Land Cover	22.602	3.2289	7	22.642	1.36823	0.26606
Depth	0.050	0.0501	1	21.313	0.02124	0.88550
Clay	1.674	1.6741	1	21.339	0.70939	0.40899
Land Cover: Depth	4.205	0.6008	7	23.271	2.98789	0.96485
Land Cover: Clay	49.358	7.0511	7	23.271	2.98789	**0.02176**
Depth: Clay	0.310	0.3101	1	21.727	0.13151	0.72038

Table A8. Estimates from the reduced interaction model from the linear mixed model. The response (estimate) is back transformed to produce an arithmetic average for easier understanding. Land cover, depth and clay are first order terms and are not interpretable in this model, because there are significant interactions among the higher terms (land cover * depth; clay * depth; land cover *clay). Lines denote the group of information related to each term order. Concentrated and Ephemeral Riparian are statistically significantly different from Dryland Crop (p=0.08 and p=0.004, respectively) due to a difference in clay content of the soil. All other comparisons are non significant. When looking at the table, the estimate is the amount of organic carbon in kilograms per hectare (kg ha^{-1}).

	Estimate	**Pr(>|t|)**
Dryland Crop	873771	0.00333
Concentrated	-7.371	0.6927
Ephemeral Riparian	-9.999	0.011

Table A8. (Continued).

	Estimate	**Pr(>|t|)**
Forest	-3.635	0.9094
Grassland	3.720	0.9909
Irrigated Crop	-9.912	0.4914
Perennial Riparian	-8.515	0.8599
Sagebrush	-9.176	0.3949
Depth	0.6545	0.6128
Clay	-1.418	0.11854
Concentrated: Depth	-1.779	0.2663
Ephemeral Riparian: Depth	-0.7928	0.46154
Forest: Depth	-0.897	0.4116
Grassland: Depth	-0.621	0.8142
Irrigated Crop: Depth	-0.741	0.2954
Perennial Riparian: Depth	-0.685	0.6513
Sagebrush: Depth	-0.805	0.4238
Concentrated: Clay	2.265	**0.08607**
Ephemeral Riparian: Clay	54.559	**0.00455**
Forest: Clay	2.653	0.1536
Grassland: Clay	0.474	0.9806
Irrigated Crop: Clay	3.092	0.2388
Perennial Riparian: Clay	2.037	0.5205
Sagebrush: Clay	2.179	0.13407
Depth: Clay	-0.011	0.72038

Table A9. One way ANOVA to determine the difference in soil organic carbon between land cover types on Cabin Creek Ranch with the perennial riparian site included.

	Df	**Sum Sq.**	**Mean Sq.**	**F value**	**Pr(>F)**
Treatment	7	88.521	12.6459	4.9946	8.56e-05
Residuals	88	222.809	2.5319		

Table A10. One-way ANOVA to determine the difference in soil organic carbon between land cover types without the perennial riparian site.

	Df	**Sum Sq.**	**Mean Sq.**	**F value**	**Pr(>F)**
Treatment	6	84.066	14.0110	5.2372	0.000129
Residuals	83	222.048	2.6753		

Table A11. Estimate from the one-way ANOVA, excluding the perennial riparian location, to determine the difference between land cover types and organic carbon content. (E. Riparian – ephemeral riparian). The last column in the table is the back transformed carbon amount from the estimate. In order to determine the increase in the amount of organic carbon that could be stored, take the dryland crop transformed estimate and multiply it by the land cover type transformed percentage. An example for grassland would be: (exp(3.18)-1)*100% = 230%; in other words, grassland locations can store 230% more carbon than dryland crop locations. The reason behind this is because the dryland crop is being used as the intercept, and that is what the other land cover types are being based on.

