SHORT TERM EFFECTS OF ANNUAL RYEGRASS, RED CLOVER AND HAIRY VETCH COVER CROPS ON VARIOUS INDICATORS OF SOIL HEALTH

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Abstract

The world's population has passed 7 billion and is expected grow to more alarming numbers by the year 2050. The increase in human life on the planet ushers the need to responsibly and sustainably grow more food. In order to meet the demand necessary, it is crucial that soil remains healthy and crop yields continue to increase in efficiency. Irresponsible or ill-informed practices can lead to depleted resources and degradation of fertile soils that may limit a producers' ability to sustainably grow food. Cover crops are a tool that can be used to address issues the modern producer may face. Cover crops have been shown to increase cash crop productivity, improve soil health by improving soil physical and chemical properties as well as providing protection from soil erosion runoff or nutrient leaching.

A study was conducted in 2014 to examine the short term effects associated with cover cropping systems. The effects of ryegrass, red clover and a cover crop cocktail (mixture of ryegrass, red clover and hairy vetch) compared to bare tilled and bare control plots were studied. The five treatments were replicated three times in a completely randomized study and analyzed. Soil physical health indicators such as bulk density and porosity were calculated. Soil and cover crop nutrient use, as well as, soil moisture content data was collected and analyzed using excel and ANOVA statistical procedures.

In the short term, the study found that there was only statistically significant differences between cover cropping regimens, tilled and control plots in regards to biomass production and biomass nutrient concentrations (α=0.05). The cocktail mix provided more biomass, N and P than the ryegrass and clover plots alone. Observable differences in cover crop volumetric soil moisture and water used between plots demonstrated that cover crops utilize soil moisture in the short term, which must be considered in areas experiencing water stress. Although more long-term data is needed to truly quantify how cover crops effect various aspects of soil health, this study demonstrated how cover crops have the potential for providing numerous benefits such as increased erosion control, lower reliance on anthropogenically created nutrients and the reduction of weeds. Overall the benefits associated with cover crops are still being researched and while adoption of cover cropping systems has been slow, a push towards agricultural sustainability while increasing food production will increase the amount of producers utilizing cover crops in the coming years.

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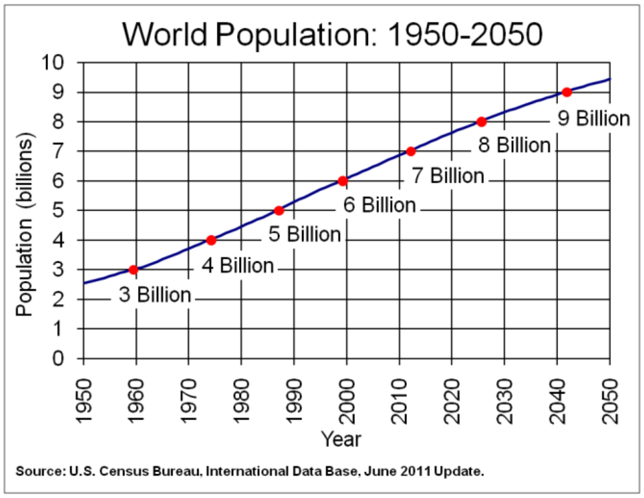
Chapter 1 - Conservative Land Management

The World's population has grown to staggering numbers and is expected to grow to almost 9 billion humans by the year 2040 (Figure 1-1). To meet the food supply demands of a higher population, the use of sustainable cropping systems is necessary. Traditionally, producers leave farm fields fallow after cash crop harvest (Tonitto et al., 2006). These systems are a popular choice as primary tillage prepares the ground for secondary tillage and subsequent planting. Unprotected soils are highly susceptible to negative scenarios such as erosion, which in turn creates situations causing loss of organic matter, increased nitrogen leaching, phosphorous runoff and decreased soil biological activity.

Figure 1-1. World Population prediction 1950-2050 (U.S. Census Bureau, International Data Base, June 2011 updated).



Sediment is considered the number one pollutant from the agricultural sector (Dabney et al., 2001). This sediment can be transported by wind or water and it is estimated that in the United States, the amount of soil eroded by water from pastures and fields equals roughly 75 billion metric tons each year (Fangmeier et al., 2006). Surface runoff from agricultural fields takes place during and after rainfall events and carries with it sediments laden with nutrients, organic matter, pesticides, fine soil particles (Brady and Weil, 2004).

Eutrophication of water bodies takes place when disproportionate amounts of nutrients, like nitrogen (N) and phosphorous (P), enter an ecosystem (Pierzynski et al., 2004). These nutrients are commonly transported via surface runoff and leaching. Increases in nutrients that aid in plant production, along with sunlight and temperature changes cause substantial amounts of algae to bloom (Pierzynski et al., 2004). The massive amounts of algae in eutrophic and hypereutrophic systems negatively affect economic and recreational routines. Issues such as water safety, problems with taste and odor, decrease in biodiversity and impairment of navigation and recreational use are all problems associated with poor water quality from surface run off and eutrophication (Pierzynski et al., 2004). Sustainable agricultural practices such as conservation tillage systems and best management practices (BMP's) help to ensure that land being worked continues to stay profitable while attempting to prevent ecosystem degradation.

In addition to soil erosion and water quality issues, loss of soil health is associated with uncovered soils. Lower moisture availability and premature breakdown of organic matter occur when soils are left exposed to wind and sunlight. The Natural Resources Conservation Service (NRCS) has worked to increase focus on soil development and health in its "Unlock the Secrets in the Soil" campaign (USDA NRCS, 2014). This campaign aims to explain to farmers the benefits linked to improving and sustain soil health such as increased production, increased profits and natural resource protection (USDA NRCS, 2014).

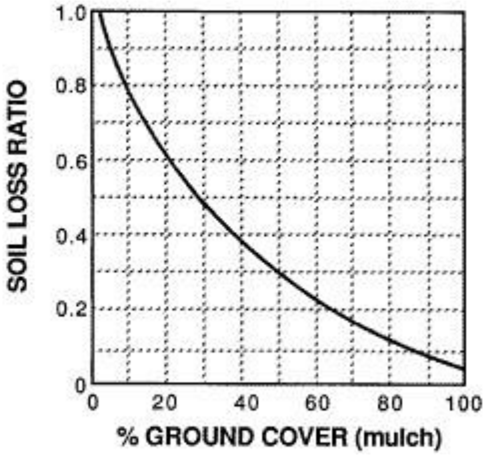
The term soil health is often construed in many different ways. According to the United States Department of Agriculture (USDA), the definition of soil health, or soil quality as it is also referred to, is defined as the "continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans"(USDA NRCS, 2014). That being said, there are many different aspects of soils that can be targeted to improve overall soil health. Soil physical and chemical properties, such as bulk density, soil texture, soil structure and proper horizonation can be considered soil health indicators (USDA NRCS 2014). Techniques to improve soil health are numerous and are considered on a case by case basis.

Overall soil protection is a key issue when examining soil health. The loss of soil to erosion greatly affects every aspect of the environment. Addressing soil erosion is one way producers can take ecosystem function and sustainability into account when creating and maintaining agricultural systems. There are many ways to increase soil health and sustainability in food production but still more research and innovation is necessary to address feeding the world's exploding population.

Chapter 2 - Cover Crops

Crop residues help play an important role in maintaining soil health, as residue provides mulch that leads to an increase organic matter and water retention capabilities as well as decreased amounts of soil loss (Figure 2-1). Management of crop residues and adoption of a proper crop rotation are two important conservation techniques that can be implemented among numerous others (Villamil et al., 2006). Reduced tillage systems have increased in popularity with producers as a way of maintaining healthy soil and crop production.

Figure 2-1. Effect of residue cover (mulch) on the soil loss ratio (as compared to bare, fallow) (McCarthy, et al., 1993).



No-Till Farming

No-till is a conservative farming technique that provides benefits such as increased water holding capacity, decreased erosion potential and increased soil aggregate capacity (McCarthy, et al., 1993). No-till systems plant within existing residues of previous plantings and weeds, utilizing implements that cut small openings in the soil, followed by seed placing equipment that covers the opening once the seed is placed (Figure 2-2) (Brady and Weil, 2004). This method helps to prevent scenarios such as compressed plow pans, which are areas of untilled soil the plow did not reach (Brady and Weil, 2004). Benefits from a producer standpoint include target application of fertilizers, reduced passes over the field, reduction in machinery costs, reduced terrace maintenance in terrace systems and increased soil productivity in the long run (McCarthy et al., 1993).

Figure 2-2. Great Plains no-till planter.

Cover Crops

Another way to increase surface residue is to adopt a cover cropping regimen. Cover crops are defined as crops grown in order to protect the soil from erosion and or nutrient loss from leaching or runoff (Stute and Posner, 1995). Cover crops can be grown in between periods of normal crop production when fields are generally left fallow or they may planted within rows during primary crop production. In addition to surface cover, cover crops can also help to preserve water quality by decreasing nutrient, pesticide and sediment losses (Dabney et al., 2001). Cover crops are also grown in certain situations to provide weed suppression, integrated pest management and sequestration of carbon (Isik et al., 2009).

Generally, these crops are not grown for market and can be killed before they are mature by the use of herbicides or mechanical methods (Harramoto and Gallant, 2005). Traditionally, cover crops that do not winter-kill are incorporated into the soil as part of seed bed preparation.

In no-till, cover crops can be treated with glyphosate (N-[phosphono-methyl] glycine), paraquat (1, 1-dimethy-4-bipryridium ion) or a mixture of non-selective, post emergence and pre emergence herbicide (Fageria et al., 2005). Producers that are making an effort to reduce chemical inputs often turn to mechanical approaches for killing cover crops. These methods include mowing, roll-chopping, rolling, partial rototilling and undercutting (Fageria et al., 2005).

Cover Crop Types

Specific cover crops are chosen based on the direct needs of producers. Problems that produced may wish to address can include: protecting the soil from erosion and leaching, decreasing the amount of fertilizers used within a system, reduce compacted soils, or reduce weed growth (Jerkins, 2012). Region and timing should be carefully considered as there is not a one-crop-fits-all approach to cover cropping. Overall the types of cover crops that may be used are plentiful thus allowing many choices to fit the specific needs of producers.

The term green manure is used to describe cover crops that are incorporated into the soil before cash crop planting (Sweeney and Moyer, 1994). This term is used frequently when examining cover crops, as in traditional systems covers are likely to be incorporated into soil before cash crop planting. This is an important aspect associated with cover crops because it helps to reduce the amount fertilizer inputs by the producer (Rannells and Wagger, 1997). Catch crop is another term used by many to describe cover crops that produce deep, quickly establishing roots (Fageria et al., 2005). These non-leguminous plants enhance nutrient cycling by scavenging nutrients that otherwise may have leached out of the soil profile (SARE, 2012).

Non –Legumes

Non-legume cover crops are beneficial due to their ability to reduce the erosion of soil, recover nutrients and increase organic matter over time (Smith and Kallenbach, 2004). These crops generally establish rapidly and help to keep soil in place. Common non-leguminous crops include sorghum-sudangrass, pearl millet and buckwheat (SARE, 2012). Typically non-leguminous crops are considered nutrient scavengers as they quickly create roots that utilize left over nutrients from the previous crop. Studies throughout the United States showed that non-legumes have the potential to reduce losses of NO_3 to leaching by up to 70% (Kaspar et al., 2012). Types of non-leguminous cover crops are examined in the following sections.

Annual and Perennial Forage and Warm Season Grasses

Annual and perennial forage grasses are used as productive cover crops due to their ability to quickly scavenge for nutrients, provide ground cover and smother competing plants, reducing the abundance of weedy invaders (Krueger et al., 2011). Annual or perennial forage and warm season grasses include: ryegrass, sorghum-sudangrass, foxtail millet, teff, proso millet and annual fescue (SARE, 2012). Warm season grasses are commonly used in vegetable production and help to reduce soil erosion while providing robust soil cover that helps to prevent degradation from farming implements (Rannells and Wagger, 1997).

Cereals

Cereals are a used in many cover cropping systems due to their high yields, cold tolerance and quick establishment (Bjorkman, 2009). Barley, triticale and cereal rye are some examples of cereals used as cover crops. Rye is a popular choice as a cereal cover crop because of its hardiness and ability to effectively scavenge unused N in the soil (Bjorkman, 2009). Deep, fibrous roots establish quickly after planting and lead to ground cover that helps to trap moisture during cold months.

Oats are commonly used as cereal cover crops due to their low cost and dependability (Kaspar et al., 2012). Quick to grow and best in conditions that are cool and moist, oats help to produce large amounts of biomass that cover the ground and provide surface protection. Oat roots have been shown to have allelopathic properties that deter the early establishment of weeds (Bjorkman, 2009). Local varieties of oats can provide increased management options such as straw, grain or cereal which help to tailor the crops used to the producers needs and intentions (SARE, 2012).

Brassicas and Mustards

Brassicas are known for their ability to suppress weeds and reduce diseases (Bjorkman, 2009). Additionally, brassicas are recognized as “bio-drills” due to their extensive root systems that are generally large and have the ability to push through compacted soils (Chen and Weil, 2011). These large tap roots help to increase water infiltration due to the fact that when they are killed and decompose, channels are left open (Chen and Weil, 2011). Inexpensive seed ($2 to $6 USD/kg) and low seeding rate (5.6 to 11.2 kg/ha) make brassicas a top choice as late summer planted cover crops (Bjorkman, 2009). Mustards are a popular choice in vegetable production as they have been shown to reduce occurrences of soil-borne diseases potentially due to glucosinolates left behind in residue (Haramoto and Gallandt, 2011).

Forage radish or tillage radish is a brassica species that does not do well in extremely cold temperatures. Tillage radish is commonly used for its capacity to break through compacted soils. Large white tap roots can extend downwards up to 14 inches, with taproot extensions moving even deeper into the soil (Chen et al., 2014). Planting timing is important as 4-10 weeks is needed for establishment to winter over. Rapid growth in the fall is another desired benefit to planting tillage radish as it implies greater soil cover (>80%), scavenging of excess nutrients left after previous crop harvest and weed suppression (SARE, 2012).

Brassicas and mustards should be planted earlier than other cover crops in order to fully benefit from them since they do not survive winter in many cases. In attempts to ensure cover crop stand development, broadcast seeding into concurrent cash crop rotations can occur (Haramoto and Gallandt, 2011). Planting in rotation with other brassica cash crops such as broccoli, kale and cabbage should not be practiced. Other brassica cover crops include but are not limited to: rapeseed, turnips and mustard (Gruver et al., 2010). The increases in organic matter, bio-drilling root systems and excellent weed suppression make brassicas and mustards ideal in areas where weather is mild (Chen et al., 2014).

Legumes

Legumes help to play an important role in nutrient management as they form positive relationships with root fungi. Rhizobial bacteria allows legumes to fix atmospheric N, thus reducing the amount of fertilizer that must be applied to cash crops (Stute and Posner, 1995). Although legumes can produce their own N, they also have the ability to scavenge excess nutrients, increasing their nutrient retention capabilities. Legumes generally have a lower C: N ratio than grasses, which helps to increase breakdown of organic matter in soils and lead to more rapid nutrient release (Rannells and Wagger, 1997). This low C: N ratio must be understood however, in order to avoid rapid release of nutrients before the subsequent crop is ready to take them up. Legumes such as cowpea, soybean and sunn hemp are popular choices among producers.

Red Clover is a cool season broadleaf that provides low cost N-fixation and medium water use (Bjorkman, 2009). This crop is generally frost seeded or overseeded into existing crop stands in order to suppress weeds and manage N (Bergkvist et al., 2011). In Sweden, researchers have found that red clover can produce between 0 and 90 kg of mineral fertilizer per hectare, while researchers in Wisconsin reported that the use of red clover was equivalent to conventionally planted corn that had 179 kg of N/ha applied (Bergkvist et al., 2011) (SARE, 2012). The increase in beneficial insects associated with red clover have also been noted and help to create better soil organism diversity. Red clover must be killed mid-bloom in order to avoid issues with negatively affecting subsequent cash crop production (Chabi-Olaye et al., 2005).

Hairy vetch is a legume commonly used in corn production around the United States. Hairy vetch is a popular choice as it develops rapidly in the spring, out competes weeds and helps to supply large amounts of N (Czapar et al., 2002). Living hairy vetch mulch has proved to be the best defense against weed establishment, though mowing and leaving residue on the soil surface helps to provide dead mulch that suppresses weeds through allelopathic affects (Campiglia et al., 2010). Hairy vetch N production makes it one of the best legumes to be used as a green manure, although timing is extremely crucial for this crop. Hairy vetch must be killed at least 2 weeks before planting a cash crop. Due to its efficient ability to produce N, the amount of leachable N quickly increases after decomposition begins, thus this decomposition must be timed with cash crop planting in order to maximize the benefits of hairy vetch (Czapar et al., 2002).

Cover Crop Cocktail Mixes

Mixing of legume and non-leguminous crops has been increasing in popularity over the last few decades. Mixing two or more cover crops together creates cover crop “cocktails” (Rosecrance et al., 2000). These combinations help maximize the benefits of cover crops by reducing the reliance on a single cover crop to produce desired outcomes. Cover crop cocktails allow for improvements in a cover cropping system’s weed control, biomass and N production, ground cover, winter survival forage options and many others (Rosecrance et al., 2000).

Risk associated with cover cropping systems can be reduced by utilizing cover crop cocktail mixes that have the potential to behave differently for a given soil and conditions (SARE, 2012). Grass/legume mixture residue have both high and low C: N ratios, which helps to both slow down and stimulate the release of N. This scenario helps nutrient cycling by decreasing leaching potential while providing small amounts of nutrients for crop growth (Rosecrance et al., 2000). Triticale and vetch mixtures have been observed to increase weed suppression, nitrogen retention, beneficial insects and help to control erosion (White, 2013).

Rye-vetch mixes have been reported to produce from 20 to 100% greater amounts of above ground biomass as compared to single cropping systems (Rosecrance et al., 2000). Extensive root networks of grasses in conjunction with the N fixation capabilities of legumes are one way in which producers can benefit from cover crop cocktails. Brassicas have been shown to outcompete other cocktail species and should be carefully considered but have the potential to alleviate compacted soils and pest suppression while working together with grasses or legumes if timed properly (SARE, 2012).

Cover Crop Benefits and Disadvantages

The benefits associated with cover cropping systems are numerous and continue to prove useful in many scenarios. Producers must weigh the benefits with the disadvantages in order to fully understand the implications of cover cropping systems. In order to fully recognize the value of cover crops, adoption must become easier to a farmer. This can be done by education of long term benefits that take longer to affect the bottom line and cost sharing programs to alleviate portions of the initial investment of cover crops. Benefits and disadvantages to introduction of cover cropping systems is discussed in the following chapter.

Reduction of Sediment Transport

Reduction of sediment transport is an important benefit cover crops provide. The production of biomass is much greater in cover cropping systems versus volunteer vegetation (Wang et al., 2012). This increased biomass production leads to increased transpiration, and in non-drought scenarios, allows greater infiltration of rainfall thus decreasing runoff and erosion potential (Sweeney and Moyer, 1994). Cover crop residues help to trap and store moisture, creating dam-like areas that help to reduce the transport capabilities of water. Cover crops also help to protect soil aggregates from rain, decreasing aggregate breakdown and detachment (Wang et al., 2012). The reduction of water and wind velocities, as well as increases in aggregate stability demonstrate how cover crops can help to significantly decrease erosion by wind and water (Dabney et al., 2001) (SARE, 2012) (Alcantara et al., 2011).

Aggregate stability and legumes have been studied extensively. Researchers have reported that an increase mycorrhizae fungi associated with legumes helps to increase the amount of water-insoluble protein called glomalin (Calonego and Rosolem, 2010) (SARE, 2012) (Dabney et al., 2001). This protein acts as natural glue, holding soil particles, organic matter, plant cells, bacteria and other fungi close to each other, helping to improve soil tilth and biodiversity. In addition to glomalin production from mycorrhizae, the fungi send out hyphae, which act like roots, taking up water and nutrients that is in turn provided to plants (Calonego and Rosolem, 2010). In one Florida study, Sunn hemp and velvetbean biomass production decreased the amount of leachable P from the root zone as compared to other cover crops due their extensive root systems (Wang et al., 2012). The use of cover crops to provide soil cover is the primary goal associated with these systems. The increased nutrient and chemical losses associated with traditional systems have a grave impact on our ecosystems and cover crops help to prevent this environmental degradation by naturally protecting soil from losses. This is increasing in importance as areas around the world are affected negatively by erosion associated with agricultural production.

Nutrient Management

Nutrient management is another key aspect associated with cover crops. The Haber-Bosch process has allowed for agricultural intensification and increased production capacity. Annually, the Haber-Bosch method introduces 170 Tg of reactive N into agroecosystems (Cassman et al., 2002). Inorganic fertilizer accounts for 80 Tg of N introduced to agroecosystems yearly. Unfortunately, 45-55% of this N fertilizer is lost though leaching, denitrification and erosion (Tonitto et al., 2006). Denitrification accounts for an estimated 26-60 Tg N year^{-1}, and erosion and leaching account for an estimated 32-45 Tg N year^{-1}(Cassman et al., 2002). Current management practices in North America favor large areas of intensively managed land and consequently widespread frequency of bare fallow (Wyland et al., 1996). Adoption of these management practices globally is expected to significantly increase the use of N fertilizer worldwide as producers commonly over apply fertilizer in acknowledgment of the large amounts of nutrients lost during the growing season in order to improve crop yield.

The use of legumes as green manures to increase soil N has gained increasing popularity in modern agriculture for those hoping to reduce reliance on chemical fertilizers (Sarrantonio and

Gallandt, 2003). Researchers have estimated that legumes like hairy vetch can add over 100 kg N ha^{-1} (Sweeney and Moyer, 1994). Producers in the mid-west United States Corn Belt have adopted limited use of cover crops, partially due to the fact that soil moisture is depleted heavily by legume only systems prior to cash crop planting. A study completed by Russell and Fillery in 1996 and 1999 concluded that about 40% of the N found in wheat shoots could be attributed to legume produced below-ground-biomass-N (Flower et al., 2012). The inherent differences between inorganic fertilizer N and green manure lead to direct additions of N into soil organic N pools, equating to increased ability of the crops to take up N (Tonitto et al., 2006).

The reduction of nitrate leaching via cover crops happens in two ways. They scavenge for available N to grow biomass, as well as, utilize soil moisture which reduces the amount of available water for leaching (Rosecrance et al., 2000). In most of the United States, cereal rye is a good choice for catching nutrients after cash crop harvest. It winters down later than other covers, allowing deep roots to establish that can reach up to three feet (Tonitto et al., 2006). Researchers noted in a study that cereal rye took up more than 78 kg N/ha when planted by October 1st in the Midwest. In Iowa, researchers reported that winter rye cover that followed both stages of a corn-soybean rotation in a no-till system reduced the amount of NO_3 in drainage water by an average of 61% (Kaspar et al., 2012).

The carbon-to-nitrogen ratio (C: N) indicates the decomposition rate of plant material and the N release (Flower et al., 2012). C: N associated with cereals and oats has been shown to increase over time and help to increase the amount of soil organic N reserves which contribute to increase N mineralization over extended periods (Flower et al., 2012). Denitrification of soil N is controlled by soil O_2, mixing cover crop species is suggested in order to optimize N release (Rosecrance et al., 2000).

In addition to N cycling, cover crops have been shown to bring nutrients such as calcium and potassium from deep soil layers (Wang et al., 2012). These macronutrients travel readily with water and can be scavenged by any deep-rooted cover crop. Some cover crops, such as lupins and buckwheat, are believed to secrete acids into the soil that increase phosphorous availability by making it a more plant-usable form (Wang et al., 2012). Beneficial root fungi mycorrhizae have progressed to efficiently absorb P from the soil, which is then given to the host plant (Wang et al., 2012).

Increase Organic matter, Soil Carbon and Organisms

An additional benefit of cover cropping comes in the form of increases in organic matter, soil carbon and soil organisms. Overall, living cover of the soil surface provides food year-round to organisms that utilize root by-products or structure for those that are in need of a habitat (Sainju et al., 2008). In one study, hairy vetch had two to eight times greater concentrations of C and N than winter weeds and helped to maintain these higher concentrations across multiple years (Sainju et al., 2008). In this same study, cereal rye was also examined and reported to maintain greater organic C much like crimson clover and hairy vetch.

C: N ratios of greater than 35 cause N to become immobilized thus slowing the release of N (Rannells and Wagger, 1997). The direct increases in soil microbial biomass C from cover crops must be understood in order to efficiently balance N inputs with losses. Grasses and cereal grain residues have C: N ratios that immobilize N and may require an increase in the amount of fertilizer added to the system if not properly timed (Sainju et al., 2008). Legumes, on the other hand, have lower C: N ratios and help to reduce the amount of fertilizer needed to produce quality yields (Rannells and Wagger, 1997).

Cover crop biomass stimulates soil biological activity which increases soil organisms (Gruver et al., 2010). A study analyzing the free-living nematode community composition of soils following cover crops showed that due to the inputs of N-rich organic matter, nutrient mineralization and biological activity are both increased (Gruver et al., 2010). Mycorrhizal fungi is an important soil quality factor that is affected by cover cropping (Dabney et al., 2001). As discussed earlier, this fungi forms an important symbiotic relationship with the roots of plants which provides increased nutrient and water uptake (Dabney et al., 2001). Studies show that cover crops help to increase soil aggregate stability and enhance plant growth by increasing Mycorrhizal fungi.

Reduced Compaction

Intensive cropping systems lead to enhanced ecosystem degradation due to increased use of heavy machines, unsuitable soil management practices and short crop rotations (Chen and Weil, 2011). Soil compaction is a large problem in many agricultural areas and has been linked to decreased yields due to limited plant root development, reduction in water capacity due to soil grain rearrangement leading to decreased void space available for water (Chen et al., 2014).

Brassica cover crops, which have been reviewed earlier in the chapter, are best known for their ability to break through compacted layers of soil, working to lessen the effects of compacted soils (Chabi-Olaye, et al., 2005). Increases in root channels due to cover crop development lead to better air permeability in compacted soils planted with cover crops, this helps to relieve water availability issues and increase bulk density (Chen et al., 2014). The use of cover crop cocktails helps to improve compacted soils by providing the use of 'bio-drills" in conjunction with thick surface mulch to help retain water and open root channels (Chen and Weil, 2011) (Figure 2-3).

Figure 2-3. Tillage radish helps to break through compacted soils with its large extending root systems (Robinson, 2010)

Pest and Weed Suppression

Cover crops suppress weeds via mechanisms such as niche disruption, canopy closure and increased resource competition. One study showed that cover crops reduced weed abundance by almost 95% as compared to bare, fallow (Gruver et al., 2010). In Spain, a study conducted over summer cover crops reported that mustard reduced weeds by up to 50-60% and most notably helped to reduce the emergence of pigweed (Alcantara et al., 2011).

In addition to weed suppression, cover crops have also been linked to pest suppression. Thus far, all brassicas has been shown to contain glucosinolates that upon tissue destruction, release of an assortment of compounds via enzymatic hydrolyzation (Haramoto and Gallandt, 2011). Compounds released from brassicas have been shown to include isothiocyanates, which are toxic to both insects and plants (Haramoto and Gallandt, 2011). One study Maryland study suggests that in order to maximize the benefits associated with glucosinolates, irrigation immediately following green manure incorporation aids in moving the compounds deeper into the soil profile, thus reducing the potential for volatilization (Gruver et al., 2010).

Pests such as the Columbia root-knot nematode (Meloidogyne chitwoodi) plague areas such as Washington and Oregon and nearly $20 million dollars is spent in Washington alone on soil fumigants (SARE, 2012). Rapeseed, mustard and arugula were shown to potentially reduce up to 80% of the nematode pests. Nematicides are used in conjunction with brassicas that provide enticing habitat for hosting parasitic nematodes (Haramoto and Gallandt, 2011). This lures the non-beneficial nematodes to a specific areas, allowing for targeted control.

The use of crop rotations that contain cover crops reduce the amount of weeds in many ways. The increased ground cover associated with cover crops keep soil temperatures lower in cooler climates, this reduces the time available for weed seed germination (Rannells and Wagger, 1997). Quick biomass production smothers less mature weeds and outcompetes for soil moisture and available nutrients. Buckwheat is considered a good early summer cover crop that establishes quickly after planting and greatly reduces weed growth (Bjorkman, 2009).

Yield Effects

The bottom line affecting most decisions in agriculture is crop yield, an understanding of cover crops effects on cash crop yield is important when deciding on a cover cropping system. A meta-analysis done in 2006 reported that on average, non-legume cover crops did not cause yield declines. However the researchers found that on average, yield was decreased by 10% in legume cover cropping systems (Tonitto et al., 2006). The reasons for the reduction in yield are attributed to the low amount of biomass produced by legumes and their tendency to decrease soil moisture levels more than non-legumes. The study points out however that legumes which provided > 110 kg N ha^{-1} were adequate enough to produce corn yields comparable to yields in conventional fertilizer-driven systems (Tonitto et al., 2006).

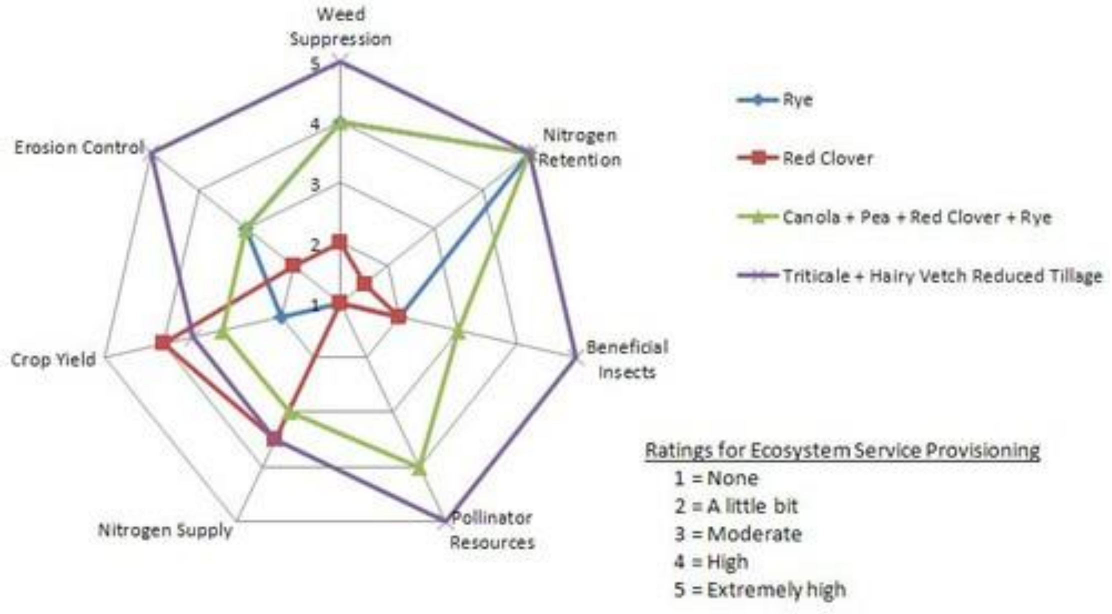
Conversely, researchers in Parsons, KS noted that yield was greatly affected positively by legume planting. Following both hairy vetch and red clover yield increased from 79 to 131% more than with continuous grain sorghum (Sweeney and Moyer, 1994). Another study conducted on a tomato vegetable cropping system in Rome reported that Hairy vetch produced tomato yields just as efficiently as fields where N fertilizer was applied (Campiglia et al., 2010). Other researchers in the US state of Georgia have noted that tomato, eggplant and corn production yields were increased following hairy vetch use (Sainju et al., 2002).

Ecosystem services

Ecosystem services are defined as services provided by the environment that are beneficial to humans, classifications of services are: provisioning, regulating, supporting or cultural (Millennium Ecosystem Assessment, 2005). For example, a provisioning ecosystem service in agriculture would be crop production while supporting services such as water and nutrient cycling also come from the environment (Millennium Ecosystem Assessment, 2005). It is important for producers to create cropping systems that are beneficial to ecosystems as well as maximizing profits from crop yield.

