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COVER CROP NUTRIENT CYCLING ON WESTERN SOUTH DAKOTA CROPLANDS

BY

JUSTIN BROWN

A thesis submitted in partial fulfillment of the requirements for the

Master of Science

Major in Plant Science

South Dakota State University

2020

THESIS ACCEPTANCE PAGE

Justin Brown

This thesis is approved as a creditable and independent investigation by a candidate for the master's degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Christopher Graham
Advisor Date

David Wright
Department Head Date

Dean, Graduate School Date

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UNIT CONVERSIONS

1 Acre (A) = 0.405 Hectares

1 Pound (lb) = 0.454 Kilogram

1 US Ton = 0.907 Metric ton

1 Bushel (bu) of grain sorghum = 22.680 Kilogram of grain sorghum

1 Pound/Acre = 1.120 Kilogram/Hectare

1 Bushel/Acre of grain sorghum = 62.775 Kilogram/Hectare of grain sorghum

1 Inch (in) = 2.54 Centimeter

1 Foot (ft) = 0.305 Meter

Degrees Fahrenheit (°F) to Celcius (°C) = (°F − 32) × 5/9 = °C

ABSTRACT

COVER CROP NUTRIENT CYCLING ON WESTERN SOUTH DAKOTA CROPLANDS

JUSTIN BROWN

2020

Cover crops (CC) are widely gaining attention and implementation by producers. Much of this is due to the positive influence that CCs can have. Increases in crop yield, biological diversity, water infiltration, and nutrient cycling have been observed as well as reductions in wind and water erosion. The semiarid climate of western South Dakota presents a challenge in the use of CCs with the limited rainfall received. Little research has been done in this area on the effects of CCs on cropland. Three studies were performed to evaluate CCs on nutrient cycling, forage production and crop yield. First, is an examination on the replacement of summer fallow with cover crops. Minimal differences were observed, though greater phosphorus cycling and availability occurred through use of cover crops. The second study involved the use of a winter cover crop planted after wheat harvest. Three CC mixes were planted along with an unplanted control. A grass, broadleaf, and 50/50 mix were used, where each mix contained the same eight CC species, however, varying in percentage of CC composition. Levels of zinc (Zn) were found to be affected by the use of CCs, where greater amounts of Zn were seen after CC growth, particularly in the broadleaf CCs. The third experiment immediately followed the second, where grain sorghum was planted in the spring following the winter CCs. After emergence of the grain sorghum, six nitrogen (N) rates were applied at 0, 40, 80, 120, 160, and 200 lbs N/A. Yield of the grain sorghum was then evaluated on CC effect, N response curve, and economic optimums. Grain sorghum yield consistently trended greater following the broadleaf CC, until very large N rates were applied, where the grass CC then had a trend of resulting in slightly greater grain sorghum yield. Broadleaf CC then again trended with the lowest optimum N rate for the greatest sorghum yield, but also the greatest revenue with the least applied N, when evaluating N response and economic optimum curves. Benefits of CC use can be seen in western SD in nutrient cycling, forage production and crop yield, though more research is still needed.

Chapter 1. Literature Review

1.1. History

A cover crop can be defined as a plant or mix of plants that are planted to slow erosion, improve soil health, enhance water availability, smother weeds, help control pests and diseases, increase biodiversity, and/or bring a host of other benefits to the farm (Clark, 2007). The term "cover crop" is a general term that encompasses a variety of applications and uses. Whereas the cash crop can be considered a crop that is grown solely (or mainly) for revenue purposes, cover crops can be considered a crop that is grown for uses other than revenue.

Green manures, and catch crops are terms that are often used interchangeably; however, these terms generally refer to specific soil function. Green manures are plants grown to provide organic matter and nutrients, mostly Nitrogen (N), for the next crop. Catch crops, on the other hand, are used to retrieve available soil nutrients with the intention of preventing leaching and erosion. Leaching is the removal of materials in solution from the soil by percolating waters, whereas, erosion is the wearing away of the land surface by running water, wind, ice or other geological agents (Weil and Brady, 2016). Green manures and catch crops utilize the same mechanisms, but still have different purposes. Residual soil nutrients are taken up and held in the cover crop during growth. When the plant dies, decomposition, the chemical and physical breakdown of a compound, will begin soon after. At the point of decomposition, nutrients are released from the plant and moved back into the soil. For the purposes of this manuscript, all of these functions will be assumed under the term, 'cover crop.'

Cover crops are not a new idea to the agriculture industry. Implementation of cover crops began in ancient cultures with the use of green manure crops. Use of cover crops is recorded as early as 70-19 BC in *Georgics*, written by Virgil. Lupins, clovers, and alfalfa were recorded to have been used to increase wheat yields. From then on, cover crops have gained additional purposes, diversify, and cycle in popularity. This idea could again be seen in North America where Native Americans employed the system called three sisters cropping (Groff, 2015). The three sisters crops were a combination of squash, edible beans and corn. Each of these crops provided a benefit to the others. Squash would provide ground cover to suppress weeds, corn provided a way for peas to climb, and the peas could provide N. Many other examples exist where historically various plants were used during, or out of the main crop time period.