	Estimate	**Std. Error**	**t value**	**Pr(>|t|)**	**Transformed**
Dryland Crop	5.9508	0.5452	10.915	2e-16	3,830 kg
Concentrated	3.2072	0.6677	4.803	6.85e-06	237%
Ephemeral Riparian	2.6395	0.8621	3.062	0.0029	130%
Forest	3.2813	0.8621	3.806	0.00027	256%
Grassland	3.1814	0.6896	4.613	1.43e-05	230%
Irrigated Crop	3.4326	0.8621	3.982	0.000146	299%
Sagebrush	3.1969	0.6216	5.143	2.78e-07	234%

Table A12. Estimate from the one-way ANOVA, excluding the perennial riparian location. These values are back transformed and shows that each land cover type, independently, are different from dryland crop. The estimates are based off the organic carbon content that is in kilograms per hectare (kg ha^{-1}). Note that the values for concentrated, ephemeral, etc indicate the added volume of soil carbon for that land use type. An easier representation of this data is shown in Figure 12. In order to interpret, you would take the dryland crop estimate and add the estimate of the land cover type that is in question to determine the amount of organic carbon that is in that particular vegetative community.

	Estimate	**Pr(>|t|)**
Dryland Crop	3830.6	<0.001
Concentrated	237.1	<0.001
Ephemeral Riparian	130.1	0.0029
Forest	256.1	<0.001
Grassland	230.8	<0.001
Irrigated Crop	299.6	<0.001
Sagebrush	234.6	<0.001

Table A13. One-way ANOVA summary of differences between land cover type based on clay fraction, Cabin Creek Ranch, Shepherd, Montana.

	Df	**Sum Sq.**	**Mean Sq.**	**t value**	**Pr(>F)**
Treatment	6	5335.5	889.26	14.842	<0.001
Residuals	41	2456.4	59.91		

Table A14. Estimates from a one-way ANOVA showing those vegetative communities that are significantly different from one another based on clay percentages. To determine the amount of clay each land cover type has, take the dryland crop estimate and subtract the land cover type in question's estimate. For example the concentrated feeding areas have ~10% clay (36.33 (dryland crop) -26.55 (concentrated) = 9.78). In this table, the estimate is in percentage of clay (%).

	Estimate	**Std. Error**	**t value**	**Pr(>|t|)**
Dryland Crop	36.333	2.580	14.082	<0.001
Concentrated	-26.556	3.649	-7.278	<0.001
Ephemeral Riparian	-27.000	4.080	-6.618	<0.001
Forest	-27.667	4.080	-6.782	<0.001
Grassland	-18.000	5.160	-3.488	0.00118
Irrigated Crop	-7.667	4.080	-1.879	0.06732
Sagebrush	-20.889	3.649	-5.725	<0.001