Cover crops offer many ecosystem services that include nutrient cycling, pest regulation, improvements in soil quality and crop productivity (Schipanski et al., 2014) (Figure 2-4). Degradation of water quality due to increased amounts of inorganic fertilizer can be directly addressed and rectified using a cover cropping regimen that works to capture and store excess nutrients. In addition to the increased ecosystem benefits, there are trade-offs associated with cover crops and ecosystem services that depend greatly on region and timing of crops (Schipanski et al., 2014). A major trade-off reported in 2013 was between N supply and the risks of denitrification, although the ability to reduce inorganic fertilizer is a positive, an increased amount of denitrification was shown to occur in legume systems where residue was incorporated (Schipanski et al., 2014).

Figure 2-4. Rating of provisions of ecosystem services by different cover cropping systems (White, 2013).



Overall, assessment of cover crop effectiveness should include their ability to enhance ecosystem services. This thought process allows for a better understanding of the long-term benefits associated with cover cropping and why they are important. Producers must focus less on maximizing crop yield and more on improving agroecosystem function and sustainability. In order to do this, assessment of ecosystem services should be adopted and considered when making cropping decisions.

Disadvantages

Although the positives associated with cover crops are numerous, there are many disadvantages that deter mass adoption of cover cropping systems. While the use of anthropogenic sources of N are decreased when using a green manure, the capability of the N to leave the system is still the same as with conventional fertilizer management (Cassman et al., 2002). Conventional plowing during incorporation can cause speedy decomposition, which may provide a greater amount of N than needed in the system. The use of a no-till cropping system reduces this loss of N, however ammonia volatilization or denitrification may occur when NO_3 is converted to gases under flooded or low oxygen conditions (Cassman et al., 2002).

Disadvantages associated with cover crops also include increases in the use of chemical herbicides and pesticides. Most notably in no-till systems, the amount of chemical inputs added to the system in order to properly kill the crops can decrease profitability (Tonitto et al., 2006). If proper timing in killing the crops is not enforced, cover crops will act as weeds themselves, tying up essential nutrients and moisture from cash crops. Unfortunately, the more successful the cover crop, the more difficult it becomes to kill (Snapp et al, 2005). It is imperative that cover crops are killed before seed production as some cover crops seeds produce a hard coat or similar mechanisms which allow them to germinate at different parts of the year, just as weeds do (Snapp et al., 2005). Soil shading is an important disadvantage in colder areas as it impedes the ability of subsequent cash crops to germinate (Snapp et al., 2005). These disadvantages can have immediate impacts on a producer's bottom line. The disadvantages of these systems still generally do not outweigh the benefits but must be carefully considered individually for each production system.

Cover Crop Adoption and Economics

Adoption of cover cropping systems relies on weighing advantages to disadvantages (Table 2-1). Many of the benefits associated with cover crops come in the form of soil conservation properties which are hard to justify to those whose management practices are driven by yield production (Snapp et al., 2005). The lack of producers utilizing cover crops suggests that many perceive the advantages to be outweighed by the disadvantages (Stute and Posner, 1995). Increased inputs are necessary and may take producers many years to break even and the costs associated with cover cropping systems are still being understood (Snapp et al., 2005). Research shows that at least five years is required in order to directly see the benefits associated with cover crops (Singer et al., 2007).

According to a review published in 2005, costs associated with cover cropping take three forms: direct, indirect and opportunity costs (Snapp et al., 2005). The cost of establishing these stands are typically higher for legumes and costs can be as much as 10% more than the cost associated with non-legume planting. Direct costs include seed, equipment, and the potential need for irrigation or fertilization (Snapp et al., 2005). Indirect costs can be attributed stand development and/or cover crop management problems. As stated above, cover crops must be managed properly in order to avoid decreases in cash crop yield. Soil shading provided by cover crops can act to slow the warming of soil in cooler areas which inhibits cash crop establishment and proper timing (Wyland et al., 1996). Indirect costs can also be attributed to the slow release of N from residues of non-legumes. It is tremendously important for a producer to understand how to synchronize nutrient release from cover crop residue with the needs of the establishing cash crop (Snapp et al., 2005).

Table 2-1. Advantages and Disadvantages of Using Cover Crops (Dabney et al., 2001).

Advantages	Disadvantages
Reduce soil erosion	Must be planted when time (labor) is limited
Increase residue cover	Additional costs (planting and killing)
Increase water infiltration into soil	Reduce soil moisture
Increase soil organic carbon	May increase pest populations
Improve soil physical properties	May increase risk of diseases
Improve field trafficability	Difficult to incorporate with tillage
Recycle nutrients	Allelopathy
Legumes fix nitrogen	
Weed control	
Increase populations of beneficial insects	
Reduce some diseases	
Increase mycorrhizal infection of crops	
Potential forage harvest	
Improve landscape aesthetics	

Crop production must maintain profitability and it is apparent that cover cropping is not seen as economical due to the fact that so little U.S. cropland is planted with cover crops (Dabney et al., 2001). Adoption of cover cropping systems remains slow and according to a 2007 study of cover crop usage in the mid-west U.S. Corn-Belt only 18% of farmers have ever used cover crops (Singer et al., 2007). Crop diversity was an important factor in the farmers' decision to use cover crops. The acknowledgement of benefits associated with cover crops signals that more work must be done in order to assist with implementation costs rather than purely focusing on education of benefits from cover crops. The mid-west U.S. study also reported 56% of the farmers surveyed stated they would plant cover crops if cost-sharing was available (Singer et al., 2007). Programs at the federal, state and county level would allow for popularization of the technique leading to increased adoption.

Mid-West U.S. Cover Crop Studies

There have been various studies done in the mid-west United States on cover crops. In Wisconsin, researchers demonstrated the use of cover crops as green manure in 1991 and 1992 and found that red clover and hairy vetch produced similar amounts of N as compared to fertilizer N treatments (Stute and Posner, 1995). Researchers in Minnesota studied the effects of cereal rye on subsurface drainage and nitrate leaching and reported in one four year study that nitrate was reduced in soybean fields by 13% in a corn-soybean cover crop system (Strock et al., 2004). In 2008 and 2009, cover crops were shown to reduce the amount of available NO_3 by 35% in corn silage production, having minimal effect on subsequent corn production (Kreuger et al., 2011). This study also demonstrated how timing of killing and trade-offs associated with rye forage production such as increased effects on following yields must be understood in order to maximize cover crop benefits. Iowa State University researchers found that after fall planted oats and rye, NO_3 concentrations in drainage water over five years was reduced by 26% and 40% respectively and are effective tools for reducing nitrate leaching in corn-soybean systems (Kaspar al., 2012).

Overseeding annual ryegrass and cereal rye into soybeans was shown to increase residue cover by 60% and reduce weeds by 70% in a two year study in Missouri (Smith and Kallenbach, 2006). In 1989 research was conducted on various sites in North East Kansas by Kansas State University's Research and Extension. Doniphan, Brown and Shawnee County sites were selected and had varying slopes of 10%, 4% and 0.7% respectively. The study aimed to examine how cover cropping and corn-soybean crop rotation affect residue production in previously mono-cropped soybean systems over a four year period of time. The use of cover crops in conjunctions with a corn-soybean crop rotation significantly affected soil surface residue cover at all of the KS study sites (Appendix A). This multiple year experiment helps to document how proper management techniques can help to reduce the availability of soil to losses from wind and water erosion which in turn help to reduce environmental degradation from the agricultural sector.

Although many long term studies have been done in the mid-west, there have not been many that explore how cover crops behave in the first growing season. In order to examine the effects of cover crops in the short term a study was conducted at Kansas State University with four objectives in mind:

- Examine the short term effects of cover crops on soil moisture use.
- Examine changes in various soil health indicators such as bulk density and porosity.
- Examine changes in soil organic matter associated with cover crop growth
- Examine biomass production and nutrient uptake associated with cover crop growth.

This study aims to address these objectives in order to better understand the short term effects of cover crops and what these effects may imply from a producer standpoint.

Chapter 3 - Materials and Methods

The Kansas State University (KSU) North Agronomy Farm has nearly 1000 acres of dryland and irrigated cropland (KSU, 2014). This experimental farm acts as a live learning farm for students and producers, as well as a research farm, with experimentation occurring on many different areas around the farm. Here, scientists have been conducting research for over 100 years and continue to pioneer agricultural innovations and techniques.

Site Description

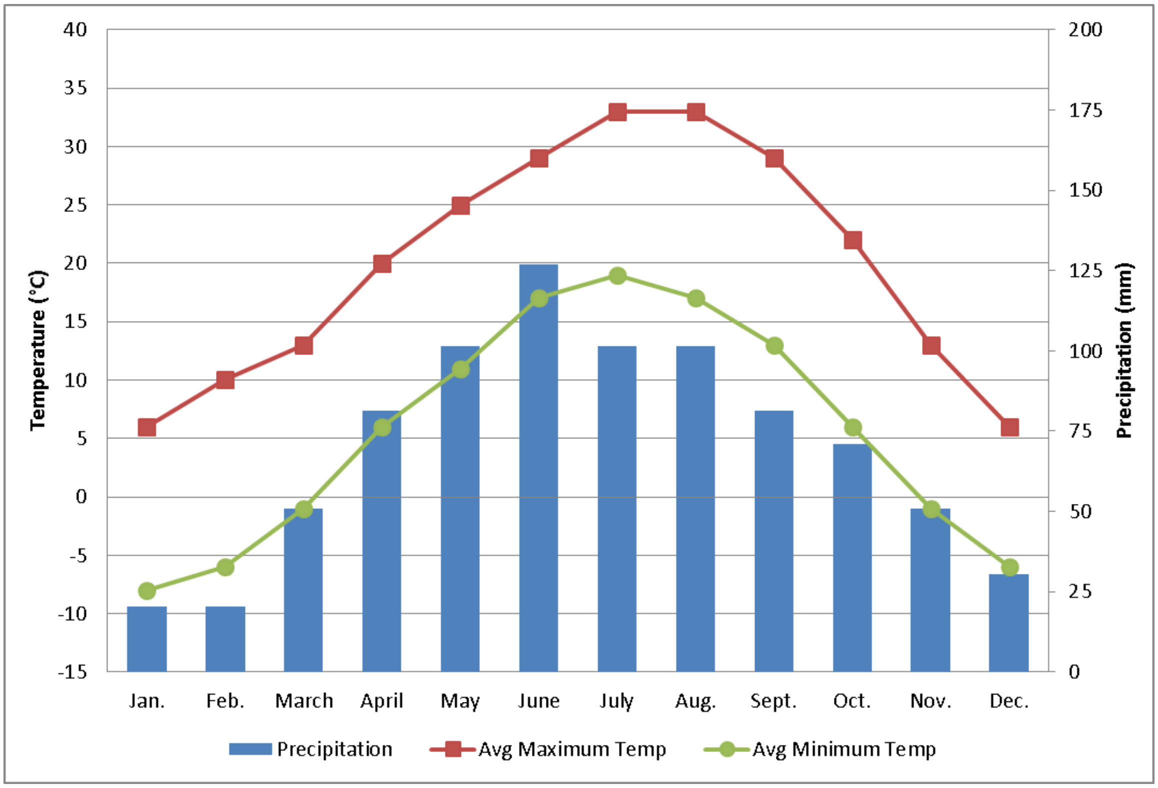
KSU's Agronomy North Farm is located in Manhattan, KS in Riley County (39.12'17° N, 96.35'33° W). The agronomy farm is positioned in the Flint Hills ecoregion (US EPA Level III ecoregions), which is noted by steep valleys, rolling hills and cattle grazing on rangeland. This ecoregion is known as the "tall grass prairie", and encompasses the largest intact tall grass prairie that remains in the Great Plains (US EPA, 2014).

Cherty limestone and shale make up the composition of most of the bedrock in the Flint Hills ecoregion (US EPA, 2014). The study plots, located in the southern end on the farm, contained two main types of soil, 90% of the soil is Wymore silty clay loam and the remaining 10% Smolan silt loam (USDA NRCS, 2014). The Wymore silty clay loam has an overall soil texture of a silty clay loam and contains 1.4% organic matter, 0-5% sand, ~26% silt, and 42-55% clay. This soil is noted as having impermeable clay layers or clay pans (USDA NRCS, 2014). Proof of this restrictive layer in this study was evident when coring soil to a depth of approximately 27cm at the North Farm site. Wymore silty clay loam is classified as Hydrologic Soil Group D. Group D soils are characterized as having slow infiltration rate when wet and low leaching potential. Soils in this group have over 40% clay and less than 5% sand, which slows water movement through the soil profile.

Climate

Climate at the North Agronomy Farm is that of typical mid-continental climate, experiencing extreme cold weather events during winter as well as dangerous heat events during the summer months (Figure 3-1). Traditionally, the warm season begins early June and ends early September, with peak temperatures at the end of July (Goodin et al., 1995). The cold season in this region begins in early November and lasts until March, with the coldest being the month of January (Goodin et al., 1995).

Figure 3-1. Climograph for Manhattan, Kansas including monthly average temperature and precipitation data for the consecutive years of 1981-2010 (adapted from NOAA/National Weather Service, 2013).



Study Area

The area used for this study is a small section approximately 82 x 12 meters of the KSU North Farm located near the entrance to the various workshops and the KSU seed sales office (Figure 3-2). The research area was divided into 15 equal sections of 3 m x 12 m plots (Figure 3-3).

Figure 3-2. Research plots at the KSU Agronomy North Farm (Google Earth, 2014).

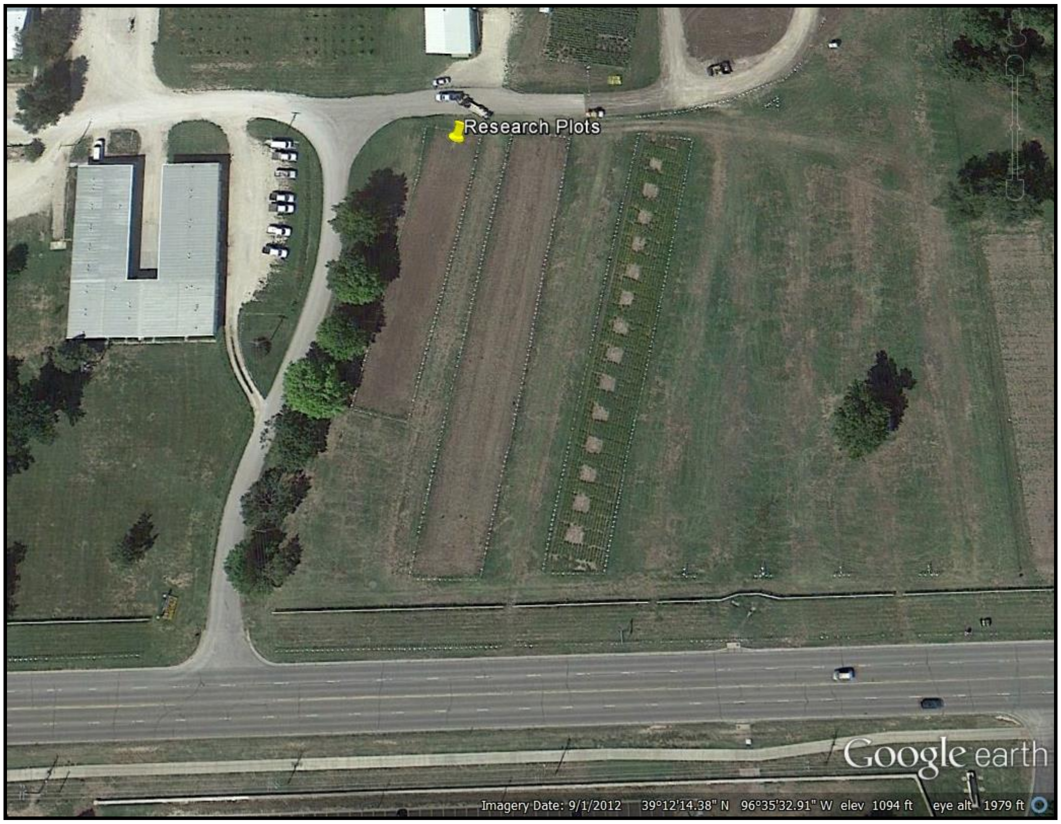
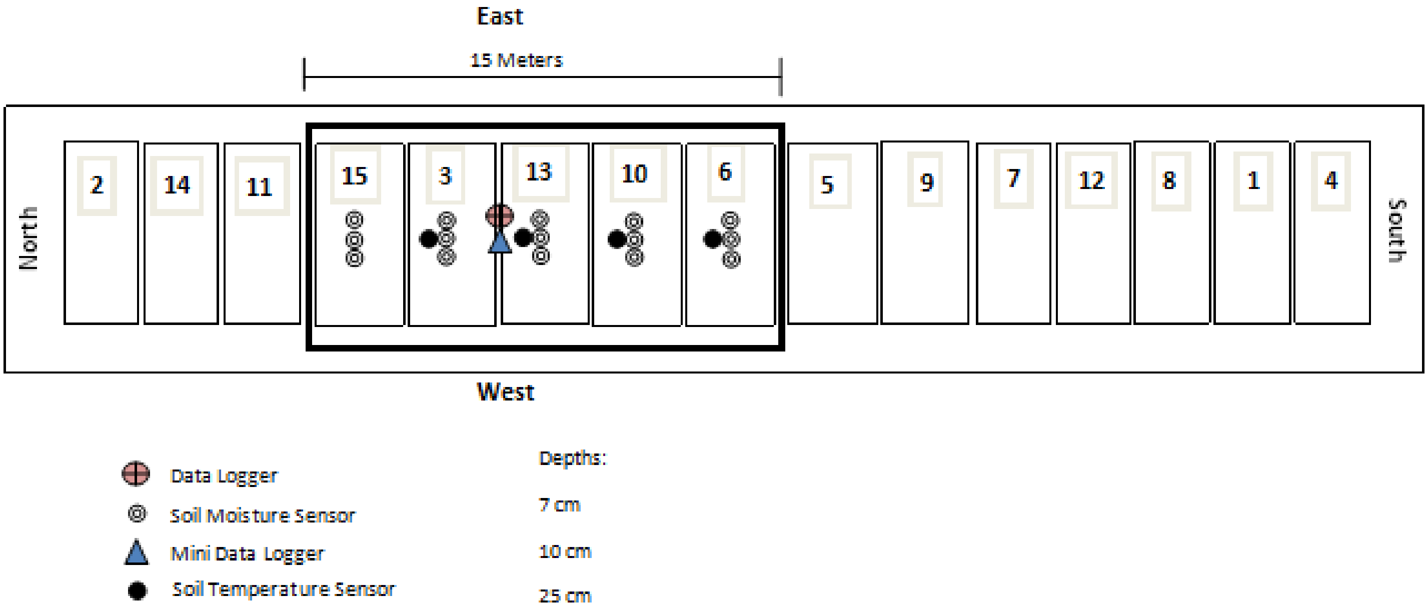


Figure 3-3. Representation of the cover crop study plots and sensor placement at KSU North Farm.



Experimental Design

The fifteen research plots were randomly assigned one of five treatments, control (bare ground), tilled (bare ground), annual ryegrass cover, red clover or a cover crop cocktail (hairy vetch, red clover and annual ryegrass). Preceding the establishment of the study plots; the area was left fallow and research had not been conducted on the land in the two growing seasons prior to the study. Originally, the intent of this experiment was to use the cover crops as winter cover, thus on October 24th, plots were seeded using a 2 m Great Plains end wheel drill. Ryegrass was seeded at a rate of 80 kg ha^{-1}, red clover at 13 kg ha^{-1} and for the cocktail mixture, hairy vetch was seeded at a rate of 25 kg ha^{-1} with the others planted using the same respective rates. The plots receiving the till treatment were disked to a depth of approximately 5cm.

Due to a relatively mild fall followed by the rapid onset of an extremely cold winter and lack of soil moisture during germination, the initial stand of cover crop unfortunately did not reemerge after the winter. Due to this, the experimental plots were thoroughly raked, weeded and reseeded on April 17th, 2014. Rye, clover and vetch seeds were broadcast applied at varying seeding rates (approximately 84 kg ha^{-1} for rye, 25 kg ha^{-1} for red clover and 35 kg ha^{-1} for hairy vetch) in order to ensure proper seed development. Glyphosate was applied to the crops at the end of the study to ensure they were killed in time for other experiments to take place.

Soil Moisture Sensors

Soil water content was monitored using a portable Campbell Scientific HydroSense II (HS2) soil water sensor (Figure 3-4). This sensor measures the percentage of volumetric water available at both 12cm and 20cm depths of soil. The HS2 probe also allowed for monitoring of all 15 plots and each week, 45 measurements were taken, 3 from each plot. Soil water content of a section of the plots was monitored using a HOBO U30 Weather Station (Figure 3-5) and dielectric soil moisture sensors (Figure 3-6). On December 17th, 2014, fifteen sensors were placed at 7, 10 and 25cm below the soil surface and the readings were recorded every minute (Figure 3-7). A HOBO mini data logger was also utilized to install temperature sensors in 4 of the 5 plots at a depth of 10cm in order to measure soil temperature (Figure 3-8). Software provided by HOBO allowed for the soil moisture and temperature reading to be downloaded approximately every 2 weeks. In order to relate the 5 plots that were monitored by the HOBO weather station to the rest of the plots, Hydrosense II data was compared to temperature calibrated HOBO weather station data.

Figure 3-4. Campbell Scientific HydroSense II used to measure volumetric water content.

Figure 3-5. HOBO U30 weather station and mini data logger used to collect soil moisture and temperature readings.

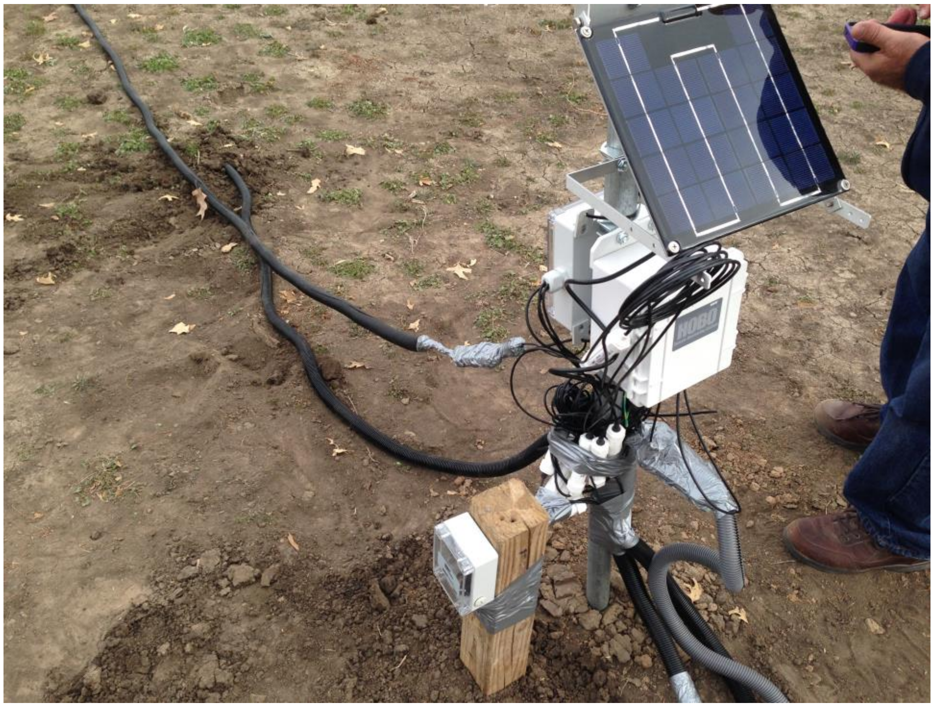


Figure 3-6. Dielectric soil moisture sensors used with HOBO weather station to record volumetric moisture content of the soil.

Figure 3-7. Soil moisture and temperature sensor placed at 10 cm.

Figure 3-8. Temperature sensor used in recording soil temperature with HOBO mini data logger.

Dielectric moisture sensors are common within research and industry. Dr. Colin Campbell and associates researched the effects of temperature on dielectric soil moisture sensor readings in an attempt to identify trends associated with incorrect data. Although in cooler temperatures and in deeper soils temperature has a miniscule effect on the moisture sensors, sensors placed near the top of the soil profile were shown to be negatively affected by temperature. Sensor readings were lower in the top soil profile and the use of calibration methods is necessary to ensure proper measurement of volumetric water content. Campbell states that temperature effects may be attributed to free and bound water on the surface of the soils and a relationship between different variables and the moisture sensors were reported. In their results, a simple temperature corrected water content equation is developed.

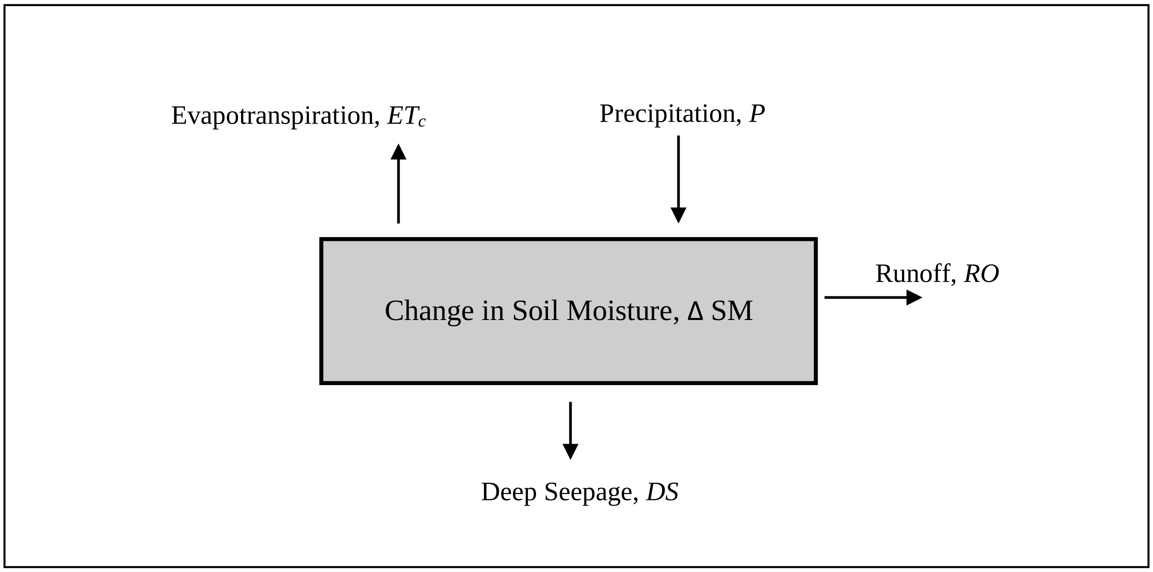
$$\theta_t = \left[\frac{T_r + C}{T_i + C}\right]\theta_m \qquad (3.1)$$

Where Ti is the temperature at which the measurement was made, Tr is the temperature of ECH2O probe calibration (20°C) and C is a constant. θm= apparent measured volumetric water content (Campbell, 2009). For this experiment, the use of equation 3.1 allowed for more accurate HOBO weather station data that was comparable to the HydroSense II probe values. This permitted a comparison of the five plots monitored by the HOBO weather station to the rest of the ten plots in the experiment. It is important to note that the calibrated values of the weather station data were similar to those given by the HS2, thus this technique is valid and demonstrates the effectiveness of multiple monitoring systems to collect experimental data and provide consistent measurements between various methods.

Soil Water Balance

A basic water balance can help to determine the amount of water entering and leaving a system and where the changes in soil moisture occur (Allen et al, 1998). Figure 3-9 demonstrates how water enters and leaves the system through precipitation, runoff, deep seepage and evapotranspiration (ET). The 1998 publication by Allen et al. states that ET occurs in cycles and depends on the growing season. This cyclic pattern of evapotranspiration is important to understand when growing any type of crop and can be an important tool for water conservation.

Figure 3-9. Individual components of a soil water balance for the study site at the KSU North Agronomy Farm.



For the study site, inputs and outputs can be placed into a simple water balance (equation 3.2).

$$\textit{Inputs} - \textit{Outputs} = \textit{Change in Soil Water Storage} \qquad (3.2)$$

In order to apply the equation to the study site, equation 3.2 can be expanded to equation 3.3 as follows:

$$\Delta SM = P - ET_c - RO - DS \qquad (3.3)$$

where ΔSM is change in soil moisture, P is precipitation as measured daily by KSU North Agronomy Farm weather station, RO is surface runoff, DS is deep seepage and ETc is evapotranspiration.

Assumptions of the cover cropping system were made for the study site in order to better understand the system water balance. It was assumed that all water was contained within the top 25cm of soil. The study soil is classified as hydrologic soil group D, characterized by a clay pan and low subsurface drainage. This clay plow pan was found while taking initial soil core measurements at around the 25cm depth, thus DS was assumed to be zero. Also, due to the relatively flat surface of study site, runoff was assumed to be zero. Rainfall was assumed to fully infiltrate into the research plots top 25 cm of soil. Thus, with the amount of rainfall entering the system and the evapotranspiration being known, the system water balance is equal to equation 3.4:

$$\Delta SM = P - ET_c \qquad (3.4)$$

Evapotranspiration and Cover Crop Coefficient

Evapotranspiration is useful for gaining an understanding of the water use potential of the study cover crops via evaporation and transpiration. Furthermore, crop coefficients enable researchers and producers to more accurately calculate evapotranspiration or predict future cover crop use. For the study site, evapotranspiration was calculated using the following equation:

$$\mathrm{ET_c = K_c * ET_o * K_s} \qquad (3.5)$$

where ET_c is the crop evapotranspiration, ET_o is the grass reference evapotranspiration as calculated by Kansas State University's weather station located at the KSU North Agronomy Farm, K_c is the crop coefficient and K_s is the water stress coefficient (Allen et al., 1998). Due to the large amounts of precipitation over the growing season at the study site, it was assumed that root zone depletion never exceeded readily available water, therefore K_s becomes 1 and can be taken out of the equation.

The water use coefficient is governed by factors such as vegetation type, soil evaporation, vegetation growth stage and climate (Allen et al., 1998). In order to determine the long term evapotranspiration potential of cocktail, clover and ryegrass systems, the crop coefficient was determined by manipulating equation 3.5:

$$K_c = ET_c / ET_o \qquad (3.6)$$

where ETc is found by using equation 3.4, utilizing the daily change in soil moisture from the HOBO U30 Weather Station and reference ET_o is available from Kansas State University weather station data.

Soil Analysis

Analysis of total N, total P and organic matter was done prior to planting and after biomass collection at the end of the study. Soil core samples were taken from each 1/3 of the 15 plots using a soil core sampler in order to better average the plots. Samples were analyzed at depths of 0-7.62 cm, 7.62 to 15.24 cm and from 15.24 to 30.48cm. KSU’s soil testing laboratory was used to analyze the amounts of total N, total P and percent organic matter in each of the soil samples. Traditional methods for calculating soil physical properties such as bulk density and porosity were used in the environmental laboratory at KSU’s Department of Biological and Agricultural Engineering.

Bulk density (ρ_b) is a ratio of the mass of dried soil to its total volume (Hillel, 1980). For bulk density, core weights were measured before and after drying in an oven at 100° for approximately 48 hours. Dry weight (Ms) of the sample over the volume (Vt) of the soil corer was used to calculate bulk density of start and ending soil core samples using equation 3.7 (Hillel, 1980).

$$\rho_b = M_s/V_t \qquad (3.7)$$

Porosity(f), an index of the relative volume of pores within a soil, was calculated by equation 3.8:

$$f = 1- (\rho_b / \rho_p) \qquad (3.8)$$

where ρ_b is soil bulk density as determined by the soil core samples and ρ_p is particle density which is assumed to be 2.65 g/cm^3 (Hillel, 1980).

In order to understand the volume of water within a given volume relative to the volume of the soil pores, degree of saturation is calculated. This percentage ranges from 0% in drier soils to 100% in saturated soil. Degree of saturation(S) was determined using equation 3.9:

$$S = \Theta / f \qquad (3.9)$$

where Θ is the volumetric water content and f is porosity (Hillel, 1980).

To quantify the amount of soil water used weekly (SW_w) in relation to rainfall equation 3.10 was used:

$$SW_w = SM_{wavg} + P_w - \Delta SW_w$$

where SM_{wavg} is Average weekly soil moisture, P_w is the weekly precipitation and $\Delta SM_w$is the change in weekly average water amount (3.10)

This calculation helps to demonstrate the amount of soil water used each week in mm. Calculations for the weekly and average amount of soil moisture used is located in Appendix C.