1.2. What Are Cover Crops

Today, cover crops have expansive uses, techniques, potential benefits, potential drawbacks and management aspects in agriculture. Cover crops are often utilized in three general time frames; during the regular cash crop (intercropping), before or after regular cash crop is planted/growing, and as a “replacement” for a regular cash crop (full season). Each time frame may depend on several factors including which cash crop is planted, weather conditions, goal of the cover crop and other factors. When considering what plant species to use, most options are grouped into three main classes; grasses, legumes, and non-leguminous broadleaves. Grasses are typically attributed with nutrient scavenging and reducing erosion. Legumes are most known for their ability to fix atmospheric Nitrogen. Non-leguminous broadleaves have the reputation to alleviate soil compaction, promote beneficial insects, and possibly suppress soil pests.

1.3. Potential Benefits

Cover crops have shown many benefits to the soil, atmosphere, cash crop performance and production economics. Many of these benefits arise from the replacement of a typical fallow (land left unsown) period with the implementation of cover crops. Fallow periods are a result of modern agricultural practices with production of annual crops, with some prolonged fallow periods in semi-arid to arid climates used to conserve soil moisture. Land can be left fallow from as soon as late summer to early the following spring, or for an entire crop production season. Natural ecosystems have no fallow period, until the ground is frozen. Kaspar and Singer (2011) noted that "modern agricultural systems typically only have plants growing for four to six months out of the year and a result of these fallow periods and fallow spaces in annual cropping systems is that soil is left unprotected from erosive forces, nutrients and organic matter are lost or not replenished, runoff increases, soil fauna are stressed, and soil productivity diminishes."

Many losses (nutrient, physical, chemical, etc.) can occur in agricultural fields. Few are as apparent and visually observed as erosion. Erosion by water is caused by three main mechanisms: detachment, transportation, and deposition (Weil and Brady, 2016). Each of these mechanisms play into three recognized water erosion types: sheet, rill and gully (Weil and Brady, 2016). Sheet erosion occurs when splashed soil is removed more or less uniformly (for example a rock will cause a column of soil to be formed underneath). As erosion becomes more severe, tiny channels (termed rills) begin to form by larger volumes of water carrying soil particles "downstream". As rills cut deeper and wider, gullies then form due to even larger volumes of runoff. In general, the plant canopy (uppermost leaves, stems forming a more or less continuous layer of foliage) slows the impact of rain on soil, and stems slow the rate water flows down the field which can reduce erosion. For example, in Iowa Kaspar et al. (2001) showed through a 3-year simulation that when a winter rye cover crop was seeded late in the summer into no-till soybean, inter-rill and rill erosion were reduced by 54% and 90% respectively the following spring – also, oat cover crops reduced inter-rill and rill erosion by 26% and 65% respectively. Wind erosion also remains a major environmental concern in semiarid soils (Blanco-Canqui et al, 2015), though cover crops can be used to reduce such erosion (Unger and Vigil, 1998).

Another soil quality that aids in reducing erosion by water is soil infiltration rate. Through a meta-analysis of cover crop use in the pampas region Alvarez et al. (2017) found that infiltration was increased in 82% of the studies averaging a 36% increase of water infiltration.

In a similar aspect, cover crops providing an extended period of living roots in the soil have been proven to reduce leaching. Cover crops can be used as a way to "soak up" excess nitrogen that is present in the soil from not being utilized by the previous cash crop. Crops may not utilize nitrogen due to unfavorable growing conditions (too much/little of light, heat, water, etc.), mechanisms of nutrient loss, and/or over-application by a producer. "Nitrate leaching is also a major source of concern because of its direct impact on drinking water, its potential of eutrophication of costal sea water and its indirect contribution to the pollution of the atmosphere with ammonia or nitrogen oxides" (Bouwman et al., 2013). Tonitto et al. (2005) found through a cover crop meta-analysis that nitrate leaching on average was reduced by 40% in legume cover crops and

70% on average by non-legume cover crops as compared to the conventional fertilizer systems.

However, grain legume cover crops are a concern for the fact that they supply extra nitrogen through fixation, but also decompose rapidly. When this is coupled with a fallow period, the risk of nitrate leaching is increased. Plaza-Bonilla et al. (2015) evaluated this and found that through several crop sequences N leaching over the 6-year period increased when the number of grain legumes in the rotation was increased when no cover crops were used, however, the use of cover crops reduced N leaching. Hence, where legume cover crops are used as a full-season cover crop similar leaching may occur if the crop is not followed with a subsequent cover crop.

Moreover, cover crops contribute to the soil biological community as well. Biological activity is paramount in maintaining soil function and plant productivity. Cover crops have been shown to increase microbe activity and populations. For example, Bolton et al. (1985) reported that an Austrian winter pea green manure crop had a larger soil fauna and significantly higher levels of urease, phosphatase, and dehydrogenase activities compared with the same rotation without cover crops (utilizing commercial fertilization). In Pennsylvania, cover cropping (single species and mixed species) after spring oats increased total microbial biomass (Finney et al., 2017). The authors also observed a shift in microbial community composition from cover crops.