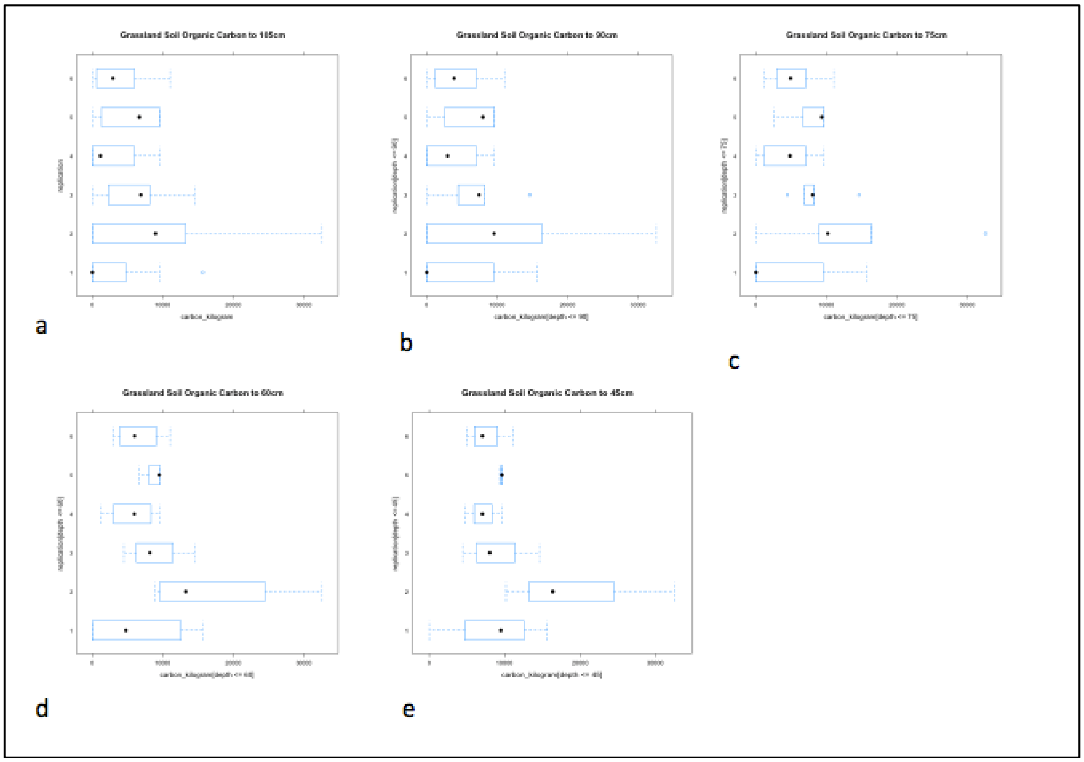

Figure A1. Average distribution of organic carbon with each depth interval for grassland locations at Cabin Creek Ranch, in Shepherd, MT. The 45cm depth interval shows limited variation compared to other depth intervals.

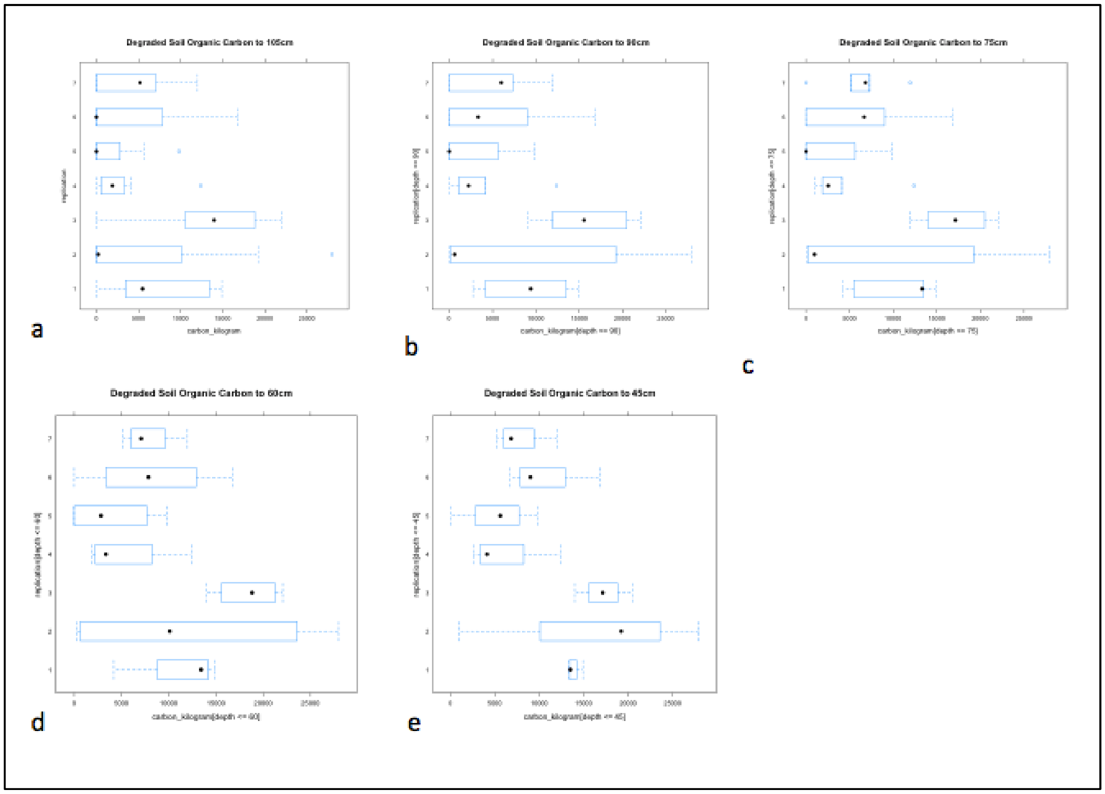

Figure A2. Average distribution of organic carbon with each depth interval for degraded locations at Cabin Creek Ranch, in Shepherd, MT. The 45cm depth interval shows limited variation compared to other depth intervals.