Cover Crop Biomass

Cover crop biomass was assessed using a 30.48 cm x 30.48 cm square (Figure 3-10). All biomass on the soil surface was collected, dried at 70°C for 72 hours and weighed in grams. Biomass analysis was also done in the Throckmorton soil testing lab at Kansas State. There, lab technicians assessed the percentage of total N and total P within the biomass. Calculations to equate these findings into grams per hectare of the plots and are located in Appendix E.

Figure 3-10. Biomass was collected using a 30.48 x 30.48 cm square.

Statistical Analysis

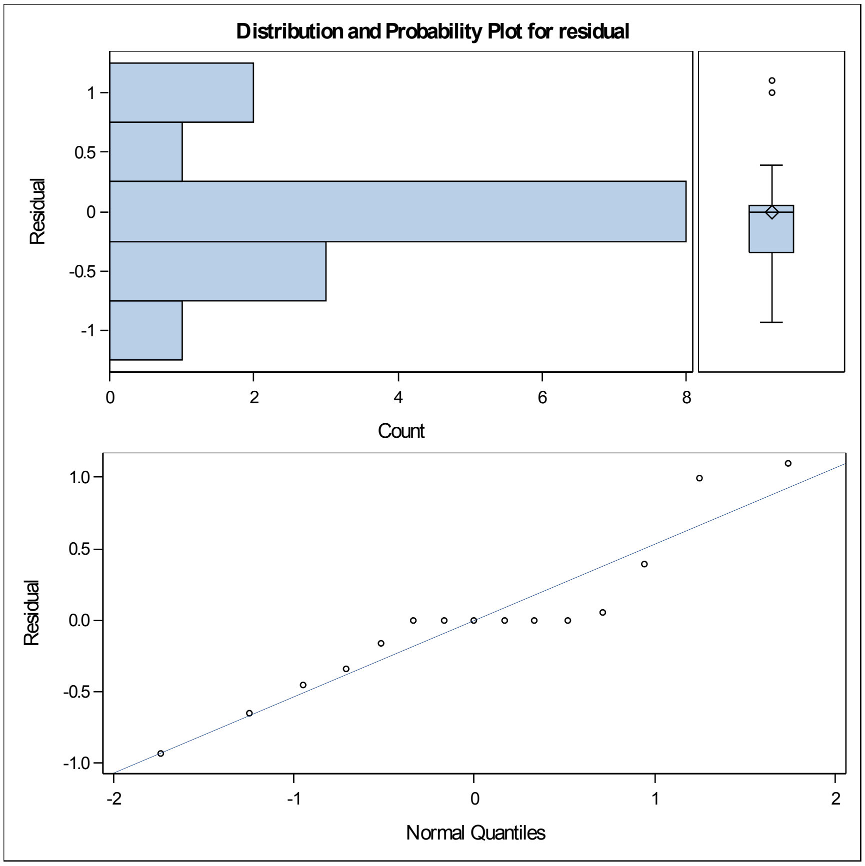
Statistical Analysis Software (SAS) was used to analyze HydroSense II data, N, P, organic matter, biomass and bulk density. Utilizing a one way analysis of variance (ANOVA), statistical tests were run to determine whether or not the various treatments were statistically significant from one another. The independent variable for the experiment was the different cover cropping treatments. There were five levels of the independent variable: control, tilled, ryegrass, clover and cocktail. The dependent variables for each test were changes in soil moisture data, total soil N (ppm), total soil P (ppm), organic matter (%), biomass(kg/ha) and bulk density.

Assumptions are made when an ANOVA test is done in order to ensure ANOVA is the proper technique for statistical analysis and that results from the tests are proper and valid:

- The residual values follow a normal distribution
- The values are independent observations and there is no correlation between error terms
- Variances are homogeneous and have the same finite variance

In order to assess if model assumptions are violated, the SAS procedure PROC UNIVARIATE is run on residuals from the ANOVA test. PROC UNIVARIATE produces scatterplots and histograms allowing the user to evaluate whether or not the statistical analysis is valid. Figure 3-12 shows the output given from SAS PROC UNIVARIATE, the residuals seem to follow a normal distribution and data on the qq plot follows the trend line, which is desired. This procedure shows that model assumptions of our ANOVA are in fact met and so therefore the results from the ANOVA procedures run on the study data are valid.

Figure 3-11. Results from PROC UNIVARIATE assess if model assumptions are violated.



Chapter 4 - Results and Discussion

Data collection and analysis took place from April 17th 2014 to June 26th 2014. During this time the data was stored and organized into multiple worksheets. Weekly analysis was done for both HydroSense II readings and HOBO weather station soil moisture data measurements. As stated in chapter 3, the HydroSense II values were compared to the temperature calibrated (equation 3.1) HOBO soil moisture data in order to establish the connection between the five plots monitored by the HOBO weather station soil moisture probes to the rest of the plots. The HOBO soil moisture readings were slightly lower than the HydrosSenseII data, but comparable and thus both measurement techniques were essential.

Weekly amounts of rainfall captured by Kansas State University's Mesonet Weather Station was used in order to assess the amounts of precipitation entering the system. Each of the plots were broken up into three sections for soil moisture data collection, the east, middle and west. These numbers were averaged together in order to address any issues on non-uniformity within the plots.

Soil Moisture

Average weekly measurements of volumetric soil moisture were calculated using Excel and are displayed in Appendix B and C. Using equation 3.10, it was found that each of the plots uniformly took in moisture, following the precipitation trend, but were not significantly different statistically from one another in terms of how the moisture was lost or utilized. The tilled plots had the lowest overall volumetric water content, as the top 12 cm of soil had much less soil moisture as compared to the 20 cm depth. The increased amounts of air worked into the top soil within tilled systems accounts for the low soil moisture content within these plots. The control plot, late in May, retained more water than the other plots during increased rain events (Figure 4-1). The differences in soil moisture between the control plots and the cover crop plots late in the growing season are similar to those findings reported by (Quemada and Cabrera, 2002) (Krueger et al., 2011) (Bodner et al., 2007) in that cover crops do utilize soil moisture. Although minor in this study, the use of soil moisture by cover crops can become problematic is areas experiencing drought or managed improperly.

Figure 4-1. Weekly Average HydroSense II (20 cm) and precipitation readings vs time.

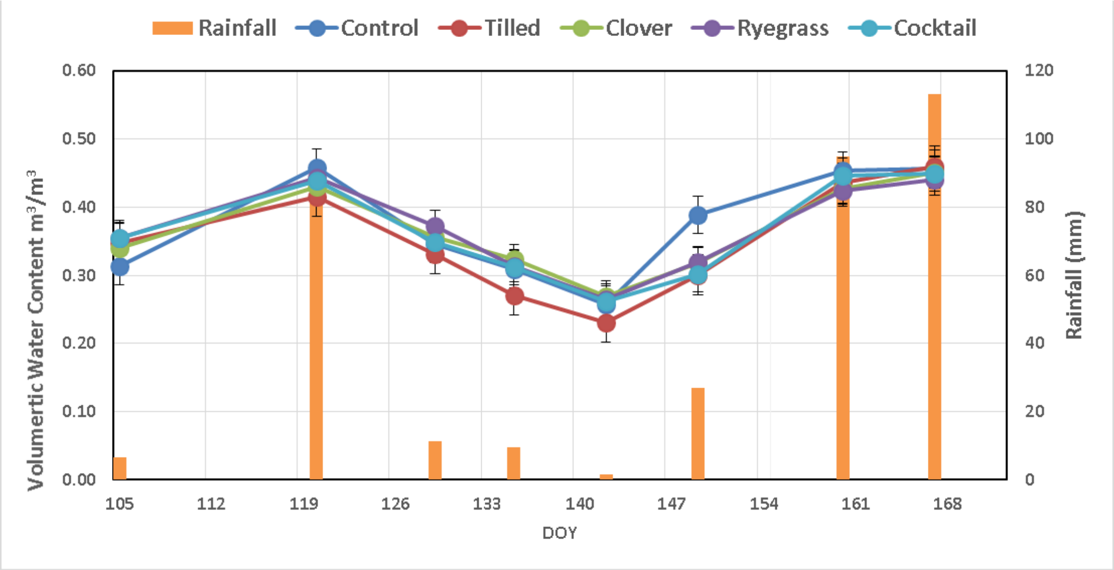
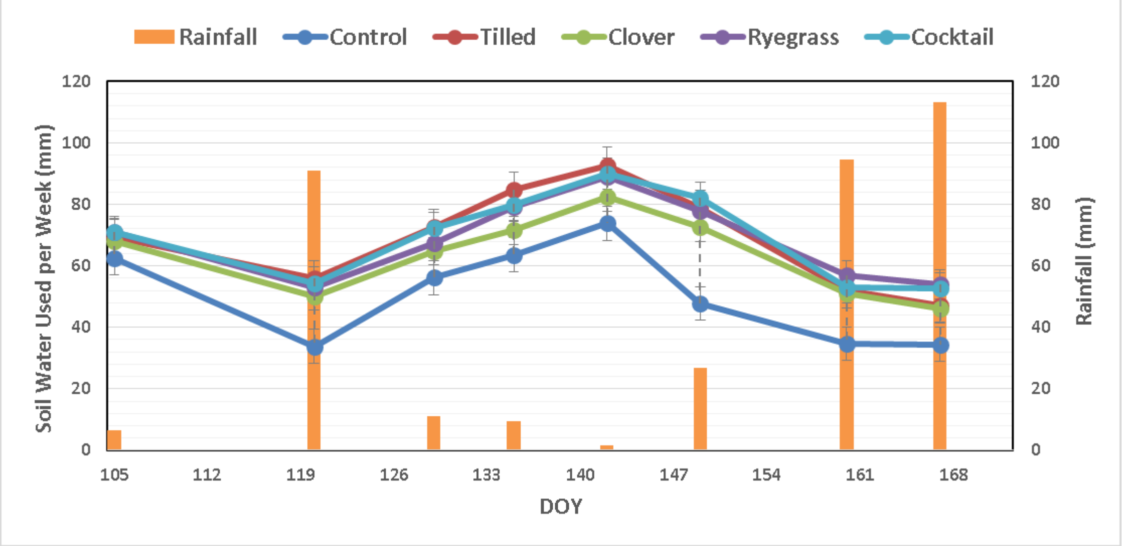
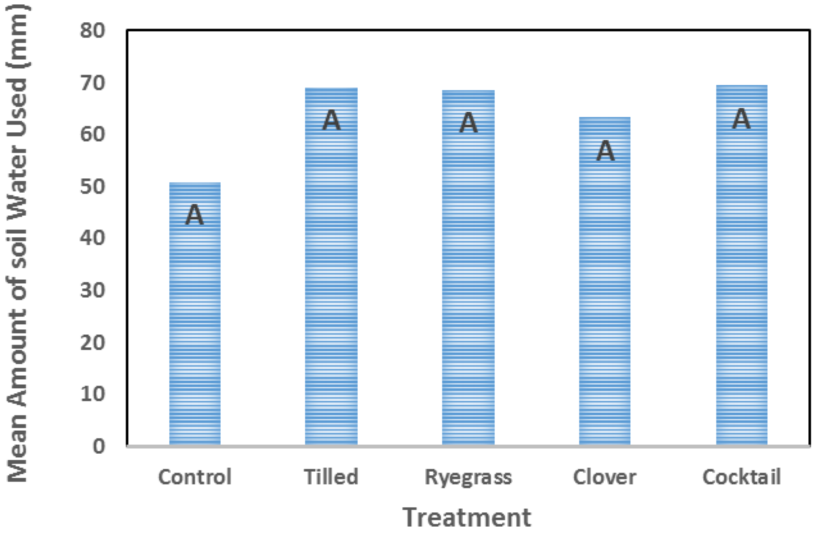


Figure 4-2. Weekly changes in soil water used (mm) and precipitation readings vs time.



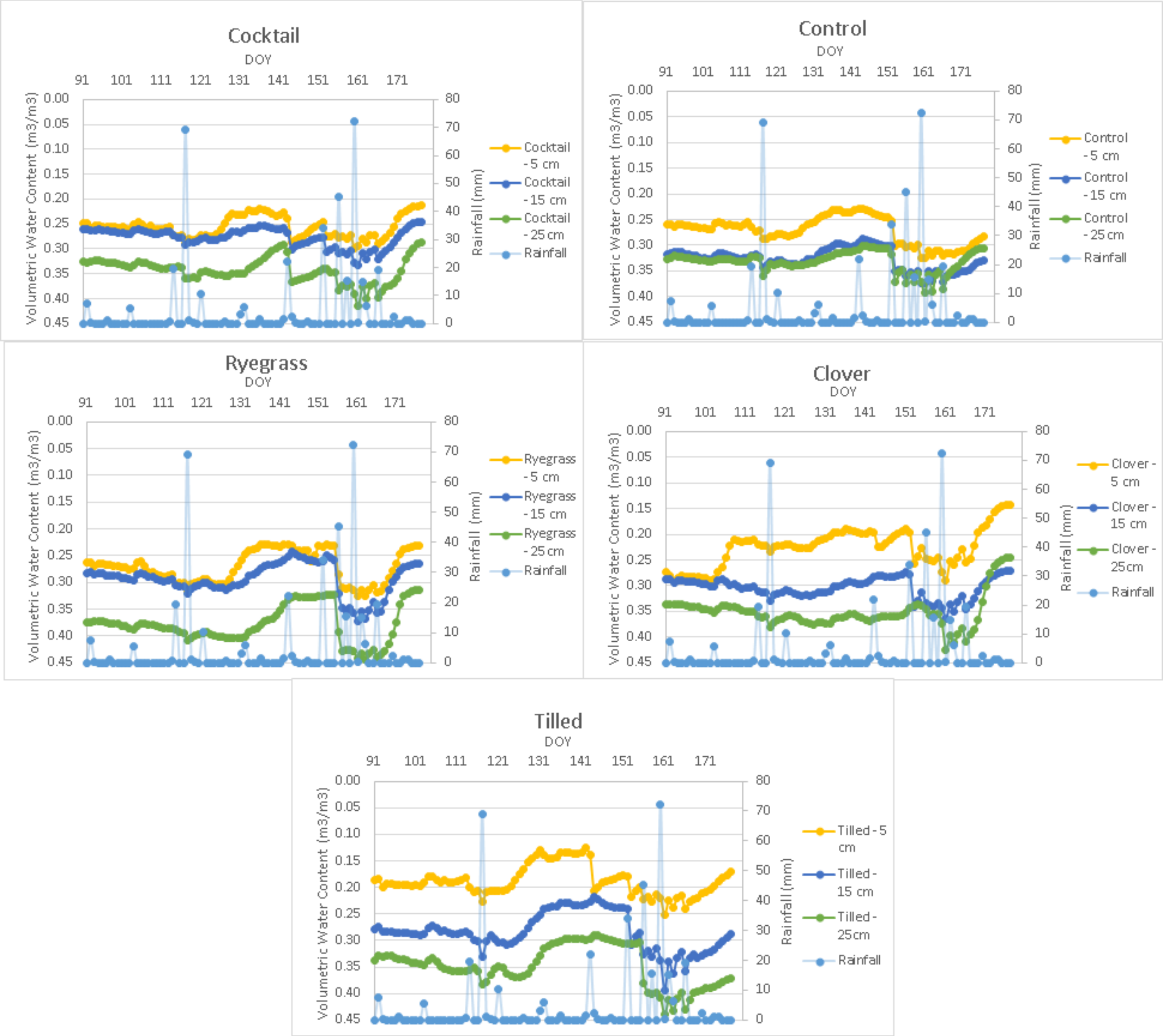
The weekly amount of soil water used in each plot was graphed as shown in figure 4-2 and as stated above, was calculated from equation 3.10. Additionally, amount of soil water used was analyzed using SAS one way analysis of variance, PROC ANOVA. Null and alternative hypotheses are as follows: H_0 = No treatments are significantly different from one another and H_1 = At least one treatment was significantly different, with the percentage of making a type I error (rejection of the null when the null is true) at 5% (α=0.05). Results from the ANOVA show that there is no significant differences between treatments and their use of soil moisture while the crop is still alive (Figure 4-3). This is most probably due to the short growing season, coupled with it being the first year of growth. Shown in figure 4-2, the control used less water throughout the experiment than the other plots, which was to be expected. Many researchers over longer periods of time (+3 years) have noted that soil moisture conditions are enhanced by the use of cover crops via residues ability to increase water retention and slow infiltration rates however in drought stressed regions, water use from cover crops can be detrimental to cash crop production as the cover crops do utilize soil moisture for growth and establishment (Bodner et al., 2007) (Ward et al., 2012) (Krueger et al., 2011).

Figure 4-3. ANOVA LS means grouping use of soil water (mm), means with same letter are not statistically different.



Depth of the soil played a role in the amount of water available for crop growth and is noted in figure 4-4. The graphs show that volumetric water content (θ) is greater with increasing soil depth. This is to be expected as more moisture is loss in the top layer of soil due to interactions with air and weather events. The three depths were noticeably different for each treatment other than the control as the bottom 15cm and 25cm data was very similar in this case. The similarities in the 5cm and 15 cm depth in the cocktail and ryegrass treatments suggest that the large extending root system of the ryegrass used soil moisture more deeply than clover which is noted by other researchers (SARE, 2012). The clover plot had lower soil moisture in the top 5cm layer more consistently than the ryegrass and cocktail plots, shallow roots and shallow seed placement of clover may explain why soil moisture is predominately from the top layer. The tilled plot behaved much like the clover plot, most probably due to the fact that when tilled, larger amounts of soil interacts with air and thus moisture is lost (Brady and Weil, 2004).

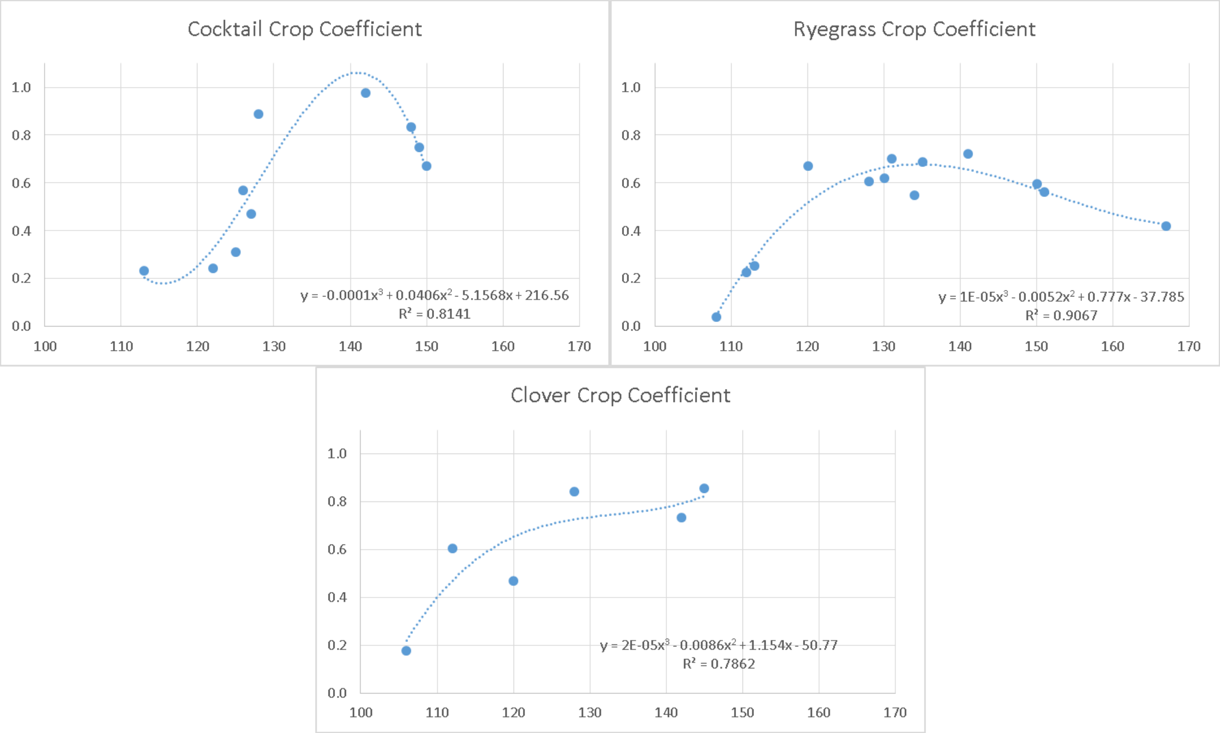
Figure 4-4. Volumetric water content at each sensor depth from HOBO U30 soil moisture probes.



Evapotranspiration and Crop Coefficients

The cover crop coefficients were calculated using equation 3.6 and HOBO weather soil moisture data, which can be found in Appendix C. Discrete values were used in figure 4-5 to demonstrate the crop coefficients of the cover crop plots. The discrete values were chosen due to scattered coefficient values calculated for some of the dates. This irregularity in the data was due to intense rainfall that more than likely caused storm water runoff events to occur, which violates the assumptions of no runoff and no subsurface drainage in the water balance. Other factors included the possible root penetration through the clay pan in the cocktail and ryegrass plots. It was observed at final coring that the core measurements were more easily taken than during the initial soil coring and the ability of cover crops to alleviate compaction has been noted and confirmed by researchers (Chen et al, 2014; Chabi-Olaye, et al., 2005; Chen and Weil, 2011; SARE 2012).

Figure 4-5. Calculated cover crop coefficients for cocktail, ryegrass and clover.



The cover crop cocktail and ryegrass behaved similarly to traditional crop coefficient curves (Allen et al., 1998). A 3rd order polynomial curve fit cocktail, ryegrass and clover data the best, although very small, the third variable helps to more accurately model the data for prediction. For example, from figure 4-5, the cocktail cover crop coefficient (K_c) can be calculated for a specific day of the year (DOY) using equation 4.1:

$$K_c = -0.0001(DOY)^3 + 0.0406(DOY)^2 - 5.1568(DOY) + 216.56 \qquad (4.1)$$

The crop coefficient calculated for clover was not as typical as the cocktail and ryegrass crop coefficients. This difference from the other plots may have been caused by the low amount of biomass produced by clover as well as the longer amount of time needed for initial establishment of clover versus the others. Ryegrass and hairy vetch grew larger and more quickly than clover, thus the crop coefficient for clover is not as well recognized and subsequent growing seasons are needed to more accurately describe evapotranspiration potential of red clover.

Cover Crop Biomass

Cover crop biomass was collected and weighed on the last day of the experiment. Cover had been growing for 63 days. At initial planting, there was no cover present on any of the plots however, weed emergence was high in many of the plots starting around mid-April. The late planting of the second stand lead to competition with weeds, especially on the south west plots. In these south western plots, weed growth was estimated to cover about 15% of each of the plots. The northern most plots grew impressive amounts of biomass. The presence of a diverse amount of insects demonstrates cover crops ability to create habitats for various creatures and organisms (SARE, 2014).

Figure 4-6 is a photograph of plot 3, cocktail treatment on October 24th, 2013. Figure 4-7 is of plot 3 on June 19th, 2014. This plot grew the greatest amount of biomass over the growing season. Figure 4-8 is a graph of the amount of total nitrogen (kg/ha) that was present in the biomass when analyzed by Kansas State University’s soil testing lab. The cocktail had higher amounts of N overall with the red clover legume having the lowest amount. This can be attributed the low amount of biomass of red clover. A graph of biomass total phosphorous content (kg/ha) is found in figure 4-9. Again, the cocktail had the highest amount of biomass total P. The differences between the cocktail and the other cover crops is most probably due to the hairy vetch. Hairy vetch has been touted as the best cover crop for N production and P scavenging (Campiglia et al., 2010) (Czapar et al., 2002) (Rosecrance et al., 2000) due to its ability to fix higher levels of N than other legumes and because the weather during the growing season was relatively mild, the vetch had no problem establishing quickly and growing the most out of all of the cover crops.

Figure 4-6. Plot 3, cover crop cocktail mix, on October 24th, 2013.

Figure 4-7. Plot 3, cover crop cocktail mix, on June 19th, 2014.

Figure 4-8. Biomass total nitrogen content (kg/ha) of the three cover crop treatments.

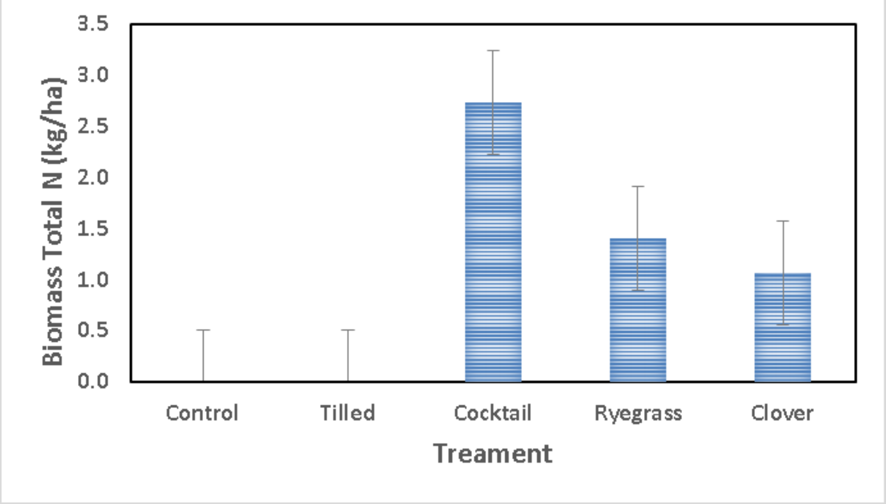
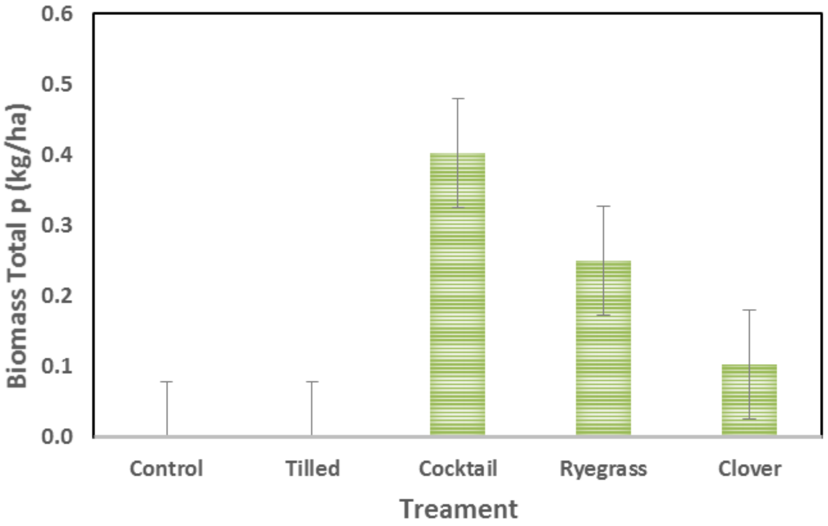


Figure 4-9. Biomass total phosphorous content (kg/ha) of the three cover crop treatments.



Kilograms of biomass per hectare was used in SAS to perform a one way analysis of variance using PROC ANOVA. Null and alternative hypotheses are: H_0 = No treatments biomass production is significantly different from one another and H_1 = Biomass production in at least one treatment was significantly different from another. As with the other statistical analyses, the percentage of making a type I error (rejection of the null when the null is true) was set at 5% (α=0.05).

Results from the ANOVA show that there is a significant difference between treatments and their biomass production, biomass nitrogen production and biomass phosphorous production (Figure 4-10) (Figure 4-11) (Figure 4-12). The increased biomass production in the cocktail treatment (9% more than control and tilled plots) is also noted in studies that researched the effects of multiple cropping systems versus monocropping (Rosecrance et al., 2000) (Miguez and Bollero, 2005) (Sarrantonio and Gallandt, 2003).

Figure 4-10. ANOVA LS means grouping use biomass production (kg/ha), means with same letter are not statistically different.

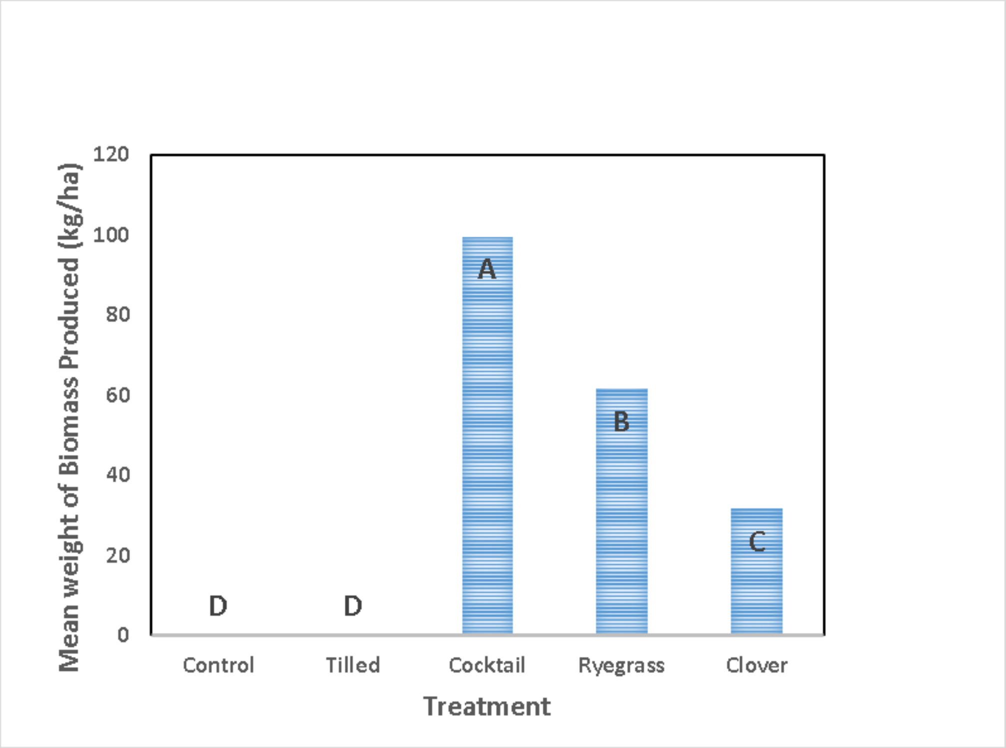


Figure 4-11. ANOVA LS means grouping of biomass nitrogen content (kg/ha), means with same letter are not statistically different.

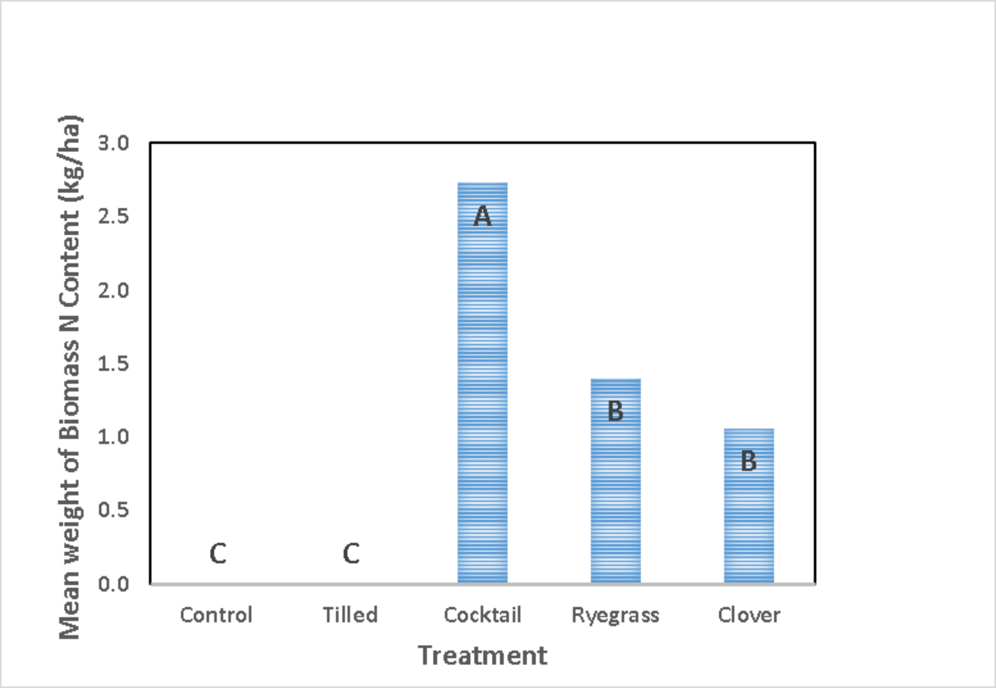
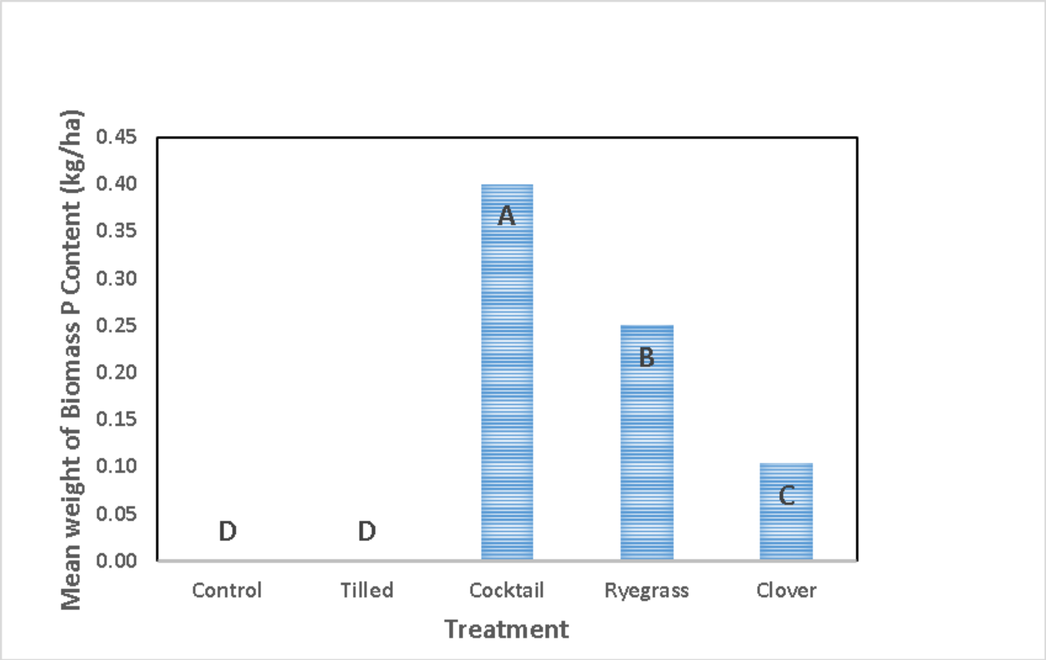


Figure 4-12. ANOVA LS means grouping of biomass phosphorous content (kg/ha), means with same letter are not statistically different.



Soil Bulk Density

Starting and ending measurements of bulk density were used in an ANOVA test in order to determine if the treatments effect on bulk density were statistically significant and were calculated using equation 3.7. Although bulk density was different from beginning to end (Figure 4-13), the one way ANOVA statistical analysis did not find significant differences in the cover crops and their effects on bulk density (Figure 4-14) versus the control and tilled plots. This almost uniform change for all plots indicates the soil bulk density increase was not related to cover crops but some other factors that may have affected pore space, texture and organic matter (Hillel, 1980). The increase in bulk density was not expected and is generally not desired in cropping systems. This increase in bulk density may have been due to variation in measurement techniques and lack of precision of initial versus final core samples.

Figure 4-13. Changes in bulk density over study period for each treatment.

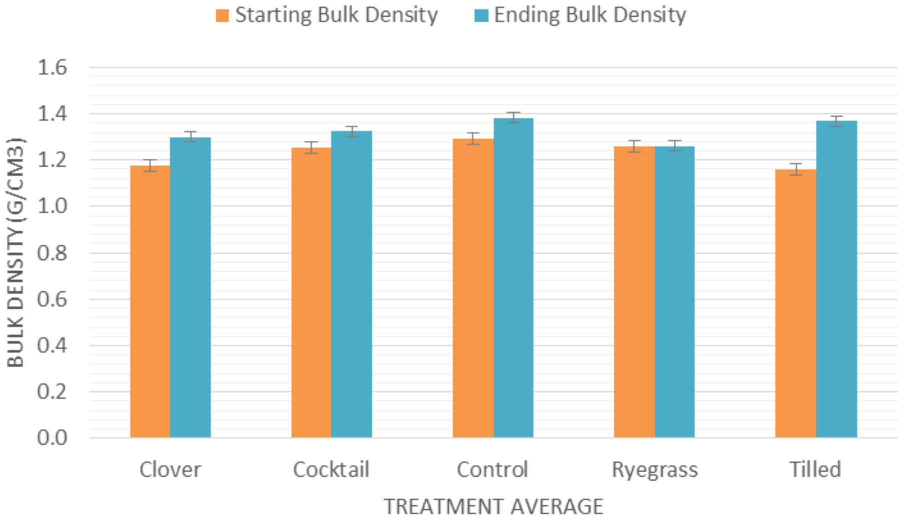
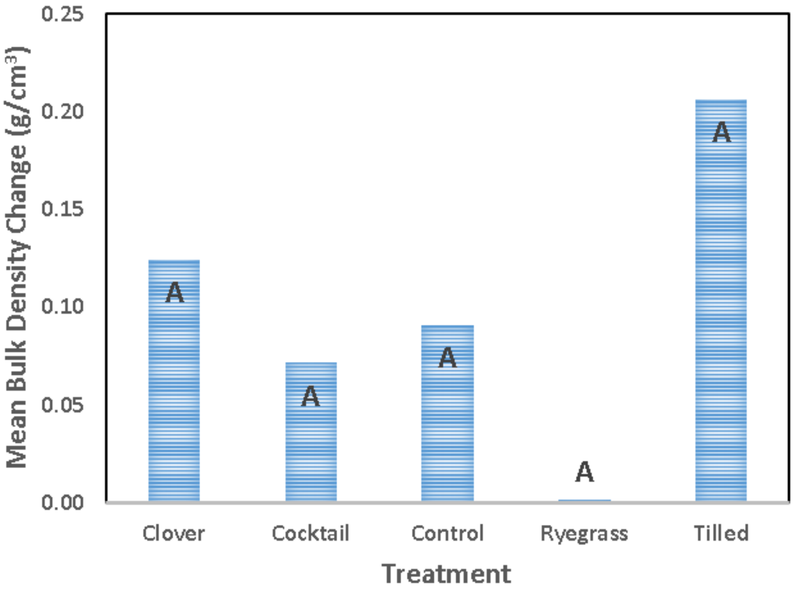


Figure 4-14. ANOVA LS means grouping of change in bulk density (g/cm3), means with same letter are not statistically different.



Soil Nitrogen and Phosphorous

Starting and ending values of soil total N and total P content were analyzed using the one way analysis of variance. This procedure did not find any significant differences in soil nitrogen or phosphorous content for this study between treatments. The uniform increase in N throughout all of the plots may be attributed to N mineralization within the soil due to increases in favorable conditions such as ample growing season precipitation (Figure 4-15) (Flower et al., 2012). If multiple growing seasons had been studied in this experiment, the effects of cover crop on N immobilization and mineralization could become more understood as there are many studies that attribute cover crops to better nutrient cycling (Rosecrance et al., 2000) (Kuo and Jellum, 2002) (Stute and Posner, 1995) (Flower et al., 2012).

An ANOVA was done on the change in starting and ending total soil N content. Null and alternative hypotheses are: H_0 = No treatment's N content are significantly different from one another and H_1 = At least one treatment's N content was significantly different, with the percentage of making a type I error at 5% (α=0.05). The ANOVA procedure did not find significant differences in the cover crops and their effects on total soil N (Figure 4-16). This uniform change for all plots indicates the soil N increases were not related to cover crops.

Figure 4-15. Starting and Ending Total Soil Nitrogen content (kg/ha) for each treatment.

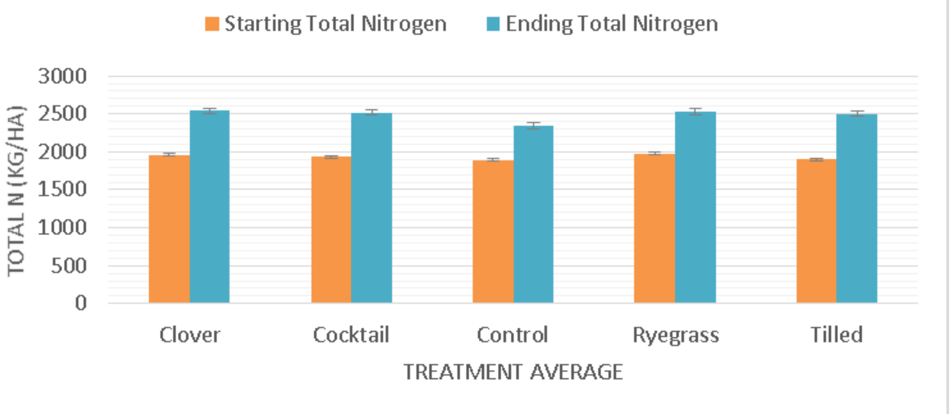
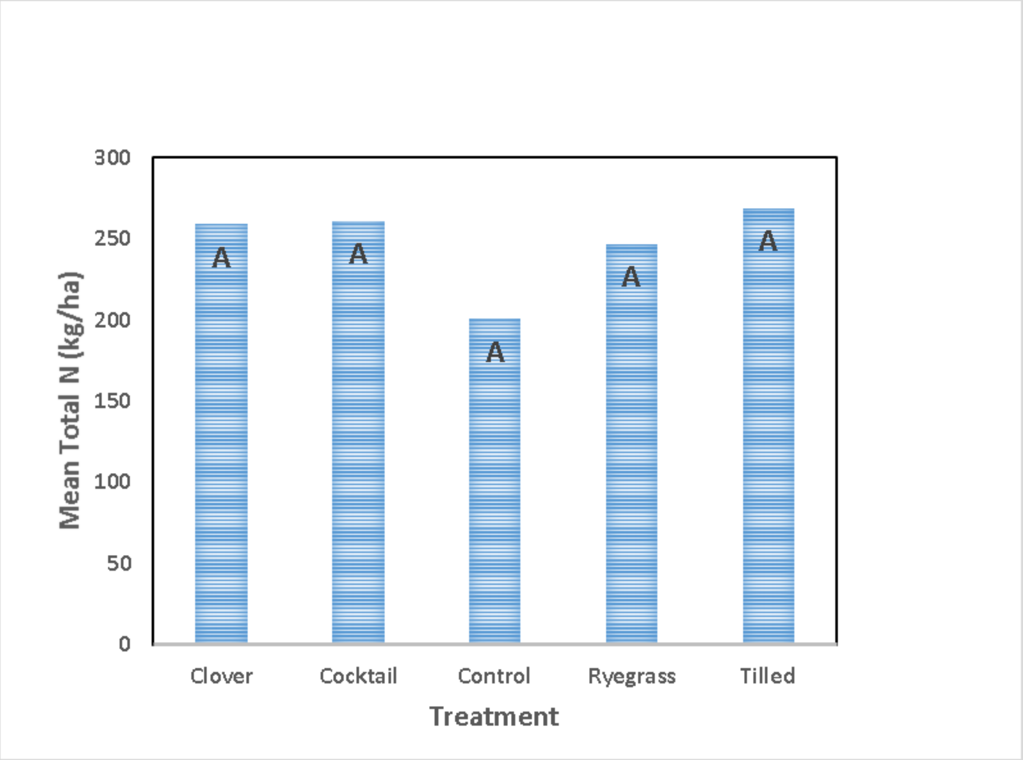


Figure 4-16. ANOVA LS means grouping of change in soil total nitrogen content (kg/ha), means with same letter are not statistically different.



All of the plots lost or utilized phosphorous, with the cover crop cocktail having the greatest difference between starting and ending P values. Although noticeable when graphed (Figure 4-17), the one way analysis of variance of the differences in total soil P was insignificant (Figure 4-18). Phosphorous loss due to P immobilization or leaching may be attributed to the reduction in overall soil P (Dabney et al., 2001) (Snapp et al., 2005).

Figure 4-17. Starting and ending Total Soil Phosphorous content (kg/ha) for each treatment.

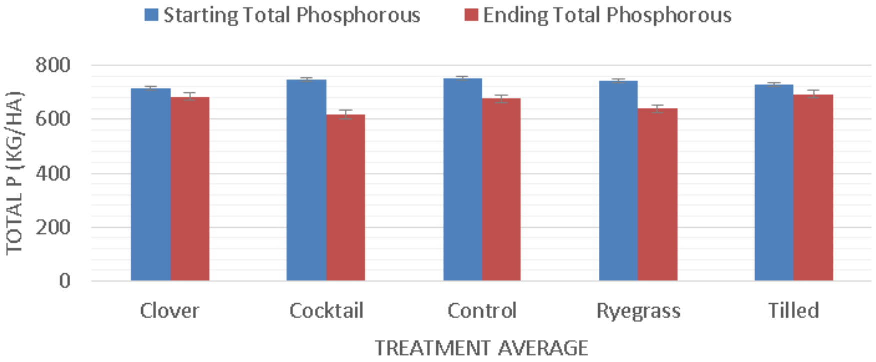
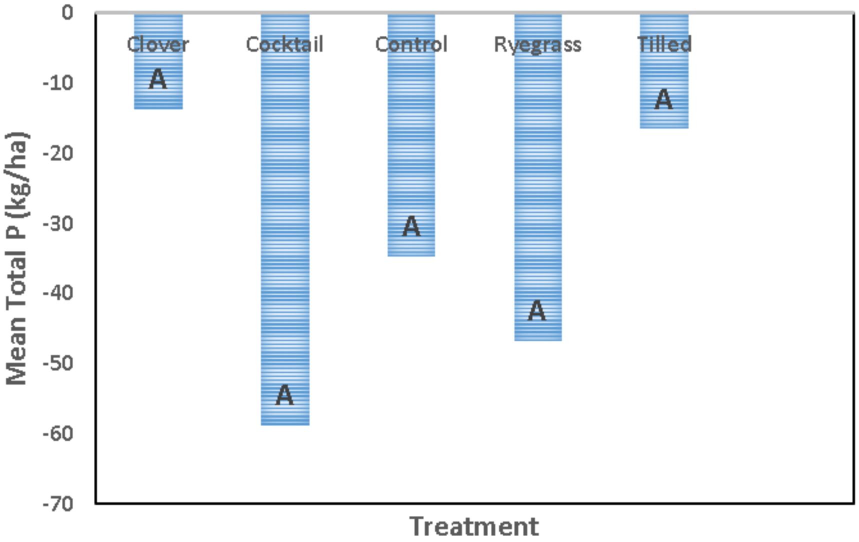


Figure 4-18. ANOVA LS means grouping of change in soil total phosphorous content (kg/ha), means with same letter are not statistically different.



Soil Organic Matter

The graph of the percent soil organic matter change from beginning to end of the study displayed that the cover cropping treatments increased the amount of total soil organic matter (Figure 4-19). Increases in organic matter can lead to decreased soil erosion by increasing soil aggregate stability (Fageria et al., 2005). Although the graph shows changes in use from beginning to end, these changes are minute, thus the significance of the change was not noticeable. Although insignificant in the short term, it is expected that in the long term organic matter would increase significantly in areas where cover crops have been planted versus fallow (SARE, 2012).

An ANOVA was used to assess the change in percentage of organic matter from start to end. Results from the ANOVA show that there is a not significant difference between treatments and their organic matter (Figure 4-20). The increased biomass production in the cocktail treatment demonstrates how increases of biomass production positively affect the amount of organic matter put into the soil systems. This increase in organic matter within the cocktail treatments is corroborated by Sainju et al. in 2002.

Figure 4-19. Starting and ending total soil organic matter (%).

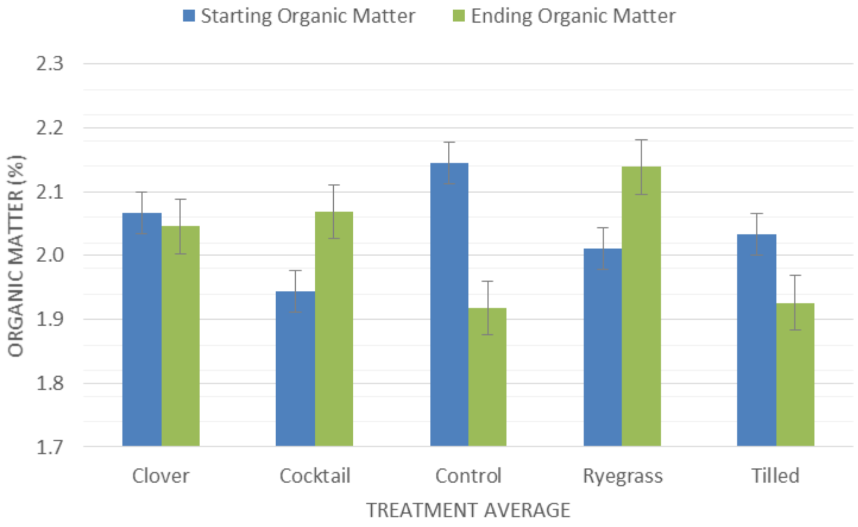
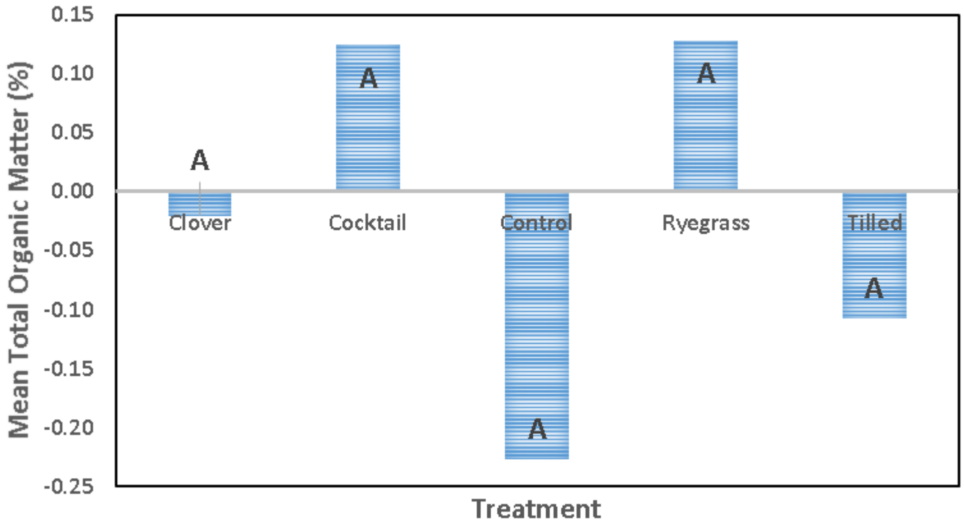


Figure 4-20. ANOVA LS means grouping of change in soil organic matter (%), means with same letter are not statistically different.



The statistical insignificance of cover crop treatments in all but one of the ANOVA's suggests that short term effects of cover crops on soil moisture, total N and P, bulk density and organic matter are indistinguishable from bare fallow. However, the observed differences in volumetric water content in the plots establishes that soil moisture is utilized by cover crops, which must be accounted for as extreme weather is expected in the coming decades in the mid-west. The significance of the biomass production and amount of N and P produced demonstrates how cover crops can provide benefits such as ground cover and decreased need for inorganic fertilizers. For this study, the length of time the experiment was conducted more than likely led to the statistically insignificant results. Research on cover crops is usually done on two or 3+ years in order to establish what effects can be attributed to the cover crops and not changes due to the system undergoing different land management.

Chapter 5 - Conclusions

Cover crops are important tools that will continue to gain popularity as producers begin making decisions based on ecosystem health and not just optimized crop yield. The increased amounts of organic matter, pest and weed suppression, decreased dependence on inorganic fertilizers and soil surface protection are all benefits associated with adopting cover crops permanently into a system. The beneficial effects of cover crops can be enhanced when coupled with other conservation techniques like no-till farming, crop rotation and fertilizer best management practices.

The observable differences in the soil moisture associated with the cover crops versus the control demonstrate that within the first growing season, soil moisture is utilized by the cover crops and this must be considered in areas of low rainfall. It is also noted that soil moisture levels in tilled plots were comparable to the plots growing crops, which exhibits how no-till land management can help to decrease losses in soil moisture. From a statistical standpoint, this study suggests that the short term effects associated with cover crops at the Manhattan, KS North Farm were neither beneficial nor detrimental except in regards to biomass.

The significant amounts of biomass produced by the cover crops directly correlates to the ability of cover crops to provide surface protection. The nutrients found within the plant biomass also demonstrate the capacity of cover crops to take up nutrients, which if managed properly can greatly reduce inorganic fertilizer application. Soil health indicators such as bulk density and porosity were insignificant in the first growing season, more than likely due to the limited time the study was conducted. Soil organic matter changes are observable in the short term in the cover crop plots but more time is needed to attribute organic matter changes to cover crop use.

The climate during the cover crop growing season demonstrated how important weather, moisture availability, planting timing and seed choice is when utilizing cover crops. Proper establishment of the cover must take place in order to survive the winter. Also, late planting of the second stand lead to competition with weeds within the cover crop stands. Competition from weeds in all of the plots was observed, yet as the crops grew, the amount of weeds present in the plots with the most biomass was lessened. All in all, more research is needed to examine how subsequent years will change the soil profile.

Research that has been done on cover crops such as the NE Kansas study conducted from 1989-1993 demonstrate the importance for cover crops paired with other conservative techniques like crop rotation, best management practices and no-till. The fact that sediment loss is one of the greatest concerns facing agriculture shows that increasing the amount of residue on farm fields will help to reduce the losses of soil to water and wind erosion. Cover crops used singly or in cocktail mixtures have benefits that outweigh the disadvantages if used correctly. In order to sustainably grow food while protecting ecosystem functionality, conservation and innovation must continue to take place. The worlds growing population requires ground-breaking and revolutionary management practices. Although they have been present for many years, cover crops are continuing to gain popularity among producers as a way to responsibly keep ecosystem health in mind while producing food for the rising population.

References

Alcántara, C., Pujadas, A., & Saavedra, M. (2011). Management of sinapis alba subsp. mairei winter cover crop residues for summer weed control in southern Spain. *Crop Protection, 30*(9), 1239-1244.

Bergkvist, G., Stenberg, M., Wetterlind, J., Båth, B., & Elfstrand, S. (2011). Clover cover crops under-sown in winter wheat increase yield of subsequent spring barley—Effect of N dose and companion grass. *Field Crops Research, 120*(2), 292-298.

Bjorkman, T. (2009). *Cover crops for vegetable growers.* Retrieved 06/05, 2013, from http://www.hort.cornell.edu/bjorkman/lab/covercrops/index.php

Bodner, G., Loiskandl, W., & Kaul, H. -. (2007). Cover crop evapotranspiration under semi-arid conditions using FAO dual crop coefficient method with water stress compensation. *Agricultural Water Management, 93*(3), 85-98.

Brady, N. C., & Weil, R. R. (2004). In Helba S., Yarnell D. and Lisner K. C., M. (Eds.), *Elements of the nature and properties of soils* (13th ed.). Upper Saddle River, New Jersey: Pearson Education Ltd.

Calonego, J. C., & Rosolem, C. A. (2010). Soybean root growth and yield in rotation with cover crops under chiseling and no-till. *European Journal of Agronomy, 33*(3), 242-249.

Campbell, C. S. (2009). Response of ECH20 soil moisture sensor to temperature variation. Bourne, MA: Onset Computer Corporation.

Campiglia, E., Caporali, F., Radicetti, E., & Mancinelli, R. (2010). Hairy vetch (vicia villosa roth.) cover crop residue management for improving weed control and yield in no-tillage tomato (lycopersicon esculentum mill.) production. *European Journal of Agronomy, 33*(2), 94-102.

Cassman, K. G., Dobermann, A., & Walters, D. T. (2002). Agroecosystems, nitrogen-use efficiency, and nitrogen management. *A Journal of the Human Environment, 31*(2), 132-140.

Chabi-Olaye, A., Nolte, C., Schulthess, F., & Borgemeister, C. (2005). Effects of grain legumes and cover crops on maize yield and plant damage by busseola fusca (fuller) (lepidoptera: Noctuidae) in the humid forest of southern Cameroon. *Agriculture, Ecosystems & Environment, 108*(1), 17-28.

Chen, G., Weil, R. R., & Hill, R. L. (2014). Effects of compaction and cover crops on soil least limiting water range and air permeability. *Soil and Tillage Research,* (136), 61-69.

Chen, G., & Weil, R. R. (2011). Root growth and yield of maize as affected by soil compaction and cover crops. *Soil and Tillage Research, 117*(0), 17-27.

Czapar, G. F., William S., F., & Bullock, D. G. (2002). Delayed control of a hairy vetch (vicia villosa roth) cover crop in irrigated corn production. *Crop Protection, 21*(6), 507-510.

Dabney, S. M., Delgado, J. A., & Reeves, D. W. (2001). Using winter cover crops to improve soil and water quality. *Communications in Soil Science and Plant Analysis, 32*(7-8), 1221-1250.

Fageria, N. K., Baligar, V. C., & Bailey, B. A. (2005). Role of cover crops in improving soil and row crop productivity. *Communications in Soil Science and Plant Analysis, 36*, 2733-2757.

Fangmeier D.D., Elliot W.J., Workman S.R., Huffman, R. L., & Schwab G.O. (2006). *Soil and water conservation engineering* (5th ed.). Clifton Park, NY: Thomson Delmar Learning.

Flower, K. C., Cordingley, N., Ward, P. R., & Weeks, C. (2012). Nitrogen, weed management and economics with cover crops in conservation agriculture in a Mediterranean climate. *Field Crops Research, 132*(0), 63-75.

Goodin, D. G., Mitchell, J. E., Knapp, M. C., & Bivens, R. E. (1995). *Climate and weather atlas of Kansas*

Grimes, W. E. (2014). Agronomy farm history - report of foreman. http://www.agronomy.k-state.edu/about-us/department-history/

Gruver, L. S., Weil, R. R., Zasada, I. A., Sardanelli, S., & Momen, B. (2010). Brassicaceous and rye cover crops altered free-living soil nematode community composition. *Applied Soil Ecology, 45*(1), 1-12.

Haramoto, E. R., & Gallandt, E. R. (2005). Brassica cover cropping: 1. effects on weed and crop establishment. *Weed Science, 53*, 695-701.

Isik, D., Kaya, E., Ngouajio, M., & Mennan, H. (2009). Weed suppression in organic pepper (capsicum annuum L.) with winter cover crops. *Crop Protection, 28*(4), 356-363.

Jerkins, D. (2012). *Cover crops reduce crop loss during drought.* http://blogs.usda.gov/2012/09/20/cover-crops-reduce-crop-loss-during-drought/

Kaspar, T. C., Jaynes, D. B., Parkin, T. B., Moorman, T. B., & Singer, J. W. (2012). Effectiveness of oat and rye cover crops in reducing nitrate losses in drainage water. *Agricultural Water Management, 110*(0), 25-33.

Krueger, E. S., Ochsner, T. E., Porter, P. M., & Baker, J. M. (2011). Winter rye cover crop management influences on soil water, soil nitrate, and corn development. *Agronomy Journal, 103*(2), 316-323.

Kuo, S., & Jellum, E. J. (2002). Influence of winter cover crop and residue management on soil nitrogen availability and corn. *Agronomy Journal, 94*(3), 501-508.

McCarthy, J. R., Pfost, D. L. & Currence, H. D. (1993). Conservation tillage and residue management to reduce soil erosion.

Miguez, F. E., & Bollero, G. A. (2005). Review of corn yield response under winter cover cropping systems using meta-analytic methods. *Crop Science, 45*(6), 2318.

Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being: Synthesis*. Washington, DC: Island Press.

Pierzynski, G. M., Sims, T. J., & Vance, G. F. (2005). *Soils and environmental quality*. Boca Raton, FL: Taylor & Francis Group.

Quemada, M., & Cabrera, M. L. (2002). Characteristic moisture curves and maximum water content of two crop residues. *Plant and Soil, 238*, 295-299.

Ranells, N. N., & Wagger, M. G. (1997). Grass-legumes bicultures as winter annual cover crops. *Agronomy Journal, 89*(4), 659-665.

Robinson, D. (2010). Radish/Pea mix video.http://plantcovercrops.com/radish-pea-mix-video/

Rosecrance, R. C., McCarty, G. W., D.R. Shelton, D. R., & Teasdale, J. R. (2000). Denitrification and N mineralization from hairy vetch (vicia villosa roth) and rye (secale cereale L.) cover crop monocultures and bicultures. *Plant and Soil, 227*, 283-290.

Sainju, U. M., Singh, B. P., & Whitehead, W. F. (2002). Long-term effects of tillage, cover crops, and nitrogen fertilization on organic carbon and nitrogen concentrations in sandy loam soils in Georgia, USA. *Soil and Tillage Research, 63*(3–4), 167-179.

Sarrantonio, M., & Gallandt, E. (2003). The role of cover crops in North American cropping systems. *Journal of Crop Production, 8*(1-2), 53-74.

Schipanski, M. E., Barbercheck, M., Douglas, M. R., Finney, D., Haider, K., Kaye, J. P., et al. (2014). A framework for evaluating ecosystem services provided by cover crops in agroecosystems. *Agricultural Systems,* (125), 12-22.

Singer, J. W., Nusser, S. M., & Alf, C. J. (2007). Are cover crops being used in the US Corn Belt? *Journal of Soil and Water Conservation, 62*(5), 353.

Smith, L. B., & Kallenbach, R. L. (2006). Overseeding annual ryegrass and cereal rye into soybean as part of a multifunctional cropping system: I. grain crop yields, winter annual weed cover, and residue after planting. *Forage and Grazinglands,* Snapp, S. S., Swinton, S. M., Labarta, R., Mutch, D., Black, J. R., Leep, R., et al. (2005). Evaluating cover crops for benefits, costs and performance within cropping system niches. *Agronomy Journal, 97*, 322-332.

Soil health fact sheets. (2014). Retrieved 4/11 http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/soils/health/?cid=stelprdb1049236

Strock, J. S., Porter, P. M., & Russelle, M. P. (2004). Cover cropping to reduce nitrate loss through subsurface drainage in the northern U.S. corn belt. Journal of Environmental Quality, (33), 1010-1016.

Stute, J. K., & Posner, J. (1995). Synchrony between legume nitrogen release and corn demand in the upper Midwest. *Agronomy Journal, 87*(6), 1063-1069.

Sustainable Agriculture Research and Education Program (SARE). (2012). In Clark A. (Ed.), *Managing cover crops profitably* (3rd ed.). Washington D.C.: Government Printing Office.

Sweeney, D. W., & Moyer, J. L. (1994). Legume green manures and conservation tillage for grain sorghum production on prairie soil. *Soil Science Society of America Journal, 58,* 1518-1524.

Tonitto, C., David, M. B., & Drinkwater, L. E. (2006). Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: A meta-analysis of crop yield and N dynamics. *Agriculture, Ecosystems & Environment, 112*(1), 58-72.

US EPA. (2014). *Level II and IV ecoregions of the continental united states.* http://www.epa.gov/wed/pages/ecoregions/level_iii_iv.htm

USDA NRCS. (2014). *Web soil survey.* http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm

Villamil, M. B., Bollero, G. A., Darmody, R. G., Simmons, F. W., & Bullock, D. G. (2006). No-till Corn/Soybean systems including winter cover crops: Effects on soil properties. *Soil Science Society of America Journal, 70*(6), 1936.

Wang, Q., Li, Y., Klassen, W., & Alva, A. (2012). High retention of N P nutrients, soil organic carbon and fine particles by cover crops under tropical climate. *Agronomy for Sustainable Development, 32*(3), 781-790.

White, C. (2013). Observations from the cocktails & crimpers field day.http://extension.psu.edu/plants/crops/news/2013/09/observations-from-the-cocktails-crimpers-field-day

Wyland, L. J., Jackson, L. E., Chaney, W. E., Klonsky, K., Koike, S. T., & Kimple, B. (1996). Winter cover crops in a vegetable cropping system: Impacts on nitrate leaching, soil water, crop yield, pests and management costs. *Agriculture, Ecosystems & Environment, 59*(1–2), 1-17.

Appendix A - NE Kansas Cover Crop Study

In 1989, a study was done by researchers at Kansas State University Research and Extension exploring the effects of cover crops and crop rotations on continuous cropping systems. Continuous soybean production can have negative effects on soil health and commonly increases erosion potential due to its limited amount of surface residue after harvest. The study hoped to examine the outcomes of adopting cover crops and soybean-corn crop rotations to reduce the potential of soil erosion. Three sites of varying slope and erosion potential (0.7%-10%) were selected for analysis in this study. Sites in the Kansas Counties of Brown, Doniphan and Shawnee were chosen.

Site Description

The Brown County study site is located near Hiawatha, KS (39.48’51° N, 95.30’35° W). The Doniphan County study site is located near Troy, KS (39.46’04° N, 95.08’23° W) and the Shawnee County study site is located near Silver Lake, KS (39.04’32° N, 95.46’11° W). The average slope of these sites differ dramatically, with the slope of the Doniphan field at 10% versus the slope of the Shawnee field which was 0.7%.

Soil at the Brown County site was dominated by Wymore silty clay loam 3 to 6 percent slopes (USDA NRCS, 2014). The Wymore silty clay loam has an overall soil texture of a silty clay loam and contains 1.4% organic matter, 0-5% sand, ~26% silt, and 42-55% clay. This soil is reported as having impermeable clay layers or clay pans (USDA NRCS, 2014). Wymore silty clay loam is classified as Hydrologic Soil Group D. Group D soils are characterized as having slow infiltration rate when wet. Soil at the Doniphan County site is dominated by Monona silt loam, 5 to 11% slopes eroded. The Monona silt load has an overall soil texture of a silt loam and is well drained within 1.8 m of soil. This silt loam of comprised of <5% sand, >60% silt and 20-35% clay. Monona silt loam is classified as Hydrologic Soil Group B. Group B soils are characterized as being moderately well drained (USDA NRCS, 2014). Eudora-Bismarkgrove silt loam is the main soil found at the Shawnee County site. This soil has an overall silt loam structure and contains <5% sand, 20-30% clay and >60% silt. This soil is well drained and is classified as Hydrologic soil group B.

Experimental Design

Cover crops were grown at the sites in order to assess their usefulness at providing soil cover and protecting soil from erosion. This study occurred over a period of four years and each treatment was replicated four times within the study areas. Factors such as type of cover chosen (hairy vetch, oats and clover) spacing (7.5” or 30”) , number of replications (four) and cash crop regimen (continuous soybean or soybean/corn rotation) were used to assess the percent residue cover at the end of the growing season. Crop residue was determined by using the transect sampling method. In this experiment, only single cover crops were used as the benefits of cover crop cocktails were not commonly practiced.

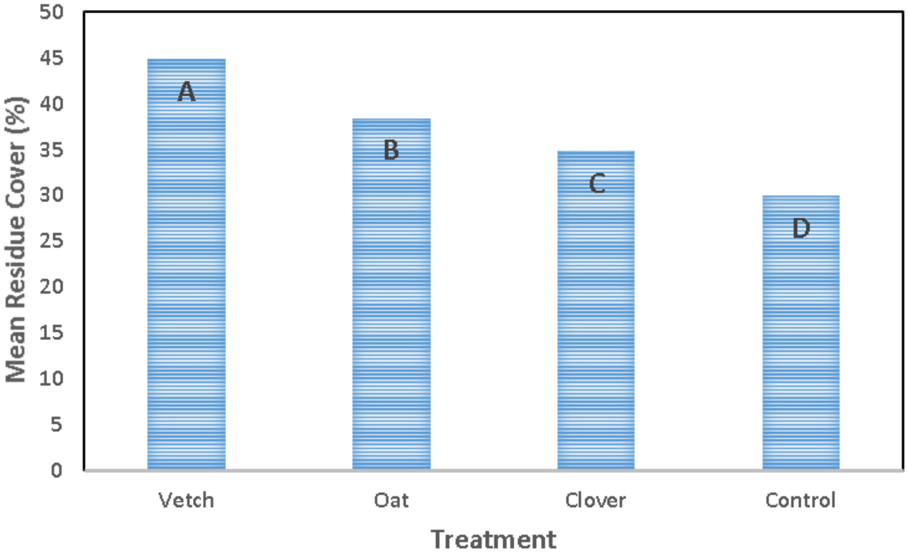
Results and Discussion

Statistical Analysis Software (SAS) was used to analyze crop spacing, cropping regimen, replications, type of cover crop used and percent residue cover. An ANOVA was used to determine whether or not the various treatments were statistically different from one another. The independent variables for the experiment were the different cover cropping treatments, whether or not the system was continuous corn or corn/soybean rotation, replication number and whether or not the crop was spaced at 7.5” or 30” when planted. There were four levels of the variable cover crop: control, oats, clover and vetch. The dependent variable for each test was percent cover. The hypothesis associated with the ANOVA tests help to determine what a significant test means. H_0: the means of all of the treatments equal one another, thus they are not significantly different. H_1: At least one treatment mean is statistically different from the others. The chance of making a type I error (rejecting the null in favor of H_1 when the null was actually true) was set to $\alpha = 0.05$.

Brown County

The statistical analysis of data at the Brown County site showed that use of cover crops, crop rotation and crop spacing all had significant effects on soil residue cover. From the means statement of the analysis, hairy vetch was shown to be the most significant of the four treatments (Figure F-1). The hairy vetch (cover 4) produced almost 15% more cover than the control (cover 1). As noted in the review above, hairy vetch is known for its ability to quickly establish large amounts of biomass, this helps to protect the soil surface from erosion (Kuo and Jellum, 2002).

Figure A-1. Mean grouping for residue production cover crop treatments in Brown Co., KS.

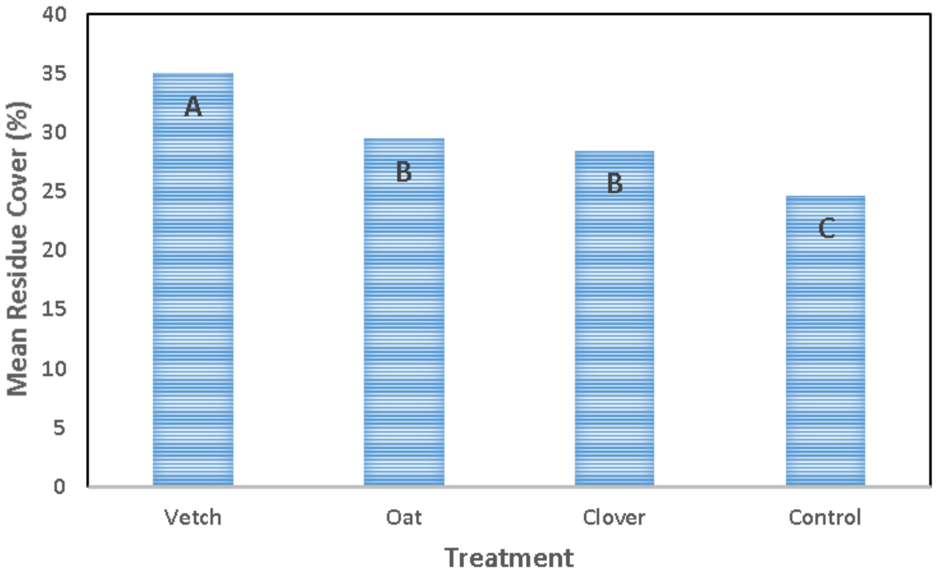


Doniphan County

The statistical analysis of data at the Doniphan County site found that use of cover crops, crop rotation, and crop spacing all had significant effects on soil residue cover. Again, hairy vetch was shown to be the most significant of the 4 treatments (Figure F-2). The hairy vetch (cover 4) produced almost 11% more cover than the control (cover 1). At this site, oats and clover behaved similarly and were grouped together due to their comparable residue production.

The 10% slope of the Doniphan site may have limited the ability of oats and red clover to establish and thus produced less surface cover than the hairy vetch, which is known to grow quickly, build deep roots and large amounts of biomass (SARE, 2012).

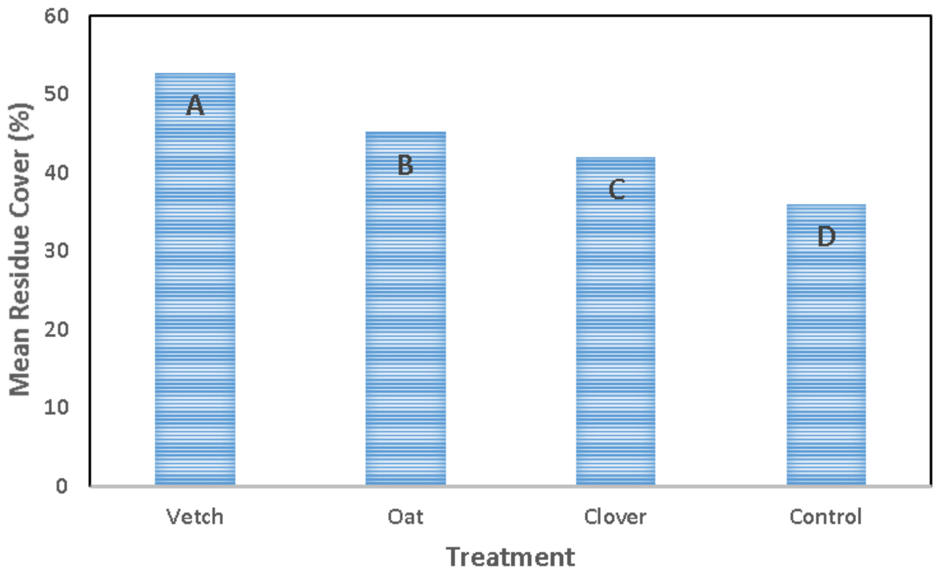
Figure A-2. Mean crop residue cover (%) at Doniphan Co., KS study site, means with same letter are not statistically different.



Shawnee County

In Shawnee County, the ANOVA also found that cover crops, crop rotation, crop spacing and replication number all had significant effects on soil residue cover. Also like the other two sites, hairy vetch was shown to be the best of the four treatments at providing residue cover (Figure F-3). The hairy vetch (cover 4) produced almost 17% more cover than the control (cover 1). Hairy vetch continues to correspond with reports of excellent residue cover and soil surface protection (Campiglia et al., 2010). The oats and clover at this site also provided more residue cover than control with the oats outperforming the clover in residue production.

Figure A-3. Mean crop residue cover (%) at Shawnee Co., KS study site, means with same letter are not statistically different.



Overall the significance of each of the treatment variables in the study demonstrated how percent cover can be significantly affected by management practices. Techniques that allow for increased residue and surface cover are known to reduce the overall amounts of soil lost via erosion (Singer et al., 2007). In areas that are highly susceptible to erosion, crop residues and crop rotations can significantly reduce soil loss and are important tools used in these areas. Cover crops are just one way in which soil can be positively affected by proper management practices.

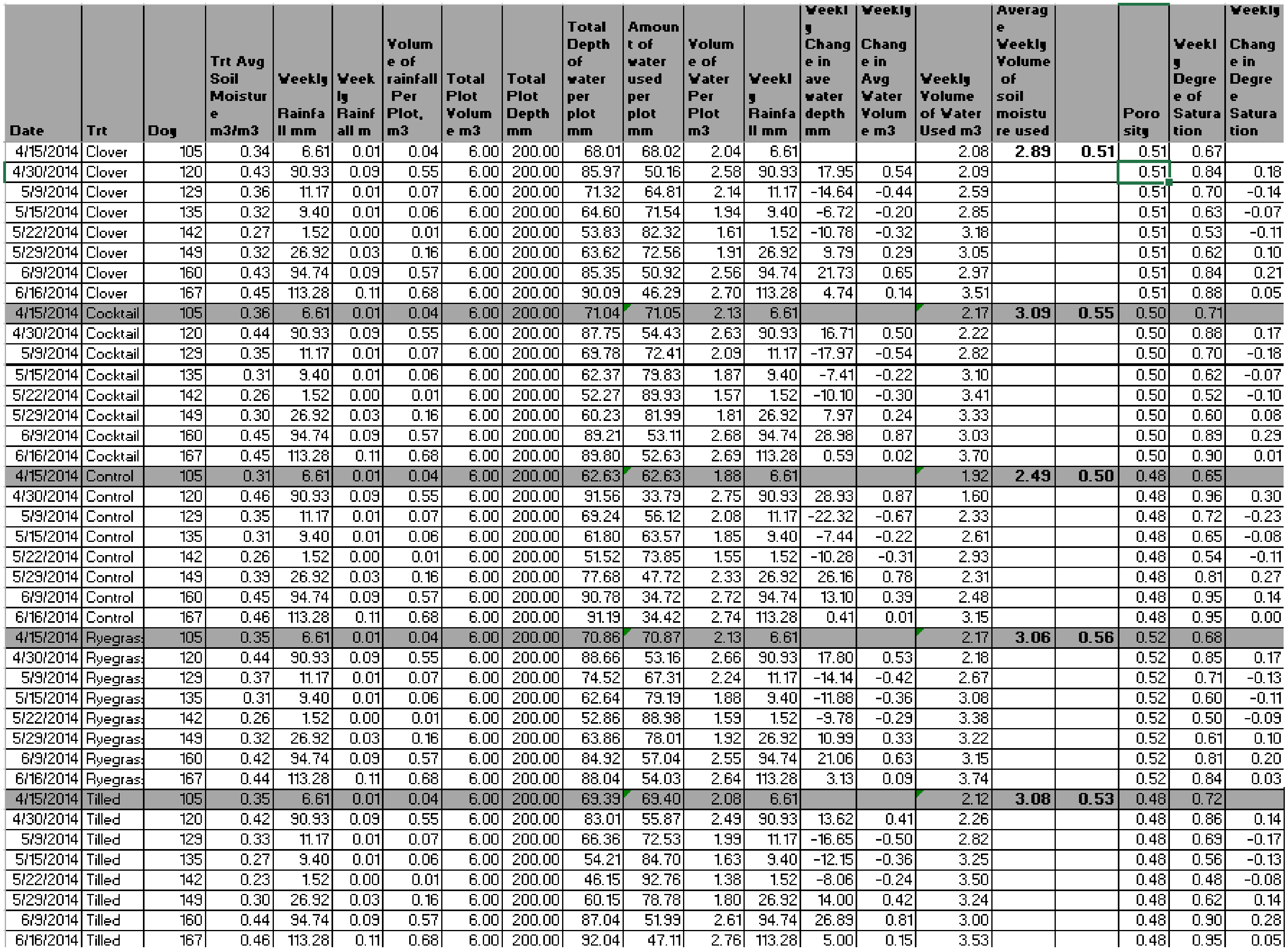
Appendix B - HydroSense II

The Campbell Scientific HydroSense II soil moisture probe has the ability to take moisture samples at two different depths using probes of two different lengths. Attach the first of the two rods to the bottoms of the meter. Slots on the bottom of the meter align with the rod's cord. After this is done, power on the device by using the power button. Please wait for a GPS signal to be acquired, when this happens a message will appear on the top of the display indicating location.

Soil type is taken into account by the device and type must be selected in order to more accurately take measurements. Identifying the soil type the measurement will be taken on will give the information needed to choose the soil type. Soil type 3 was used in measurements at the KSU North Farm.

Carefully insert the rods into the soil while gently pushing downwards. When in place, press the read button. Once the data is read, press the store button and wait for the confirmation message. When this is finished, carefully pull the rods out of the soil and move to the next area. Downloading of this data must be done via Bluetooth connection to HydroSense II software. Simply turning on your computer's ability to see Bluetooth devices allows for the connection to the HydroSense II. Data downloads into a specified excel file when chosen.

Table B-1. Hydrosense II data calculations.

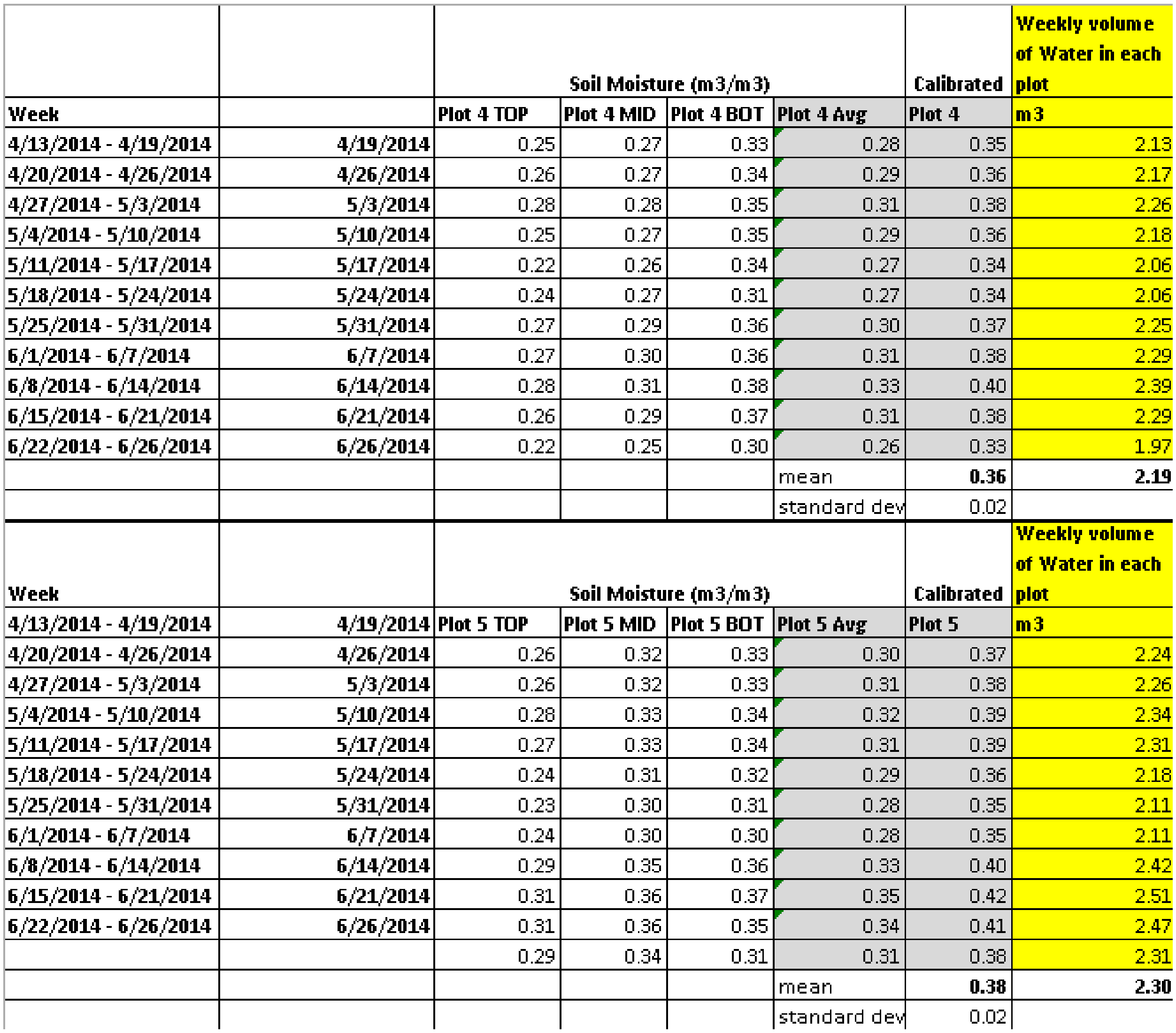


Date	Trt	Dog	Trt Avg Soil Moisture m3/m3	Weekly Rainfall mm	Weekly Rainfall m	Volume of rainfall Per Plot, m3	Total Plot Volume m3	Total Plot Depth mm	Total Depth of water per plot mm	Amount of water used per plot mm	Volume of Water Per Plot m3	Weekly Rainfall mm	Weekly Change in ave water depth mm	Weekly Change in Avg Water Volume m3	Weekly Volume of Water Used m3	Average Weekly Volume of soil moisture used		Porosity	Weekly Degree of Saturation	Weekly Change in Degree Saturation
4/15/2014	Clover	105	0.34	6.61	0.01	0.04	6.00	200.00	68.01	68.02	2.04	6.61			2.08	**2.89**	**0.51**	0.51	0.67	
4/30/2014	Clover	120	0.43	90.93	0.09	0.55	6.00	200.00	85.97	50.16	2.58	90.93	17.95	0.54	2.09			0.51	0.84	0.18
5/9/2014	Clover	129	0.36	11.17	0.01	0.07	6.00	200.00	71.32	64.81	2.14	11.17	-14.64	-0.44	2.59			0.51	0.70	-0.14
5/15/2014	Clover	135	0.32	9.40	0.01	0.06	6.00	200.00	64.60	71.54	1.94	9.40	-6.72	-0.20	2.85			0.51	0.63	-0.07
5/22/2014	Clover	142	0.27	1.52	0.00	0.01	6.00	200.00	53.83	82.32	1.61	1.52	-10.78	-0.32	3.18			0.51	0.53	-0.11
5/29/2014	Clover	149	0.32	26.92	0.03	0.16	6.00	200.00	63.62	72.56	1.91	26.92	9.79	0.29	3.05			0.51	0.62	0.10
6/9/2014	Clover	160	0.43	94.74	0.09	0.57	6.00	200.00	85.35	50.92	2.56	94.74	21.73	0.65	2.97			0.51	0.84	0.21
6/16/2014	Clover	167	0.45	113.28	0.11	0.68	6.00	200.00	90.09	46.29	2.70	113.28	4.74	0.14	3.51			0.51	0.88	0.05
4/15/2014	Cocktail	105	0.36	6.61	0.01	0.04	6.00	200.00	71.04	71.05	2.13	6.61			2.17	**3.09**	**0.55**	0.50	0.71	
4/30/2014	Cocktail	120	0.44	90.93	0.09	0.55	6.00	200.00	87.75	54.43	2.63	90.93	16.71	0.50	2.22			0.50	0.88	0.17
5/9/2014	Cocktail	129	0.35	11.17	0.01	0.07	6.00	200.00	69.78	72.41	2.09	11.17	-17.97	-0.54	2.82			0.50	0.70	-0.18
5/15/2014	Cocktail	135	0.31	9.40	0.01	0.06	6.00	200.00	62.37	79.83	1.87	9.40	-7.41	-0.22	3.10			0.50	0.62	-0.07
5/22/2014	Cocktail	142	0.26	1.52	0.00	0.01	6.00	200.00	52.27	89.93	1.57	1.52	-10.10	-0.30	3.41			0.50	0.52	-0.10
5/29/2014	Cocktail	149	0.30	26.92	0.03	0.16	6.00	200.00	60.23	81.99	1.81	26.92	7.97	0.24	3.33			0.50	0.60	0.08
6/9/2014	Cocktail	160	0.45	94.74	0.09	0.57	6.00	200.00	89.21	53.11	2.68	94.74	28.98	0.87	3.03			0.50	0.89	0.29
6/16/2014	Cocktail	167	0.45	113.28	0.11	0.68	6.00	200.00	89.80	52.63	2.69	113.28	0.59	0.02	3.70			0.50	0.90	0.01
4/15/2014	Control	105	0.31	6.61	0.01	0.04	6.00	200.00	62.63	62.63	1.88	6.61			1.92	**2.49**	**0.50**	0.48	0.65	
4/30/2014	Control	120	0.46	90.93	0.09	0.55	6.00	200.00	91.56	33.79	2.75	90.93	28.93	0.87	1.60			0.48	0.96	0.30
5/9/2014	Control	129	0.35	11.17	0.01	0.07	6.00	200.00	69.24	56.12	2.08	11.17	-22.32	-0.67	2.33			0.48	0.72	-0.23
5/15/2014	Control	135	0.31	9.40	0.01	0.06	6.00	200.00	61.80	63.57	1.85	9.40	-7.44	-0.22	2.61			0.48	0.65	-0.08
5/22/2014	Control	142	0.26	1.52	0.00	0.01	6.00	200.00	51.52	73.85	1.55	1.52	-10.28	-0.31	2.93			0.48	0.54	-0.11
5/29/2014	Control	149	0.39	26.92	0.03	0.16	6.00	200.00	77.68	47.72	2.33	26.92	26.16	0.78	2.31			0.48	0.81	0.27
6/9/2014	Control	160	0.45	94.74	0.09	0.57	6.00	200.00	90.78	34.72	2.72	94.74	13.10	0.39	2.48			0.48	0.95	0.14
6/16/2014	Control	167	0.46	113.28	0.11	0.68	6.00	200.00	91.19	34.42	2.74	113.28	0.41	0.01	3.15			0.48	0.95	0.00
4/15/2014	Ryegras	105	0.35	6.61	0.01	0.04	6.00	200.00	70.86	70.87	2.13	6.61			2.17	**3.06**	**0.56**	0.52	0.68	
4/30/2014	Ryegras	120	0.44	90.93	0.09	0.55	6.00	200.00	88.66	53.16	2.66	90.93	17.80	0.53	2.18			0.52	0.85	0.17
5/9/2014	Ryegras	129	0.37	11.17	0.01	0.07	6.00	200.00	74.52	67.31	2.24	11.17	-14.14	-0.42	2.67			0.52	0.71	-0.13
5/15/2014	Ryegras	135	0.31	9.40	0.01	0.06	6.00	200.00	62.64	79.19	1.88	9.40	-11.88	-0.36	3.08			0.52	0.60	-0.11
5/22/2014	Ryegras	142	0.26	1.52	0.00	0.01	6.00	200.00	52.86	88.98	1.59	1.52	-9.78	-0.29	3.38			0.52	0.50	-0.09
5/29/2014	Ryegras	149	0.32	26.92	0.03	0.16	6.00	200.00	63.86	78.01	1.92	26.92	10.99	0.33	3.22			0.52	0.61	0.10
6/9/2014	Ryegras	160	0.42	94.74	0.09	0.57	6.00	200.00	84.92	57.04	2.55	94.74	21.06	0.63	3.15			0.52	0.81	0.20
6/16/2014	Ryegras	167	0.44	113.28	0.11	0.68	6.00	200.00	88.04	54.03	2.64	113.28	3.13	0.09	3.74			0.52	0.84	0.03
4/15/2014	Tilled	105	0.35	6.61	0.01	0.04	6.00	200.00	69.39	69.40	2.08	6.61			2.12	**3.08**	**0.53**	0.48	0.72	
4/30/2014	Tilled	120	0.42	90.93	0.09	0.55	6.00	200.00	83.01	55.87	2.49	90.93	13.62	0.41	2.26			0.48	0.86	0.14
5/9/2014	Tilled	129	0.33	11.17	0.01	0.07	6.00	200.00	66.36	72.53	1.99	11.17	-16.65	-0.50	2.82			0.48	0.69	-0.17
5/15/2014	Tilled	135	0.27	9.40	0.01	0.06	6.00	200.00	54.21	84.70	1.63	9.40	-12.15	-0.36	3.25			0.48	0.56	-0.13
5/22/2014	Tilled	142	0.23	1.52	0.00	0.01	6.00	200.00	46.15	92.76	1.38	1.52	-8.06	-0.24	3.50			0.48	0.48	-0.08
5/29/2014	Tilled	149	0.30	26.92	0.03	0.16	6.00	200.00	60.15	78.78	1.80	26.92	14.00	0.42	3.24			0.48	0.62	0.14
6/9/2014	Tilled	160	0.44	94.74	0.09	0.57	6.00	200.00	87.04	51.99	2.61	94.74	26.89	0.81	3.00			0.48	0.90	0.28
6/16/2014	Tilled	167	0.46	113.28	0.11	0.68	6.00	200.00	92.04	47.11	2.76	113.28	5.00	0.15	3.53			0.48	0.95	0.05

Appendix C - HOBO Weather Station

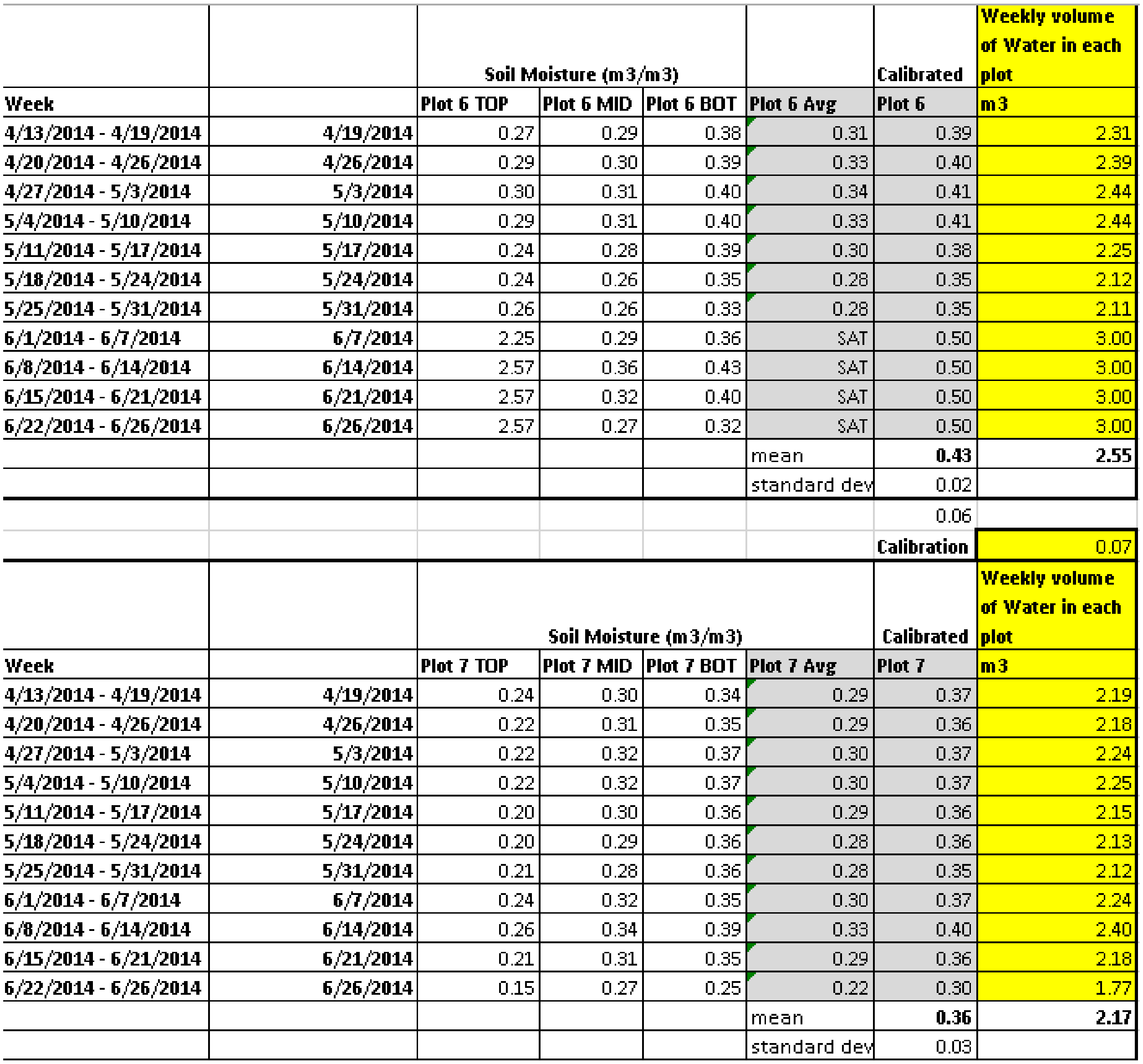
In order to download data from the HOBO weather station, software from HOBO must be installed on the laptop. The user simply connects a mini USB to the weather station. Through the use of the software, the user is able to select data for downloading.

Table C-1. Weekly calculated soil moisture data from HOBO Weather Station



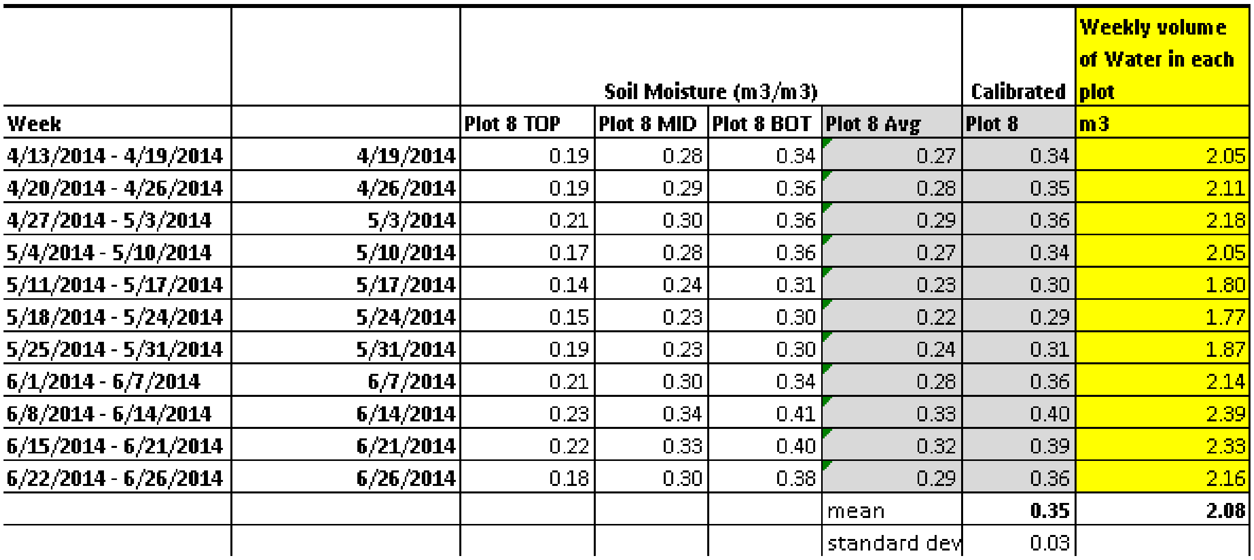
		Soil Moisture (m3/m3)				Calibrated	Weekly volume of Water in each plot
Week		Plot 4 TOP	Plot 4 MID	Plot 4 BOT	Plot 4 Avg	Plot 4	m3
4/13/2014 - 4/19/2014	4/19/2014	0.25	0.27	0.33	0.28	0.35	2.13
4/20/2014 - 4/26/2014	4/26/2014	0.26	0.27	0.34	0.29	0.36	2.17
4/27/2014 - 5/3/2014	5/3/2014	0.28	0.28	0.35	0.31	0.38	2.26
5/4/2014 - 5/10/2014	5/10/2014	0.25	0.27	0.35	0.29	0.36	2.18
5/11/2014 - 5/17/2014	5/17/2014	0.22	0.26	0.34	0.27	0.34	2.06
5/18/2014 - 5/24/2014	5/24/2014	0.24	0.27	0.31	0.27	0.34	2.06
5/25/2014 - 5/31/2014	5/31/2014	0.27	0.29	0.36	0.30	0.37	2.25
6/1/2014 - 6/7/2014	6/7/2014	0.27	0.30	0.36	0.31	0.38	2.29
6/8/2014 - 6/14/2014	6/14/2014	0.28	0.31	0.38	0.33	0.40	2.39
6/15/2014 - 6/21/2014	6/21/2014	0.26	0.29	0.37	0.31	0.38	2.29
6/22/2014 - 6/26/2014	6/26/2014	0.22	0.25	0.30	0.26	0.33	1.97
					mean	**0.36**	**2.19**
					standard dev	0.02	

		Soil Moisture (m3/m3)				Calibrated	Weekly volume of Water in each plot
Week							
4/13/2014 - 4/19/2014	4/19/2014	Plot 5 TOP	Plot 5 MID	Plot 5 BOT	Plot 5 Avg	Plot 5	m3
4/20/2014 - 4/26/2014	4/26/2014	0.26	0.32	0.33	0.30	0.37	2.24
4/27/2014 - 5/3/2014	5/3/2014	0.26	0.32	0.33	0.31	0.38	2.26
5/4/2014 - 5/10/2014	5/10/2014	0.28	0.33	0.34	0.32	0.39	2.34
5/11/2014 - 5/17/2014	5/17/2014	0.27	0.33	0.34	0.31	0.39	2.31
5/18/2014 - 5/24/2014	5/24/2014	0.24	0.31	0.32	0.29	0.36	2.18
5/25/2014 - 5/31/2014	5/31/2014	0.23	0.30	0.31	0.28	0.35	2.11
6/1/2014 - 6/7/2014	6/7/2014	0.24	0.30	0.30	0.28	0.35	2.11
6/8/2014 - 6/14/2014	6/14/2014	0.29	0.35	0.36	0.33	0.40	2.42
6/15/2014 - 6/21/2014	6/21/2014	0.31	0.36	0.37	0.35	0.42	2.51
6/22/2014 - 6/26/2014	6/26/2014	0.31	0.36	0.35	0.34	0.41	2.47
		0.29	0.34	0.31	0.31	0.38	2.31
					mean	**0.38**	**2.30**
					standard dev	0.02	



		Soil Moisture (m3/m3)				Calibrated	Weekly volume of Water in each plot
Week		**Plot 6 TOP**	**Plot 6 MID**	**Plot 6 BOT**	**Plot 6 Avg**	**Plot 6**	**m3**
4/13/2014 - 4/19/2014	**4/19/2014**	0.27	0.29	0.38	0.31	0.39	2.31
4/20/2014 - 4/26/2014	**4/26/2014**	0.29	0.30	0.39	0.33	0.40	2.39
4/27/2014 - 5/3/2014	**5/3/2014**	0.30	0.31	0.40	0.34	0.41	2.44
5/4/2014 - 5/10/2014	**5/10/2014**	0.29	0.31	0.40	0.33	0.41	2.44
5/11/2014 - 5/17/2014	**5/17/2014**	0.24	0.28	0.39	0.30	0.38	2.25
5/18/2014 - 5/24/2014	**5/24/2014**	0.24	0.26	0.35	0.28	0.35	2.12
5/25/2014 - 5/31/2014	**5/31/2014**	0.26	0.26	0.33	0.28	0.35	2.11
6/1/2014 - 6/7/2014	**6/7/2014**	2.25	0.29	0.36	SAT	0.50	3.00
6/8/2014 - 6/14/2014	**6/14/2014**	2.57	0.36	0.43	SAT	0.50	3.00
6/15/2014 - 6/21/2014	**6/21/2014**	2.57	0.32	0.40	SAT	0.50	3.00
6/22/2014 - 6/26/2014	**6/26/2014**	2.57	0.27	0.32	SAT	0.50	3.00
					mean	**0.43**	**2.55**
					standard dev	0.02	
						0.06	
						Calibration	0.07

		Soil Moisture (m3/m3)				Calibrated	Weekly volume of Water in each plot
Week		**Plot 7 TOP**	**Plot 7 MID**	**Plot 7 BOT**	**Plot 7 Avg**	**Plot 7**	**m3**
4/13/2014 - 4/19/2014	**4/19/2014**	0.24	0.30	0.34	0.29	0.37	2.19
4/20/2014 - 4/26/2014	**4/26/2014**	0.22	0.31	0.35	0.29	0.36	2.18
4/27/2014 - 5/3/2014	**5/3/2014**	0.22	0.32	0.37	0.30	0.37	2.24
5/4/2014 - 5/10/2014	**5/10/2014**	0.22	0.32	0.37	0.30	0.37	2.25
5/11/2014 - 5/17/2014	**5/17/2014**	0.20	0.30	0.36	0.29	0.36	2.15
5/18/2014 - 5/24/2014	**5/24/2014**	0.20	0.29	0.36	0.28	0.36	2.13
5/25/2014 - 5/31/2014	**5/31/2014**	0.21	0.28	0.36	0.28	0.35	2.12
6/1/2014 - 6/7/2014	**6/7/2014**	0.24	0.32	0.35	0.30	0.37	2.24
6/8/2014 - 6/14/2014	**6/14/2014**	0.26	0.34	0.39	0.33	0.40	2.40
6/15/2014 - 6/21/2014	**6/21/2014**	0.21	0.31	0.35	0.29	0.36	2.18
6/22/2014 - 6/26/2014	**6/26/2014**	0.15	0.27	0.25	0.22	0.30	1.77
					mean	**0.36**	**2.17**
					standard dev	0.03	

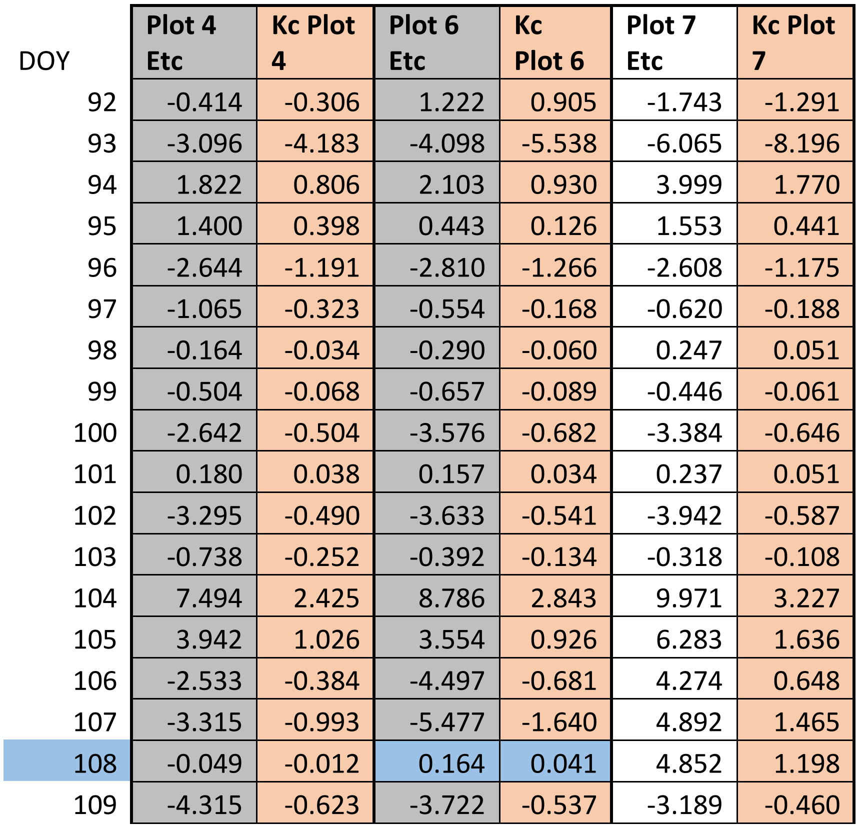


Week		Soil Moisture (m3/m3)				Calibrated	Weekly volume of Water in each plot
Week		Plot 8 TOP	Plot 8 MID	Plot 8 BOT	Plot 8 Avg	Plot 8	m3
4/13/2014 - 4/19/2014	4/19/2014	0.19	0.28	0.34	0.27	0.34	2.05
4/20/2014 - 4/26/2014	4/26/2014	0.19	0.29	0.36	0.28	0.35	2.11
4/27/2014 - 5/3/2014	5/3/2014	0.21	0.30	0.36	0.29	0.36	2.18
5/4/2014 - 5/10/2014	5/10/2014	0.17	0.28	0.36	0.27	0.34	2.05
5/11/2014 - 5/17/2014	5/17/2014	0.14	0.24	0.31	0.23	0.30	1.80
5/18/2014 - 5/24/2014	5/24/2014	0.15	0.23	0.30	0.22	0.29	1.77
5/25/2014 - 5/31/2014	5/31/2014	0.19	0.23	0.30	0.24	0.31	1.87
6/1/2014 - 6/7/2014	6/7/2014	0.21	0.30	0.34	0.28	0.36	2.14
6/8/2014 - 6/14/2014	6/14/2014	0.23	0.34	0.41	0.33	0.40	2.39
6/15/2014 - 6/21/2014	6/21/2014	0.22	0.33	0.40	0.32	0.39	2.33
6/22/2014 - 6/26/2014	6/26/2014	0.18	0.30	0.38	0.29	0.36	2.16
					mean	**0.35**	**2.08**
					standard dev	0.03	

Evapotranspiration and Crop Coefficients

Below are the discrete values used to graph the cover crop coefficients in chapter 4, highlighted values are the discrete values used to create figure 4.5.

Table C-2. Cover crop coefficients and ET$_c$ for cocktail, ryegrass and clover plots.



DOY	Plot 4 Etc	Kc Plot 4	Plot 6 Etc	Kc Plot 6	Plot 7 Etc	Kc Plot 7
92	-0.414	-0.306	1.222	0.905	-1.743	-1.291
93	-3.096	-4.183	-4.098	-5.538	-6.065	-8.196
94	1.822	0.806	2.103	0.930	3.999	1.770
95	1.400	0.398	0.443	0.126	1.553	0.441
96	-2.644	-1.191	-2.810	-1.266	-2.608	-1.175
97	-1.065	-0.323	-0.554	-0.168	-0.620	-0.188
98	-0.164	-0.034	-0.290	-0.060	0.247	0.051
99	-0.504	-0.068	-0.657	-0.089	-0.446	-0.061
100	-2.642	-0.504	-3.576	-0.682	-3.384	-0.646
101	0.180	0.038	0.157	0.034	0.237	0.051
102	-3.295	-0.490	-3.633	-0.541	-3.942	-0.587
103	-0.738	-0.252	-0.392	-0.134	-0.318	-0.108
104	7.494	2.425	8.786	2.843	9.971	3.227
105	3.942	1.026	3.554	0.926	6.283	1.636
106	-2.533	-0.384	-4.497	-0.681	4.274	0.648
107	-3.315	-0.993	-5.477	-1.640	4.892	1.465
108	-0.049	-0.012	0.164	0.041	4.852	1.198
109	-4.315	-0.623	-3.722	-0.537	-3.189	-0.460

110	-1.924	-0.386	-2.975	-0.597	-3.363	-0.675
111	1.153	0.206	-1.000	-0.179	-0.167	-0.030
112	1.496	0.320	1.058	0.226	0.836	0.179
113	1.474	0.233	1.619	0.255	0.827	0.130
114	-7.895	-2.181	-10.657	-2.944	-9.036	-2.496
115	-1.495	-0.233	-1.593	-0.248	-1.449	-0.226
116	-0.442	-0.073	-0.117	-0.019	-0.262	-0.043
117	-18.067	-3.346	-14.937	-2.766	-15.782	-2.923
118	5.602	2.075	9.727	3.603	9.580	3.548
119	-1.002	-0.771	2.469	1.900	3.328	2.560
120	1.943	0.507	2.569	0.671	2.317	0.605
121	7.476	2.344	4.566	1.431	3.089	0.968
122	1.323	0.243	-0.030	-0.005	-0.328	-0.060
123	-2.815	-0.598	-4.744	-1.007	-3.614	-0.767
124	-0.947	-0.159	-2.951	-0.495	-2.493	-0.418
125	1.543	0.311	-1.425	-0.287	-2.070	-0.416
126	3.969	0.570	0.221	0.032	-0.691	-0.099
127	4.465	0.472	-1.572	-0.166	-1.952	-0.207
128	5.244	0.887	3.591	0.608	2.773	0.469
129	5.700	1.088	6.428	1.227	5.196	0.992
130	-0.595	-0.096	3.860	0.621	0.374	0.060
131	-0.887	-0.148	4.211	0.701	-0.174	-0.029
132	1.870	0.862	6.338	2.921	3.045	1.403
133	7.678	1.658	9.364	2.023	8.524	1.841
134	1.214	0.278	2.405	0.550	0.847	0.194
135	1.803	0.400	3.096	0.687	1.226	0.272
136	4.245	2.123	6.432	3.216	4.845	2.422
137	2.105	0.660	3.844	1.205	1.085	0.340
138	0.819	0.166	0.926	0.188	-1.424	-0.289
139	-0.500	-0.066	1.162	0.153	-3.063	-0.404
140	-0.235	-0.032	1.937	0.261	-2.236	-0.301
141	1.617	0.317	3.690	0.722	-0.346	-0.068
142	3.796	0.976	6.178	1.588	3.283	0.844
143	-12.109	-4.309	5.550	1.975	2.240	0.797
144	-47.385	-27.233	-7.229	-4.154	-7.728	-4.441
145	4.354	1.122	-3.273	-0.844	0.487	0.125
146	3.525	0.824	-1.296	-0.303	1.725	0.403
147	2.418	0.473	-0.533	-0.104	2.317	0.453
148	4.046	0.834	-0.567	-0.117	1.612	0.332
149	4.206	0.748	1.639	0.292	2.408	0.428

150	3.508	0.671	3.113	0.595	3.841	0.734
151	4.642	0.879	2.979	0.564	4.523	0.857
152	3.502	0.670	-85.759	-16.398	-1.117	-0.214
153	-19.401	-4.370	4.559	1.027	-38.884	-8.758
154	-0.131	-0.023	-1.527	-0.265	9.127	1.582
155	3.275	0.697	-1.495	-0.318	9.949	2.117
156	-19.510	-4.506	-44.554	-10.290	-16.345	-3.775
157	5.320	1.164	-20.219	-4.424	-5.898	-1.290
158	-4.021	-0.902	-1.135	-0.255	-1.842	-0.413
159	5.896	1.532	1.494	0.388	5.961	1.548
160	-22.878	-14.665	-3.246	-2.081	-18.999	-12.179
161	-7.981	-1.550	-10.452	-2.030	-30.195	-5.863
162	26.356	4.881	9.358	1.733	30.911	5.724
163	-15.200	-2.901	-8.269	-1.578	-10.965	-2.093
164	18.638	3.328	8.444	1.508	16.909	3.019
165	2.749	0.439	7.088	1.132	12.807	2.046
166	-21.318	-3.955	-10.283	-1.908	-26.081	-4.839
167	8.478	1.420	2.502	0.419	9.629	1.613
168	8.483	1.134	7.847	1.049	16.397	2.192
169	6.980	0.956	11.597	1.589	18.974	2.599
170	8.250	1.744	11.476	2.426	18.751	3.964
171	12.008	1.828	10.995	1.673	14.039	2.137
172	11.566	1.696	14.093	2.066	14.207	2.083
173	11.948	2.032	7.446	1.266	10.821	1.840
174	7.566	1.739	2.844	0.654	6.408	1.473
175	6.053	1.408	2.024	0.471	4.445	1.034
176	4.451	0.795	1.488	0.266	2.518	0.450
177	1.821	0.454	0.350	0.087	0.782	0.195

Appendix D - Soil Core Samples

Soil cores were taken on October 24th 2013 and again on June 26th 2014. Cores were taken using a 305mm (12in) long soil core sample with a radius of 10mm. Prior to taking the core samples, sample containers were weighed. Soil samples were weighed before being placed in an oven at 100°C for up to 48 hours. Dry weight was measured and soil was brought to Kansas State University's soil testing lab. There the samples were ground using a soil grinder and placed in specimen cups for analysis.

Soil testing lab sent the results of total soil N (ppm) total soil (ppm) and percent organic matter. Table D-1 is the results from the first soil core samples on 10/24. Table D-2 is the results from the 2nd core sampling on 6/26.

Table D-1. Initial soil core data calculations.

Plot #	Treat	Can #	Sample	Wet weight + Can (g)	Dry Weight + Can (g)	Can (g)	Wet Weight (g)	Dry weight (g)	Volume (cm^3)	Bulk Density (g/cm3)	Particle Density (g/cm3)	Porosity ϕ	Total N (ppm)	Total P (ppm)	OM (%)	Gravimetric Water Content (g/g)	Water Filled Pore Space
1	1	C21	0 - 7.62cm	109.22	104.11	79.38	29.84	24.73	23.94	1.03	2.65	0.61	975.00	415.00	3.00	0.21	34.98
		C26	7.62 - 15.24 cm	120.34	112.55	76.48	43.86	36.07	23.94	1.51	2.65	0.43	950.00	366.00	3.10	0.22	75.42
		C107	15.24 - 30.48 cm	162.15	144.3	76.21	85.94	68.09	47.88	1.42	2.65	0.46	731.00	359.00	1.70	0.26	80.46
1 Avg										**1.32**		**0.50**	**885.33**	**380.00**	**2.60**	**0.23**	**63.62**
2	5	C5	0 - 7.62cm	110.78	104.93	76.28	34.5	28.65	23.94	1.20	2.65	0.55	991.00	448.00	2.80	0.20	44.56
		2627	7.62 - 15.24 cm	117.33	110.19	76.74	40.59	33.45	23.94	1.40	2.65	0.47	787.00	272.00	1.80	0.21	63.09
		3215	15.24 - 30.48 cm	149.94	133.75	76.77	73.17	56.98	47.88	1.19	2.65	0.55	818.00	280.00	1.50	0.28	61.38
2 Avg										**1.26**		**0.52**	**865.33**	**333.33**	**2.03**	**0.23**	**56.34**
3	4	2503	0 - 7.62cm	108.99	103.1	76.71	32.28	26.39	23.94	1.10	2.65	0.58	975.00	390.00	2.50	0.22	42.13
		C119	7.62 - 15.24 cm	116.13	108.85	76.49	39.64	32.36	23.94	1.35	2.65	0.49	853.00	297.00	1.90	0.22	62.07
		C32	15.24 - 30.48 cm	163.9	147.02	76.14	87.76	70.88	47.88	1.48	2.65	0.44	787.00	283.00	1.50	0.24	79.88
3 Avg										**1.31**		**0.51**	**871.67**	**323.33**	**1.97**	**0.23**	**61.36**
4	5	C118	0 - 7.62cm	112.21	105.89	76.16	36.05	29.73	23.94	1.24	2.65	0.53	911.00	374.00	2.40	0.21	49.68
		2009	7.62 - 15.24 cm	119.61	113.13	77.32	42.29	35.81	23.94	1.50	2.65	0.44	883.00	346.00	2.00	0.18	62.15
		2715	15.24 - 30.48 cm	151.38	137.8	76.86	74.52	60.94	47.88	1.27	2.65	0.52	718.00	297.00	1.60	0.22	54.57
4 Avg										**1.34**		**0.50**	**837.33**	**339.00**	**2.00**	**0.21**	**55.47**
5	1	C45	0 - 7.62cm	113.81	107.22	76.76	37.05	30.46	23.94	1.27	2.65	0.52	856.00	309.00	2.40	0.22	52.95
		3803	7.62 - 15.24 cm	118.28	110.91	75.81	42.47	35.1	23.94	1.47	2.65	0.45	821.00	287.00	2.00	0.21	68.91
		2409	15.24 - 30.48 cm	155.33	139.61	77.21	78.12	62.4	47.88	1.30	2.65	0.51	730.00	302.00	1.20	0.25	64.60
5 Avg										**1.35**		**0.49**	**802.33**	**299.33**	**1.87**	**0.23**	**62.16**
6	4	2021	0 - 7.62cm	105.1	100.42	77.25	27.85	23.17	23.94	0.97	2.65	0.63	915.00	357.00	2.30	0.20	30.80
		2303	7.62 - 15.24 cm	124.64	116.33	77.2	47.44	39.13	23.94	1.63	2.65	0.38	875.00	312.00	1.90	0.21	90.58
		2903	15.24 - 30.48 cm	155.71	140.34	76.62	79.09	63.72	47.88	1.33	2.65	0.50	831.00	286.00	1.80	0.24	64.49
6 Avg										**1.31**		**0.51**	**873.67**	**318.33**	**2.00**	**0.22**	**61.95**
7	3	2621	0 - 7.62cm	114.65	108.45	80.42	34.23	28.03	23.94	1.17	2.65	0.56	936.00	365.00	2.50	0.22	46.40
		C3	7.62 - 15.24 cm	109.97	104.2	76.43	33.54	27.77	23.94	1.16	2.65	0.56	831.00	307.00	2.00	0.21	42.87
		2921	15.24 - 30.48 cm	147.39	134.38	76.6	70.79	57.78	47.88	1.21	2.65	0.54	810.00	318.00	1.70	0.23	49.89
7 Avg										**1.18**		**0.56**	**859.00**	**330.00**	**2.07**	**0.22**	**46.39**

8	2	11	0 - 7.62cm	98.04	95.01	76.46	21.58	18.55	23.94	0.77	2.65	0.71	928.00	367.00	2.50	0.16	17.89
		3003	7.62 - 15.24 cm	112.56	106.37	76.48	36.08	29.89	23.94	1.25	2.65	0.53	841.00	305.00	2.10	0.21	48.89
		2603	15.24 - 30.48 cm	149.3	136.62	76.3	73	60.32	47.88	1.26	2.65	0.52	747.00	316.00	1.70	0.21	50.48
8 Avg										**1.09**		**0.59**	**838.67**	**329.33**	**2.10**	**0.19**	**39.09**
9	2	C103	0 - 7.62cm	118.58	110.85	76.18	42.4	34.67	23.94	1.45	2.65	0.45	974.00	384.00	2.60	0.22	71.20
		2309	7.62 - 15.24 cm	110.99	104.64	77.3	33.69	27.34	23.94	1.14	2.65	0.57	909.00	322.00	2.20	0.23	46.61
		C75	15.24 - 30.48 cm	147.74	134.83	79.51	68.23	55.32	47.88	1.16	2.65	0.56	793.00	312.00	1.70	0.23	47.81
9 Avg										**1.25**		**0.53**	**892.00**	**339.33**	**2.17**	**0.23**	**55.21**
10	3	2909	0 - 7.62cm	97.02	93.91	76.85	20.17	17.06	23.94	0.71	2.65	0.73	983.00	361.00	2.40	0.18	17.77
		C124	7.62 - 15.24 cm	114.72	108.37	76.39	38.33	31.98	23.94	1.34	2.65	0.50	978.00	304.00	2.30	0.20	53.49
		2927	15.24 - 30.48 cm	156.72	147.76	78.33	78.39	69.43	47.88	1.45	2.65	0.45	808.00	282.00	1.50	0.13	41.33
10 Avg										**1.17**		**0.56**	**923.00**	**315.67**	**2.07**	**0.17**	**37.53**
11	5	C137	0 - 7.62cm	106.03	100.71	75.44	30.59	25.27	23.94	1.06	2.65	0.60	980.00	398.00	2.50	0.21	36.93
		2415	7.62 - 15.24 cm	112.76	106.87	77.08	35.68	29.79	23.94	1.24	2.65	0.53	845.00	301.00	1.70	0.20	46.38
		2615	15.24 - 30.48 cm	147.77	134.03	77.03	70.74	57	47.88	1.19	2.65	0.55	841.00	293.00	1.20	0.24	52.10
11 Avg										**1.16**		**0.56**	**888.67**	**330.67**	**1.80**	**0.22**	**45.14**
12	4	C108	0 - 7.62cm	105.8	101.15	76.43	29.37	24.72	23.94	1.03	2.65	0.61	986.00	397.00	2.40	0.19	31.82
		C76	7.62 - 15.24 cm	109.76	104.77	77.9	31.86	26.87	23.94	1.12	2.65	0.58	908.00	328.00	2.20	0.19	36.16
		3021	15.24 - 30.48 cm	154.27	140.92	78.3	75.97	62.62	47.88	1.31	2.65	0.51	809.00	339.00	1.60	0.21	55.05
12 Avg										**1.15**		**0.56**	**901.00**	**354.67**	**2.07**	**0.20**	**41.01**
13	3	327	0 - 7.62cm	111.34	105.59	76.97	34.37	28.62	23.94	1.20	2.65	0.55	962.00	392.00	2.60	0.20	0.20
		C12	7.62 - 15.24 cm	112.99	107.86	79.95	33.04	27.91	23.94	1.17	2.65	0.56	783.00	284.00	1.90	0.18	38.26
		2803	15.24 - 30.48 cm	150.82	137.97	81.03	69.79	56.94	47.88	1.19	2.65	0.55	784.00	258.00	1.70	0.23	48.69
13 Avg										**1.18**		**0.55**	**843.00**	**311.33**	**2.07**	**0.20**	**29.05**
14	1	C30	0 - 7.62cm	110.09	103.75	76.72	33.37	27.03	23.94	1.13	2.65	0.57	944.00	404.00	2.60	0.23	46.14
		C120	7.62 - 15.24 cm	108.93	103.22	76.21	32.72	27.01	23.94	1.13	2.65	0.57	855.00	318.00	1.90	0.21	41.53
		C67	15.24 - 30.48 cm	155.17	140.57	75.62	79.55	64.95	47.88	1.36	2.65	0.49	738.00	267.00	1.40	0.22	62.47
14 Avg										**1.20**		**0.55**	**845.67**	**329.67**	**1.97**	**0.22**	**50.05**
15	2	3127	0 - 7.62cm	108.11	102.56	76.6	31.51	25.96	23.94	1.08	2.65	0.59	849.00	343.00	2.30	0.21	39.24
		C131	7.62 - 15.24 cm	107.86	102.98	78.38	29.48	24.6	23.94	1.03	2.65	0.61	828.00	294.00	1.70	0.20	33.29
		2427	15.24 - 30.48 cm	153.99	140.6	77.65	76.34	62.95	47.88	1.31	2.65	0.50	769.00	288.00	1.50	0.21	55.50
15 Avg										**1.14**		**0.57**	**815.33**	**308.33**	**1.83**	**0.21**	**42.68**

Table D-2. Ending Soil Core Data Calculations.

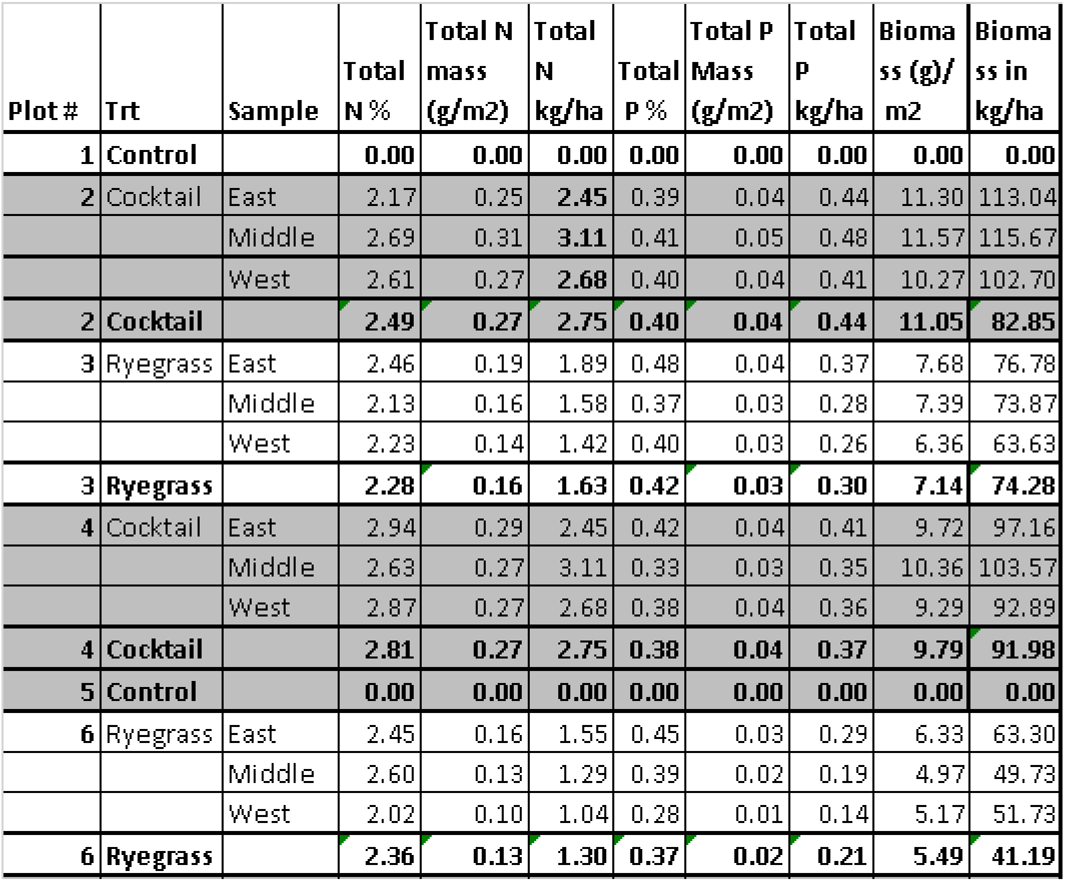
Plot #	Treat	Can #	Sample	Wet weight + Can (g)	Dry Weight + Can (g)	Can (g)	Wet Weight (g)	Dry weight (g)	Volume (cm^3)	Bulk Density (g/m^3)	Particle Density (g/cm3)	Porosity ϕ	Total N (ppm)	Total P (ppm)	OM (%)	Gravimetric Water Content (g/g)	Water Filled Pore Space
1	1	C21	0 - 7.62cm	221.28	199.05	79.38	141.90	119.67	71.82	1.67	2.65	0.37	1402.71	421.14	2.48	0.19	83.38
		C26	7.62 - 15.24 cm	196.01	173.53	76.48	119.53	97.05	71.82	1.35	2.65	0.49	888.17	249.20	1.74	0.23	63.87
		C107	15.24 - 30.48 cm	316.73	265.73	76.21	240.52	189.52	143.64	1.32	2.65	0.50	836.76	274.95	1.51	0.27	70.71
										1.45		**0.45**	**1042.55**	**315.10**	**1.91**	**0.23**	**72.65**
2	5	C5	0 - 7.62cm	210.81	191.91	76.28	134.53	115.63	71.82	1.61	2.65	0.39	1219.10	316.05	2.63	0.16	67.05
		2627	7.62 - 15.24 cm	188.09	168.00	76.74	111.35	91.26	71.82	1.27	2.65	0.52	919.10	226.77	1.62	0.22	53.74
		3215	15.24 - 30.48 cm	305.86	261.19	76.77	229.09	184.42	143.64	1.28	2.65	0.52	815.37	224.49	1.51	0.24	60.33
										1.39		**0.48**	**984.52**	**255.77**	**1.92**	**0.21**	**60.37**
3	4	2503	0 - 7.62cm	202.84	185.54	76.71	126.13	108.83	71.82	1.52	2.65	0.43	1401.82	328.50	2.70	0.16	56.26
		C119	7.62 - 15.24 cm	180.16	163.06	76.49	103.67	86.57	71.82	1.21	2.65	0.55	1028.52	270.76	2.05	0.20	43.68
		C32	15.24 - 30.48 cm	299.50	254.99	76.14	223.36	178.85	143.64	1.25	2.65	0.53	830.67	238.88	1.72	0.25	58.45
										1.32		**0.50**	**1087.00**	**279.38**	**2.16**	**0.20**	**52.79**
4	5	C118	0 - 7.62cm	192.15	176.66	76.16	115.99	100.50	71.82	1.40	2.65	0.47	1282.10	325.33	2.41	0.15	45.70
		2009	7.62 - 15.24 cm	175.62	160.48	77.32	98.30	83.16	71.82	1.16	2.65	0.56	1123.45	271.64	2.01	0.18	37.44
		2715	15.24 - 30.48 cm	301.50	259.47	76.86	224.64	182.61	143.64	1.27	2.65	0.52	937.31	218.24	1.72	0.23	56.24
										1.28		**0.52**	**1114.29**	**271.74**	**2.05**	**0.19**	**46.46**
5	1	C45	0 - 7.62cm	206.52	188.90	76.76	129.76	112.14	71.82	1.56	2.65	0.41	1124.38	328.79	2.35	0.16	59.72
		3803	7.62 - 15.24 cm	188.70	170.04	75.81	112.89	94.23	71.82	1.31	2.65	0.50	1037.17	235.39	1.90	0.20	51.46
		2409	15.24 - 30.48 cm	308.01	264.31	77.21	230.80	187.10	143.64	1.30	2.65	0.51	813.51	245.44	1.68	0.23	59.83
										1.39		**0.47**	**991.69**	**269.87**	**1.98**	**0.20**	**57.01**
6	4	2021	0 - 7.62cm	198.65	183.83	77.25	121.40	106.58	71.82	1.48	2.65	0.44	1289.43	314.80	2.42	0.14	46.90
		2303	7.62 - 15.24 cm	170.06	156.13	77.20	92.86	78.93	71.82	1.10	2.65	0.59	1008.33	287.24	2.03	0.18	33.14
		2903	15.24 - 30.48 cm	286.58	250.89	76.62	209.96	174.27	143.64	1.21	2.65	0.54	883.75	238.28	1.74	0.20	45.83
										1.27		**0.52**	**1060.50**	**280.11**	**2.06**	**0.17**	**41.95**
7	3	2621	0 - 7.62cm	202.26	186.70	80.42	121.84	106.28	71.82	1.48	2.65	0.44	1310.63	321.93	2.52	0.15	49.06
		C3	7.62 - 15.24 cm	180.63	164.85	76.43	104.20	88.42	71.82	1.23	2.65	0.54	1003.48	265.52	1.96	0.18	41.04
		2921	15.24 - 30.48 cm	291.73	253.73	76.60	215.13	177.13	143.64	1.23	2.65	0.53	912.69	256.45	1.72	0.21	49.48
										1.31		**0.50**	**1075.60**	**281.30**	**2.06**	**0.18**	**46.53**

8	2	11	0 - 7.62cm	213.64	194.34	76.46	137.18	117.88	71.82	1.64	2.65	0.38	1315.19	320.99	2.35	0.16	70.60
		3003	7.62 - 15.24 cm	188.56	169.34	76.48	112.08	92.86	71.82	1.29	2.65	0.51	1253.69	319.32	2.13	0.21	52.26
		2603	15.24 - 30.48 cm	314.90	269.13	76.30	238.60	192.83	143.64	1.34	2.65	0.49	848.35	284.33	1.62	0.24	64.58
										1.43		**0.46**	**1139.08**	**308.21**	**2.03**	**0.20**	**62.48**
9	2	C103	0 - 7.62cm	219.05	198.77	76.18	142.87	122.59	71.82	1.71	2.65	0.36	1356.43	343.52	2.29	0.17	79.34
		2309	7.62 - 15.24 cm	190.10	171.26	77.30	112.80	93.96	71.82	1.31	2.65	0.51	988.59	256.08	1.72	0.20	51.81
		C75	15.24 - 30.48 cm	312.51	269.23	79.51	233.00	189.72	143.64	1.32	2.65	0.50	912.04	320.85	1.36	0.23	60.07
										1.45		**0.45**	**1085.69**	**306.82**	**1.79**	**0.20**	**63.74**
10	3	2909	0 - 7.62cm	192.27	177.05	76.85	115.42	100.20	71.82	1.40	2.65	0.47	1512.87	397.58	2.78	0.15	44.75
		C124	7.62 - 15.24 cm	192.21	174.43	76.39	115.82	98.04	71.82	1.37	2.65	0.48	997.29	234.00	2.01	0.18	51.06
		2927	15.24 - 30.48 cm	304.88	265.63	78.33	226.55	187.30	143.64	1.30	2.65	0.51	970.39	277.04	1.49	0.21	53.80
										1.35		**0.49**	**1160.19**	**302.87**	**2.10**	**0.18**	**49.87**
11	5	C137	0 - 7.62cm	180.78	167.88	75.44	105.34	92.44	71.82	1.29	2.65	0.51	1641.31	351.03	2.74	0.14	34.92
		2415	7.62 - 15.24 cm	188.93	172.35	77.08	111.85	95.27	71.82	1.33	2.65	0.50	1175.84	280.93	2.22	0.17	46.22
		2615	15.24 - 30.48 cm	307.08	266.93	77.03	230.05	189.90	143.64	1.32	2.65	0.50	1007.63	265.27	1.75	0.21	55.78
										1.31		**0.50**	**1274.93**	**299.08**	**2.24**	**0.18**	**45.64**
12	4	C108	0 - 7.62cm	173.36	162.03	76.43	96.93	85.60	71.82	1.19	2.65	0.55	1501.29	355.37	2.70	0.13	28.67
		C76	7.62 - 15.24 cm	174.68	160.25	77.90	96.78	82.35	71.82	1.15	2.65	0.57	1265.45	284.27	2.33	0.18	35.42
		3021	15.24 - 30.48 cm	292.60	256.45	78.30	214.30	178.15	143.64	1.24	2.65	0.53	949.67	250.20	1.55	0.20	47.31
										1.19		**0.55**	**1238.80**	**296.61**	**2.19**	**0.17**	**37.13**
13	3	327	0 - 7.62cm	182.57	169.61	76.97	105.60	92.64	71.82	1.29	2.65	0.51	1486.16	384.39	2.67	0.14	0.29
		C12	7.62 - 15.24 cm	181.52	165.60	79.95	101.57	85.65	71.82	1.19	2.65	0.55	1063.52	333.70	1.88	0.19	40.30
		2803	15.24 - 30.48 cm	294.12	255.67	81.03	213.09	174.64	143.64	1.22	2.65	0.54	947.10	276.82	1.38	0.22	49.46
										1.23		**0.53**	**1165.60**	**331.63**	**1.98**	**0.18**	**30.02**
14	1	C30	0 - 7.62cm	180.85	164.85	76.72	104.13	88.13	71.82	1.23	2.65	0.54	1325.25	368.55	2.41	0.18	41.49
		C120	7.62 - 15.24 cm	198.92	177.26	76.21	122.71	101.05	71.82	1.41	2.65	0.47	1054.35	295.80	1.83	0.21	64.30
		C67	15.24 - 30.48 cm	306.90	260.38	75.62	231.28	184.76	143.64	1.29	2.65	0.51	924.10	295.46	1.36	0.25	62.93
										1.31		**0.51**	**1101.23**	**319.94**	**1.87**	**0.22**	**56.24**
15	2	3127	0 - 7.62cm	167.14	154.20	76.60	90.54	77.60	71.82	1.08	2.65	0.59	1441.12	341.31	2.46	0.17	30.42
		C131	7.62 - 15.24 cm	192.25	172.56	78.38	113.87	94.18	71.82	1.31	2.65	0.51	1043.18	279.72	1.92	0.21	54.27
		2427	15.24 - 30.48 cm	311.35	265.55	77.65	233.70	187.90	143.64	1.31	2.65	0.51	896.43	315.88	1.48	0.24	62.97
										1.23		**0.53**	**1126.91**	**312.31**	**1.95**	**0.21**	**49.22**

Appendix E - Biomass Data

The biomass was collected using a 30.48 x 30.48 square, clipping all aboveground biomass and placed into paper bags. The samples were dried in an oven at 70°C for 48 hours. Simple conversions between units took place in order to create better understanding of biomass production (Table E-1).

Table E-1. Biomass data calculations.



Plot #	Trt	Sample	Total N %	Total N mass (g/m2)	Total N kg/ha	Total P %	Total P Mass (g/m2)	Total P kg/ha	Biomass (g)/ m2	Biomass in kg/ha
1	**Control**		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
2	Cocktail	East	2.17	0.25	**2.45**	0.39	0.04	0.44	11.30	113.04
		Middle	2.69	0.31	**3.11**	0.41	0.05	0.48	11.57	115.67
		West	2.61	0.27	**2.68**	0.40	0.04	0.41	10.27	102.70
2	**Cocktail**		**2.49**	**0.27**	**2.75**	**0.40**	**0.04**	**0.44**	**11.05**	**82.85**
3	Ryegrass	East	2.46	0.19	1.89	0.48	0.04	0.37	7.68	76.78
		Middle	2.13	0.16	1.58	0.37	0.03	0.28	7.39	73.87
		West	2.23	0.14	1.42	0.40	0.03	0.26	6.36	63.63
3	**Ryegrass**		**2.28**	**0.16**	**1.63**	**0.42**	**0.03**	**0.30**	**7.14**	**74.28**
4	Cocktail	East	2.94	0.29	2.45	0.42	0.04	0.41	9.72	97.16
		Middle	2.63	0.27	3.11	0.33	0.03	0.35	10.36	103.57
		West	2.87	0.27	2.68	0.38	0.04	0.36	9.29	92.89
4	**Cocktail**		**2.81**	**0.27**	**2.75**	**0.38**	**0.04**	**0.37**	**9.79**	**91.98**
5	**Control**		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
6	Ryegrass	East	2.45	0.16	1.55	0.45	0.03	0.29	6.33	63.30
		Middle	2.60	0.13	1.29	0.39	0.02	0.19	4.97	49.73
		West	2.02	0.10	1.04	0.28	0.01	0.14	5.17	51.73
6	**Ryegrass**		**2.36**	**0.13**	**1.30**	**0.37**	**0.02**	**0.21**	**5.49**	**41.19**

7	Clover	East	2.90	0.14	1.35	0.28	0.01	0.13	4.66	46.60
		Middle	3.08	0.13	1.30	0.26	0.01	0.11	4.21	42.10
		West	3.07	0.11	1.14	0.25	0.01	0.09	3.71	37.05
7	**Clover**		**3.02**	**0.13**	**1.26**	**0.26**	**0.01**	**0.11**	**4.19**	**41.74**
8	**Tilled**		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
9	**Tilled**		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
10	Clover	East	2.84	0.11	1.13	0.28	0.01	0.11	3.98	39.80
		Middle	2.60	0.09	0.90	0.33	0.01	0.12	3.47	34.70
		West	2.38	0.07	0.72	0.31	0.01	0.09	3.01	30.10
10	**Clover**		**2.61**	**0.09**	**0.92**	**0.31**	**0.01**	**0.11**	3.49	26.15
11	Cocktail	East	2.66	0.24	2.44	0.54	0.05	0.50	9.16	91.56
		Middle	3.04	0.29	2.94	0.40	0.04	0.38	9.67	96.68
		West	3.29	0.27	2.71	0.35	0.03	0.29	8.22	82.16
11	**Cocktail**		**3.00**	**0.27**	**2.70**	**0.43**	**0.04**	**0.39**	**9.01**	**74.14**
12	Ryegrass	East	2.43	0.17	1.72	0.50	0.03	0.35	7.05	70.49
		Middle	2.33	0.15	1.46	0.35	0.02	0.22	6.29	62.86
		West	1.57	0.06	0.64	0.37	0.02	0.15	4.08	40.76
12	**Ryegrass**		**2.11**	**0.13**	**1.27**	**0.41**	**0.02**	**0.24**	**5.80**	**62.06**
13	Clover	East	2.94	0.11	1.13	0.27	0.01	0.10	3.85	38.50
		Middle	3.00	0.10	1.02	0.29	0.01	0.10	3.41	34.10
		West	3.11	0.08	0.84	0.26	0.01	0.07	2.71	27.10
13	**Clover**	**Average**	**3.02**	**0.10**	**1.00**	**0.28**	**0.01**	**0.09**	**3.32**	**40.44**
14	Control		0.00	0.00		0.00	0.00		0.00	**0.00**
15	Tilled		0.00	0.00		0.00	0.00		0.00	**0.00**

Appendix F - SAS Output

The programs for the individual analysis of variance tests (ANOVA) are as follows: Soil moisture use (Figure F-1), cover crop biomass (Figure F-2), soil bulk density changes (Figure F-3), nitrogen (Figure F-4), phosphorous (Figure F-5) and soil organic matter (Figure F-6).

Figure F-1. SAS program for soil water used.

```
DATA v;
input Number Trt$ v;
Datalines;
1 Control 6698.08782
2 Cocktail 10753.5849
3 Ryegrass 10544.55289
4 Cocktail 13027.22461
5 Control 9514.862013
6 Ryegrass 12647.20466
7 Clover 12451.48115
8 Tilled 10259.71226
9 Tilled 11267.80332
10 Clover 9190.932284
11 Cocktail 10973.20773
12 Ryegrass 11135.9042
13 Clover 10052.35264
14 Control 9224.795447
15 Tilled 13085.05676;
run;
title 'Stout Cover Crops Degrees of Saturation';
* make sure data is read correctly;
proc print data=v; run;
ODS Graphics on;
proc anova data=v;
class trt;
model v=trt;
means trt/bon;
run;

proc means data=v n mean median std stderr clm maxdec=2;
class trt;
var v;
run;
 proc univariate data=diagnostics plot normal;
 var residual;
 histogram residual;
 run;
```

Figure F-2. SAS program for analyzing biomass.

```
DATA Bio;
input Number Trt$ Bio;
Datalines;
1 Control 0
2 Cocktail 11.04679081
3 Ryegrass 7.142695392
4 Cocktail 9.787335264
5 Control 0
6 Ryegrass 5.492118048
7 Clover 3.561902554
8 Tilled 0
9 Tilled 0
10 Clover 3.225283872
11 Cocktail 9.013452941
12 Ryegrass 5.803343232
13 Clover 2.720201011
14 Control 0
15 Tilled 0

;
run;
title 'Stout Cover Crops Biomass';
* make sure data is read correctly;
proc print data=Bio; run;
ODS Graphics on;
proc anova data=Bio;
class trt;
model Bio=trt;
means trt/bon;
run;

proc means data=bio n mean median std stderr clm maxdec=2;
class trt;
var bio;
run;
 proc univariate data=diagnostics plot normal;
 var residual;
 histogram residual;
 run;
```

Figure F-3. SAS program for analyzing the change in starting and ending total nitrogen.

```
DATA N;
input Number Trt$ N;
Datalines;
1 Control 157.212704
2 Cocktail 119.1900272
3 Ryegrass 215.3350572
4 Cocktail 276.9537328
5 Control 189.3535487
6 Ryegrass 186.8358531
7 Clover 216.6035517
8 Tilled 300.4097539
9 Tilled 193.6884962
10 Clover 237.1872098
11 Cocktail 386.2626326
12 Ryegrass 337.8033947
13 Clover 322.5963838
14 Control 255.5660333
15 Tilled 311.57652
;
run;
title 'Stout Cover Crops Total Nitrogen';
* make sure data is read correctly;
proc print data=N; run;
ODS Graphics on;
proc anova data=N;
class trt;
model N=trt;
means trt/bon;
run;

proc means data=N n mean median std stderr clm maxdec=2;
class trt;
var N;
run;
 proc univariate data=diagnostics plot normal;
 var residual;
 histogram residual;
 run;
```

Figure F-4. SAS program for analyzing the change in soil total phosphorous.

```
DATA P;
input Number Trt$ P;
Datalines;
1 Control -64.90292601
2 Cocktail -77.56530212
3 Ryegrass -43.95229662
4 Cocktail -67.26429388
5 Control -29.4588114
6 Ryegrass -38.22650369
7 Clover -48.70184457
8 Tilled -21.11988687
9 Tilled -32.515158
10 Clover -12.79504425
11 Cocktail -31.58861559
12 Ryegrass -58.05635185
13 Clover 20.30161049
14 Control -9.726002088
15 Tilled 3.973759567
;
run;

title 'Stout Cover Crops Total Phosphorous';
* make sure data is read correctly;
proc print data=P; run;
ODS Graphics on;
proc anova data=P;
class trt;
model P=trt;
means trt/bon;
run;

proc means data=P n mean median std stderr clm maxdec=2;
class trt;
var P;
run;
 proc univariate data=diagnostics plot normal;
 var residual;
 histogram residual;
 run;
```

Figure F-5. SAS program for analyzing the percent of soil organic matter.

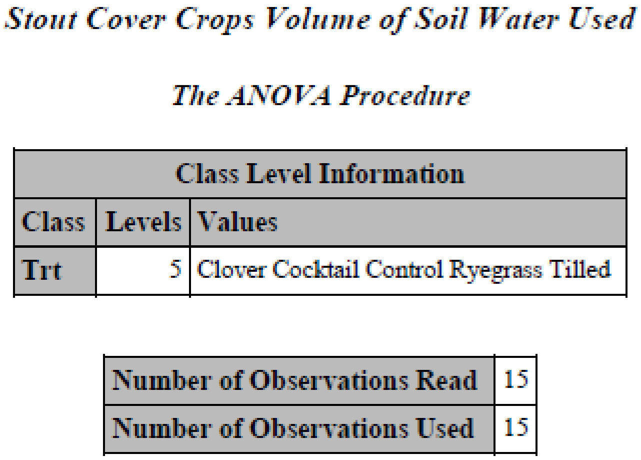
```
DATA OM;
input Number Trt$ OM;
Datalines;
1 Control -0.690590431
2 Cocktail -0.111514116
3 Ryegrass 0.190935863
4 Cocktail 0.045915698
5 Control 0.110995967
6 Ryegrass 0.06453017
7 Clover -0.002136497
8 Tilled -0.06649395
9 Tilled -0.375148754
10 Clover 0.028887623
11 Cocktail 0.438265242
12 Ryegrass 0.128164808
13 Clover -0.089004033
14 Control -0.100690865
15 Tilled 0.119510004
;
run;

title 'Stout Cover Crops Organic Matter';
* make sure data is read correctly;
proc print data=OM; run;
ODS Graphics on;
proc anova data=OM;
class trt;
model OM=trt;
means trt/bon;
run;

proc means data=OM n mean median std stderr clm maxdec=2;
class trt;
var OM;
run;
 proc univariate data=diagnostics plot normal;
 var residual;
 histogram residual;
 run;
```

The outputs of the SAS ANOVA programs for volume of soil moisture used (Figure F-6), biomass (Figure F-7), bulk density changes (Figure F-8), soil total nitrogen changes (Figure F-9), soil total phosphorous changes (Figure F-10) and soil organic matter (Figure F-11) are as follows.

Figure F-6. ANOVA and means procedure output for volume of soil water used (SAS, 2014).



Stout Cover Crops Volume of Soil Water Used

The ANOVA Procedure

Class Level Information		
Class	**Levels**	**Values**
Trt	5	Clover Cocktail Control Ryegrass Tilled

Number of Observations Read	15
Number of Observations Used	15

Stout Cover Crops Volume of Soil Water Used

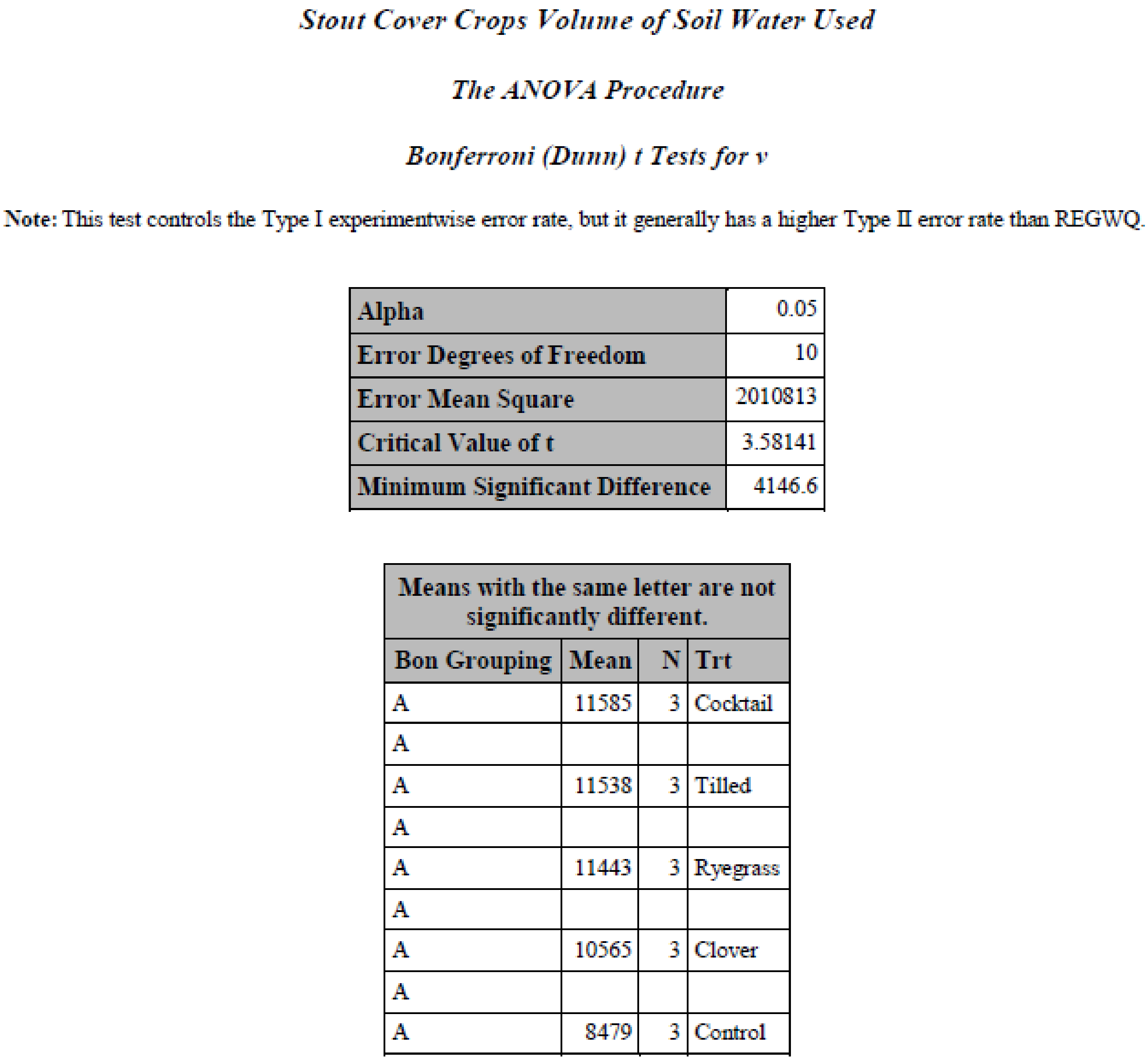
The ANOVA Procedure

Dependent Variable: v

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	20949267.29	5237316.82	2.60	0.1001
Error	10	20108134.87	2010813.49		
Corrected Total	14	41057402.16			

R-Square	Coeff Var	Root MSE	v Mean
0.510243	13.22571	1418.032	10721.78

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Trt	4	20949267.29	5237316.82	2.60	0.1001



Stout Cover Crops Volume of Soil Water Used

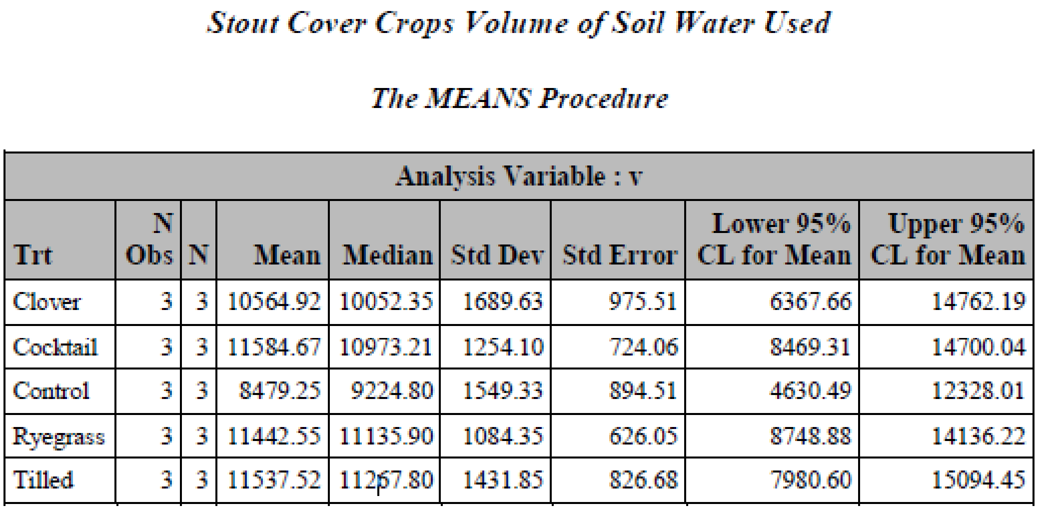
The ANOVA Procedure

Bonferroni (Dunn) t Tests for v

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	10
Error Mean Square	2010813
Critical Value of t	3.58141
Minimum Significant Difference	4146.6

Means with the same letter are not significantly different.			
Bon Grouping	**Mean**	**N**	**Trt**
A	11585	3	Cocktail
A			
A	11538	3	Tilled
A			
A	11443	3	Ryegrass
A			
A	10565	3	Clover
A			
A	8479	3	Control

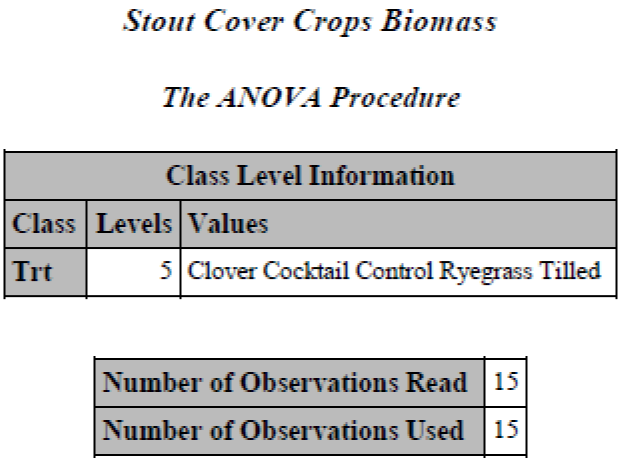


Stout Cover Crops Volume of Soil Water Used

The MEANS Procedure

Analysis Variable : v								
Trt	**N Obs**	**N**	**Mean**	**Median**	**Std Dev**	**Std Error**	**Lower 95% CL for Mean**	**Upper 95% CL for Mean**
Clover	3	3	10564.92	10052.35	1689.63	975.51	6367.66	14762.19
Cocktail	3	3	11584.67	10973.21	1254.10	724.06	8469.31	14700.04
Control	3	3	8479.25	9224.80	1549.33	894.51	4630.49	12328.01
Ryegrass	3	3	11442.55	11135.90	1084.35	626.05	8748.88	14136.22
Tilled	3	3	11537.52	11267.80	1431.85	826.68	7980.60	15094.45

Figure F-7. ANOVA and means procedure output for biomass production (SAS, 2014).

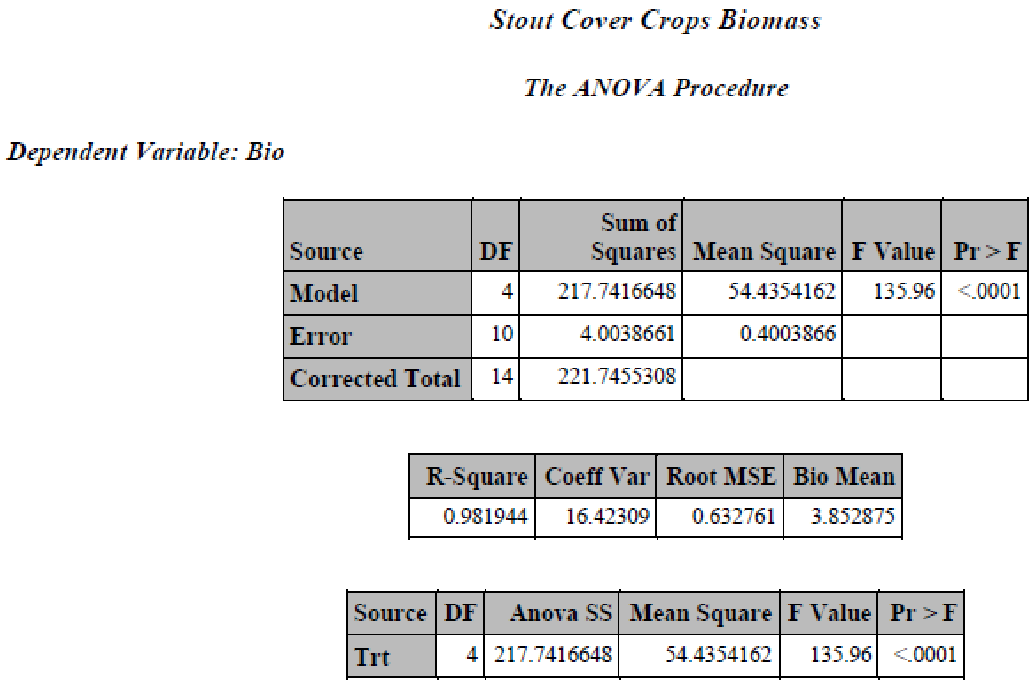


Stout Cover Crops Biomass

The ANOVA Procedure

Class Level Information		
Class	**Levels**	**Values**
Trt	5	Clover Cocktail Control Ryegrass Tilled

Number of Observations Read	15
Number of Observations Used	15



Stout Cover Crops Biomass

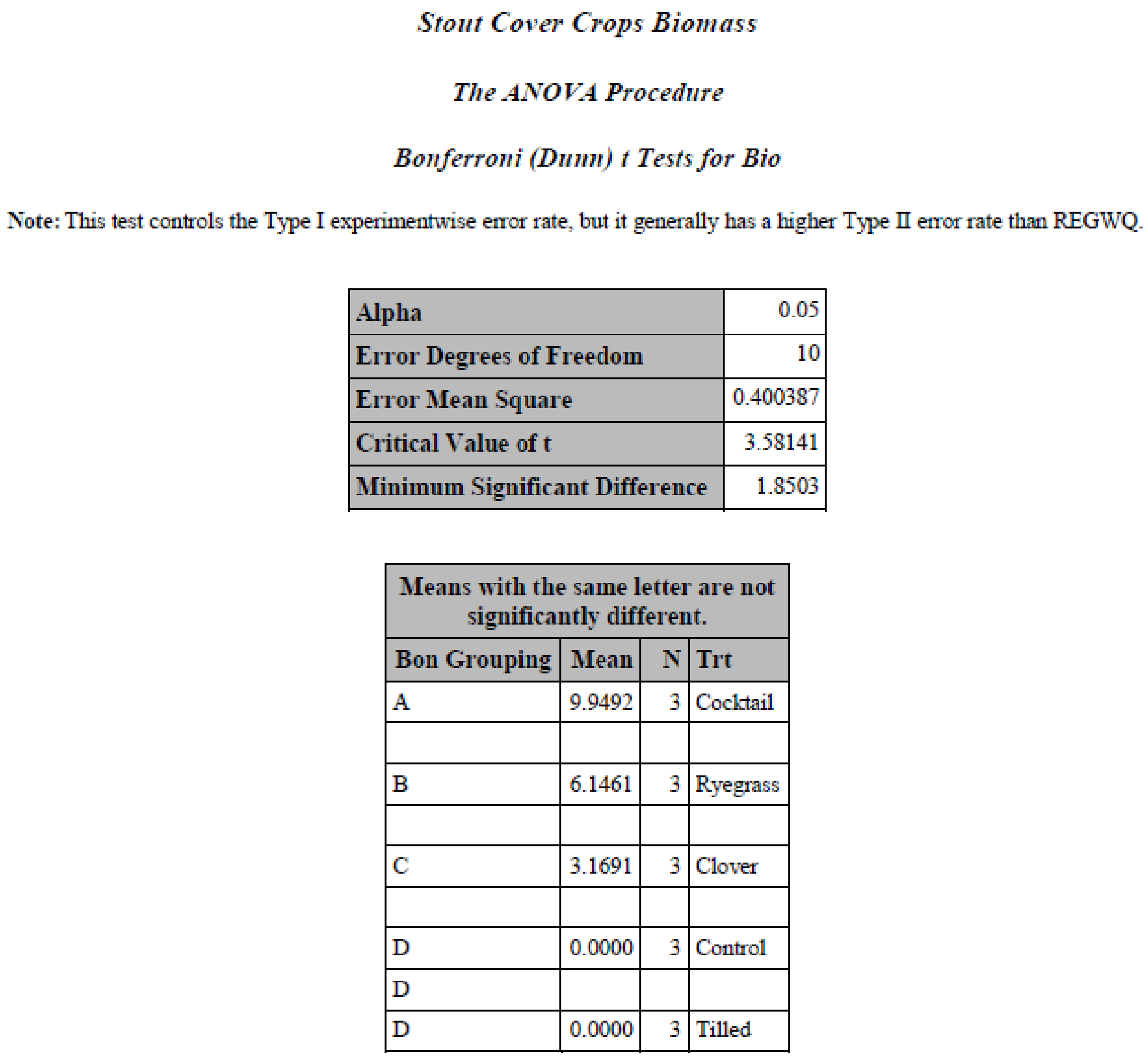
The ANOVA Procedure

Dependent Variable: Bio

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	217.7416648	54.4354162	135.96	<.0001
Error	10	4.0038661	0.4003866		
Corrected Total	14	221.7455308			

R-Square	Coeff Var	Root MSE	Bio Mean
0.981944	16.42309	0.632761	3.852875

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Trt	4	217.7416648	54.4354162	135.96	<.0001



Stout Cover Crops Biomass

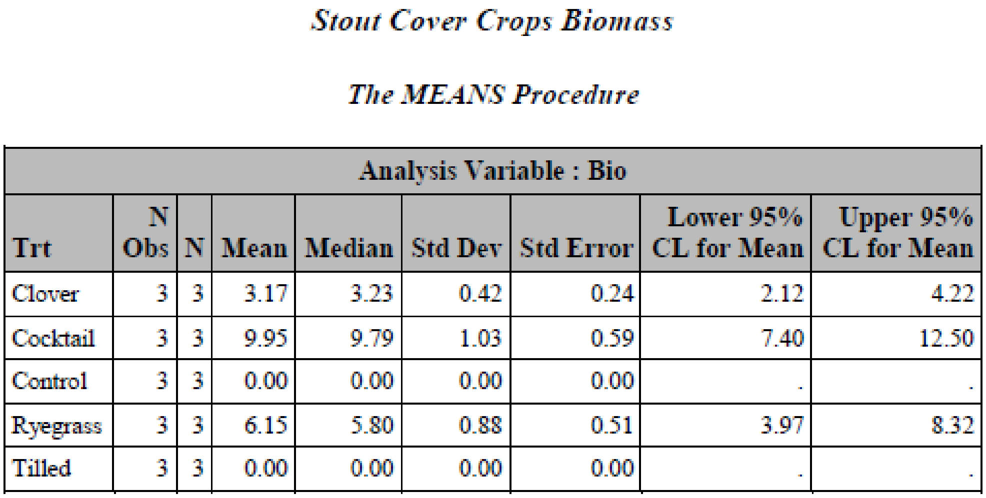
The ANOVA Procedure

Bonferroni (Dunn) t Tests for Bio

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	10
Error Mean Square	0.400387
Critical Value of t	3.58141
Minimum Significant Difference	1.8503

Means with the same letter are not significantly different.			
Bon Grouping	**Mean**	**N**	**Trt**
A	9.9492	3	Cocktail
B	6.1461	3	Ryegrass
C	3.1691	3	Clover
D	0.0000	3	Control
D			
D	0.0000	3	Tilled

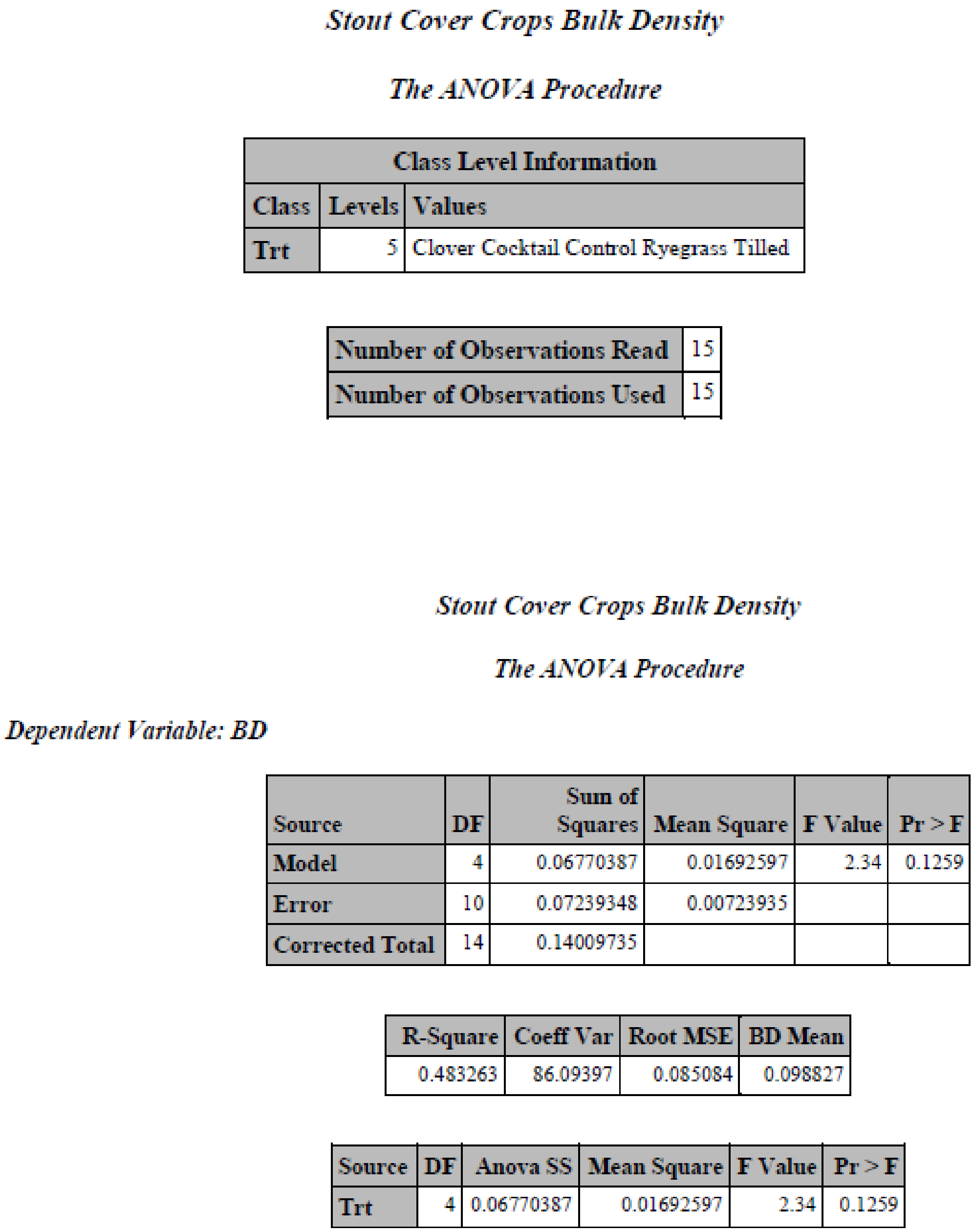


Stout Cover Crops Biomass

The MEANS Procedure

Analysis Variable : Bio								
Trt	N Obs	N	Mean	Median	Std Dev	Std Error	Lower 95% CL for Mean	Upper 95% CL for Mean
Clover	3	3	3.17	3.23	0.42	0.24	2.12	4.22
Cocktail	3	3	9.95	9.79	1.03	0.59	7.40	12.50
Control	3	3	0.00	0.00	0.00	0.00	.	.
Ryegrass	3	3	6.15	5.80	0.88	0.51	3.97	8.32
Tilled	3	3	0.00	0.00	0.00	0.00	.	.

Figure F-8. ANOVA and means procedure output for changes in bulk density (SAS, 2014).



Stout Cover Crops Bulk Density

The ANOVA Procedure

Class Level Information		
Class	**Levels**	**Values**
Trt	5	Clover Cocktail Control Ryegrass Tilled

Number of Observations Read	15
Number of Observations Used	15

Stout Cover Crops Bulk Density

The ANOVA Procedure

Dependent Variable: BD

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	0.06770387	0.01692597	2.34	0.1259
Error	10	0.07239348	0.00723935		
Corrected Total	14	0.14009735			

R-Square	Coeff Var	Root MSE	BD Mean
0.483263	86.09397	0.085084	0.098827

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Trt	4	0.06770387	0.01692597	2.34	0.1259

Stout Cover Crops Bulk Density

The ANOVA Procedure

Bonferroni (Dunn) t Tests for BD

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	10
Error Mean Square	0.007239
Critical Value of t	3.58141
Minimum Significant Difference	0.2488

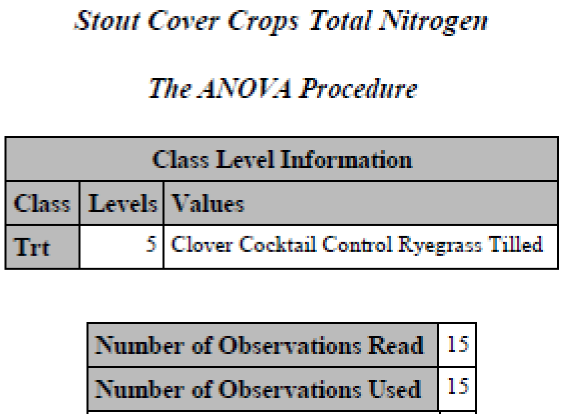
Means with the same letter are not significantly different.			
Bon Grouping	**Mean**	**N**	**Trt**
A	0.20635	3	Tilled
A			
A	0.12443	3	Clover
A			
A	0.09066	3	Control
A			
A	0.07154	3	Cocktail
A			
A	0.00115	3	Ryegrass

Stout Cover Crops Bulk Density

The MEANS Procedure

Analysis Variable : BD								
Trt	**N Obs**	**N**	**Mean**	**Median**	**Std Dev**	**Std Error**	**Lower 95% CL for Mean**	**Upper 95% CL for Mean**
Clover	3	3	0.12	0.14	0.07	0.04	-0.05	0.30
Cocktail	3	3	0.07	0.13	0.11	0.07	-0.21	0.36
Control	3	3	0.09	0.10	0.04	0.02	-0.01	0.19
Ryegrass	3	3	0.00	0.01	0.04	0.02	-0.11	0.11
Tilled	3	3	0.21	0.20	0.12	0.07	-0.09	0.51

Figure F-9. ANOVA and means procedure output for changes in soil total nitrogen production (SAS, 2014).

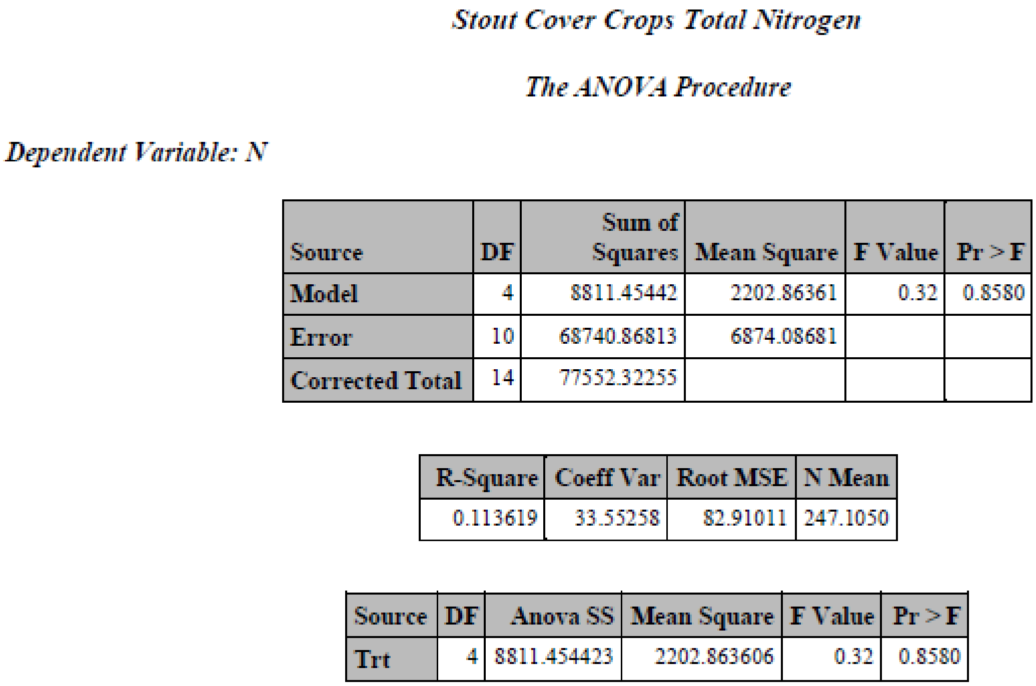


Stout Cover Crops Total Nitrogen

The ANOVA Procedure

Class Level Information		
Class	**Levels**	**Values**
Trt	5	Clover Cocktail Control Ryegrass Tilled

Number of Observations Read	15
Number of Observations Used	15



Stout Cover Crops Total Nitrogen

The ANOVA Procedure

Dependent Variable: N

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	8811.45442	2202.86361	0.32	0.8580
Error	10	68740.86813	6874.08681		
Corrected Total	14	77552.32255			

R-Square	Coeff Var	Root MSE	N Mean
0.113619	33.55258	82.91011	247.1050

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Trt	4	8811.454423	2202.863606	0.32	0.8580

Stout Cover Crops Total Nitrogen

The ANOVA Procedure

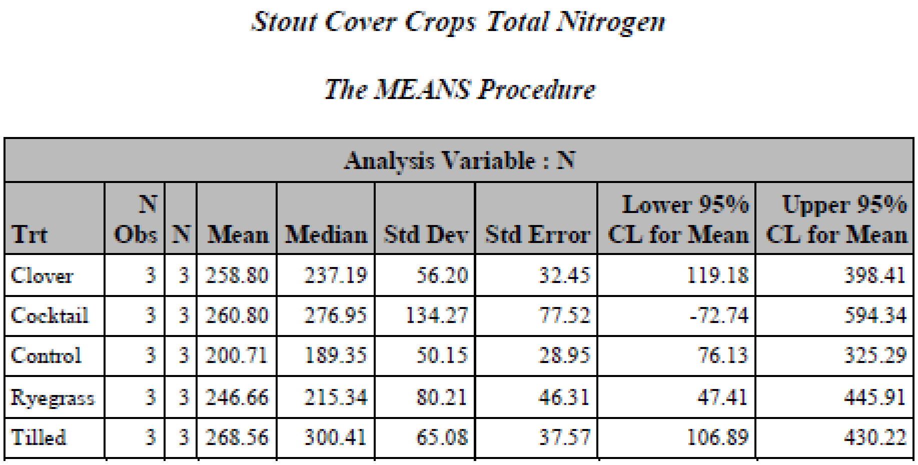
Bonferroni (Dunn) t Tests for N

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	10
Error Mean Square	6874.087
Critical Value of t	3.58141
Minimum Significant Difference	242.45

Means with the same letter are not significantly different.

Bon Grouping	Mean	N	Trt
A	268.56	3	Tilled
A			
A	260.80	3	Cocktail
A			
A	258.80	3	Clover
A			
A	246.66	3	Ryegrass
A			
A	200.71	3	Control



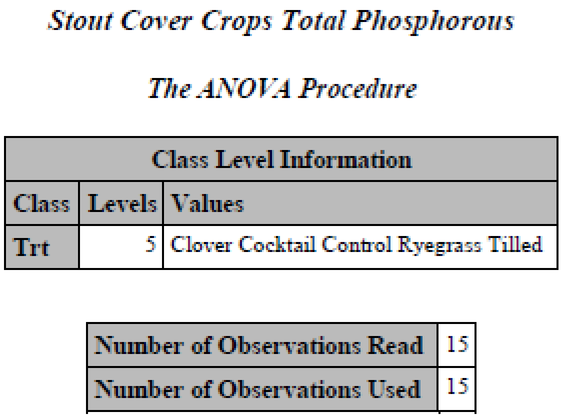
Stout Cover Crops Total Nitrogen

The MEANS Procedure

Analysis Variable : N

Trt	N Obs	N	Mean	Median	Std Dev	Std Error	Lower 95% CL for Mean	Upper 95% CL for Mean
Clover	3	3	258.80	237.19	56.20	32.45	119.18	398.41
Cocktail	3	3	260.80	276.95	134.27	77.52	-72.74	594.34
Control	3	3	200.71	189.35	50.15	28.95	76.13	325.29
Ryegrass	3	3	246.66	215.34	80.21	46.31	47.41	445.91
Tilled	3	3	268.56	300.41	65.08	37.57	106.89	430.22

Figure F-10. ANOVA and means procedure output for changes in soil total phosphorous production (SAS, 2014).

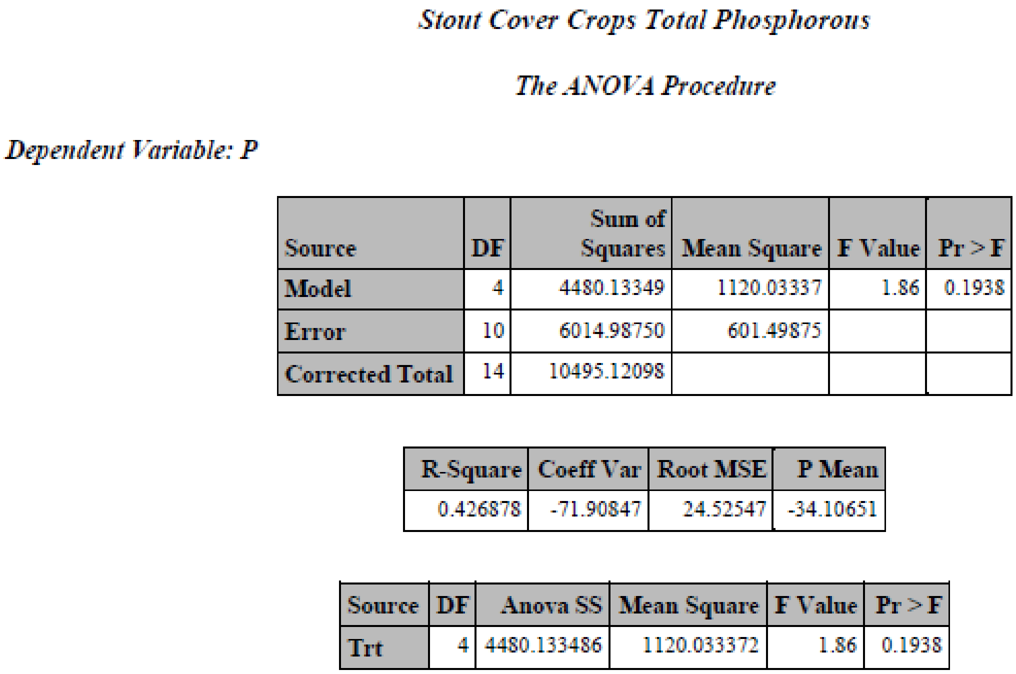


Stout Cover Crops Total Phosphorous

The ANOVA Procedure

Class Level Information		
Class	**Levels**	**Values**
Trt	5	Clover Cocktail Control Ryegrass Tilled

Number of Observations Read	15
Number of Observations Used	15



Stout Cover Crops Total Phosphorous

The ANOVA Procedure

Dependent Variable: P

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	4480.13349	1120.03337	1.86	0.1938
Error	10	6014.98750	601.49875		
Corrected Total	14	10495.12098			

R-Square	Coeff Var	Root MSE	P Mean
0.426878	-71.90847	24.52547	-34.10651

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Trt	4	4480.133486	1120.033372	1.86	0.1938

Stout Cover Crops Total Phosphorous

The ANOVA Procedure

Bonferroni (Dunn) t Tests for P

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	10
Error Mean Square	601.4987
Critical Value of t	3.58141
Minimum Significant Difference	71.718

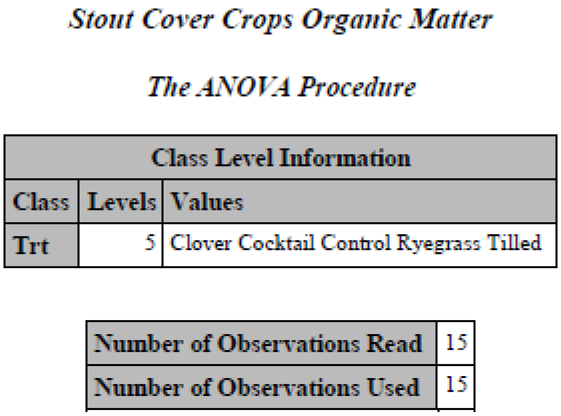
Means with the same letter are not significantly different.			
Bon Grouping	**Mean**	**N**	**Trt**
A	-13.73	3	Clover
A			
A	-16.55	3	Tilled
A			
A	-34.70	3	Control
A			
A	-46.75	3	Ryegrass
A			
A	-58.81	3	Cocktail

Stout Cover Crops Total Phosphorous

The MEANS Procedure

Analysis Variable : P								
Trt	**N Obs**	**N**	**Mean**	**Median**	**Std Dev**	**Std Error**	**Lower 95% CL for Mean**	**Upper 95% CL for Mean**
Clover	3	3	-13.73	-12.80	34.51	19.93	-99.46	72.00
Cocktail	3	3	-58.81	-67.26	24.13	13.93	-118.74	1.13
Control	3	3	-34.70	-29.46	27.96	16.14	-104.15	34.76
Ryegrass	3	3	-46.75	-43.95	10.21	5.89	-72.10	-21.39
Tilled	3	3	-16.55	-21.12	18.67	10.78	-62.93	29.82

Figure F-11. ANOVA and means procedure output for changes in soil organic matter (SAS, 2014).

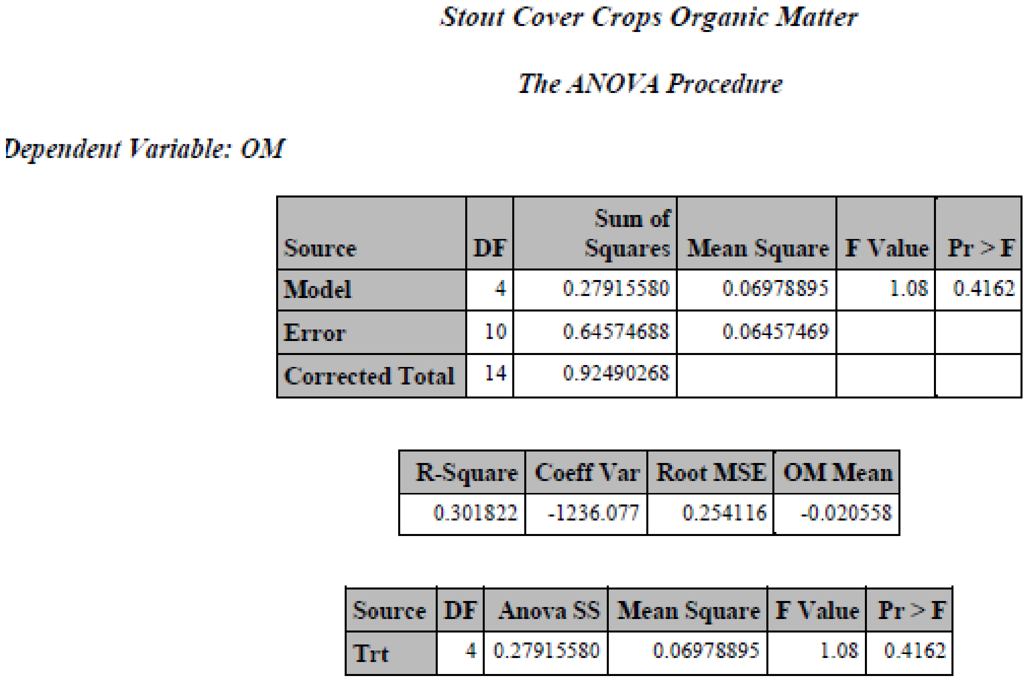


Stout Cover Crops Organic Matter

The ANOVA Procedure

Class Level Information		
Class	Levels	Values
Trt	5	Clover Cocktail Control Ryegrass Tilled

Number of Observations Read	15
Number of Observations Used	15



Stout Cover Crops Organic Matter

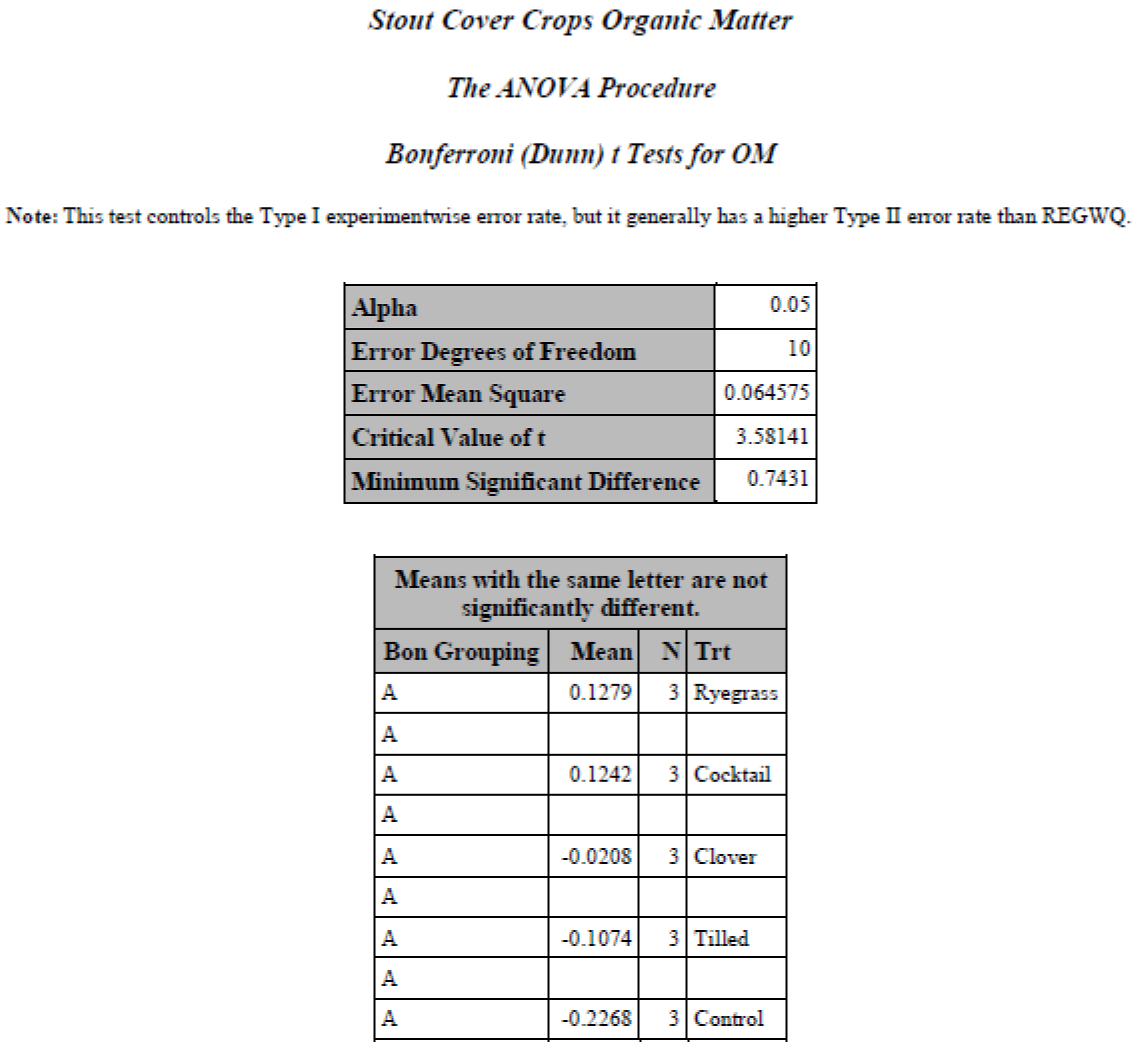
The ANOVA Procedure

Dependent Variable: OM

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	0.27915580	0.06978895	1.08	0.4162
Error	10	0.64574688	0.06457469		
Corrected Total	14	0.92490268			

R-Square	Coeff Var	Root MSE	OM Mean
0.301822	-1236.077	0.254116	-0.020558

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Trt	4	0.27915580	0.06978895	1.08	0.4162



Stout Cover Crops Organic Matter

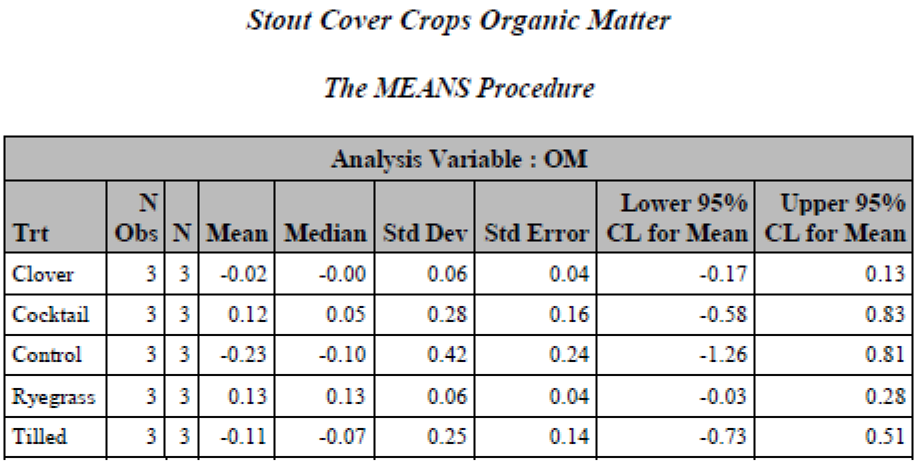
The ANOVA Procedure

Bonferroni (Dunn) t Tests for OM

Note: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	10
Error Mean Square	0.064575
Critical Value of t	3.58141
Minimum Significant Difference	0.7431

Means with the same letter are not significantly different.			
Bon Grouping	**Mean**	**N**	**Trt**
A	0.1279	3	Ryegrass
A			
A	0.1242	3	Cocktail
A			
A	-0.0208	3	Clover
A			
A	-0.1074	3	Tilled
A			
A	-0.2268	3	Control



Stout Cover Crops Organic Matter

The MEANS Procedure

Analysis Variable : OM								
Trt	**N Obs**	**N**	**Mean**	**Median**	**Std Dev**	**Std Error**	**Lower 95% CL for Mean**	**Upper 95% CL for Mean**
Clover	3	3	-0.02	-0.00	0.06	0.04	-0.17	0.13
Cocktail	3	3	0.12	0.05	0.28	0.16	-0.58	0.83
Control	3	3	-0.23	-0.10	0.42	0.24	-1.26	0.81
Ryegrass	3	3	0.13	0.13	0.06	0.04	-0.03	0.28
Tilled	3	3	-0.11	-0.07	0.25	0.14	-0.73	0.51