Due to the role that microbes play in nutrient cycling, with a change in biological activity through cover crops one would also expect to see a change in nitrogen cycling and availability. The amount of plant-available N in the soil becomes largely a balance of decomposition, mineralization, and immobilization, where several forms of loss are also occurring in lesser amounts, typically (Weil and Brady, 2016). Plant residues are decomposed by microbes from large organic molecules into smaller and smaller molecules, until they are simple amino (nitrogen containing) acids. The process of mineralization begins here when amine groups are then hydrolyzed to ammonium (NH_4^+) where the option is to now be fixed to clay colloids, immobilized to soil organic matter, taken up by the plant, or oxidized to nitrate (NO_3^-). Nitrate is then subject to plant uptake, leaching and denitrification.

Immobilization is essentially the reverse of mineralization where inorganic forms of nitrogen (NO_3^- and NH_4^+) are converted to organic forms. Even though both mineralization and immobilization continually occur at the same time, the soil nitrogen supply is net increased or decreased and this largely depends on the Carbon (C) to N ratio (C:N) of the residues being decomposed (Weil and Brady, 2016). The rate of decomposition is also largely dependent on the C:N ratio of the residues (Kaspar and Singer, 2011). A potential problem arises when the release of nutrients from the cover crop does not synchronize with uptake by a subsequent cash crop.

A meta-analysis of crop rotation effects showed that when rotations included a cover crop, total C increased by 8.5% and total N 12.8% (Mcdaniel et al., 2014). The amount of C and N added or removed from the soil is largely affected by the C:N ratio of the cover crop residues. It is known that grass and cereal cover crop residues have relatively high C:N ratios and therefore decompose slowly. Legume and many broadleaf residues, on the other hand, have lower C:N ratios, decompose more quickly, and release or mineralize more N in a shorter period of time. Ruffo and Bollero (2003) displayed this in a decomposition study by comparing rye and hairy vetch planted as a cover crop after soybean harvest and terminated before corn planting. At the end of the corn growing season, hairy vetch was completely decomposed, but the rye was not, suggesting that hairy vetch could be a N source for corn, where rye could not. Indeed, rye may actually tie-up N that would otherwise be used by the corn crop.

Nitrogen can also be added when cover crops include legumes. For example, A study in eastern Kansas found that, after four cycles of a winter wheat and grain sorghum rotation, soil total N increased by 258 kg ha^{-1} under late-maturing soybean and by 279 kg ha^{-1} under sunn hemp compared with non cover crop plots when both legume cover crops were planted after winter wheat harvest (Blanco-Canqui et al., 2011). It should be noted that, factors such as climate, soils, planting date, and termination date can lead to varying results in legume cover crop growth and N fixation (Kaspar and Singer, 2011).

Soil accumulation of N is not the only indicator of N input from cover crops. Ball Coelho et al. (2005) concluded that over the course of their experiment soil N did not increase, however, grain yields and N uptake increased from a rye cover crop. This result implies that even though the reserve of N in the soil did not increase, the output of N did, therefore, N is being added to the system, or less N loss is occurring. Nitrogen additions will also be heavily influenced by cover crop species. In general, nonlegume cover crops take up more soil N than legume cover crops. Ranells and Wagger (1997) observed that a rye cover crop recovered 39% of labeled N^{15} than the crimson clover cover crop which only recovered 4%. Shipley et al. (1992) also used labeled 15N, applied in the fall, and found that that cereal rye and annual rye-grass took up 45 and 27%, respectively, whereas hairy vetch and crimson clover only recovered 8%.

While benefits to the ecosystem are important, crop yield should not be forgotten. An increase in crop yields or no reduction in crop yields has been observed through several studies. Marcillo and Miguez (2017) observed that corn yield after a winter cover crop was not significantly different than no cover crop through a meta-analysis. Another meta-analysis performed by Tonitto et al. (2005) found that yields (corn, grain sorghum, broccoli, sweet corn, potato and tomato) under winter nonlegume cover crop management were not significantly different from those in the conventional, bare fallow systems. No effect on subsequent cash crop can suggest gaining previously listed benefits without harming future cash crop yields. Increases in crop yields after cover crops have also been seen. Marcillo and Miguez (2017) meta-analysis found that corn yields following grass winter cover crops displayed neutral effects (no increase or decrease), whereas, legume winter cover crops produced higher corn yields as compared to no cover crop. Another meta-analysis of the pampas performed by Alvarez et al. (2017) found similar results in corn, whereas, soybean was hardly affected by cover crop. As confirmed by Marcillo and Miguez (2017) N fertilization and cover crop species influence the impact of cover crops on subsequent cash crop yields.

1.4. Mixed Outcomes on The Effect of Cover Crops

While many benefits from cover crop systems have been discovered, limitations or drawbacks have also been observed. For example a meta-analysis of replacing fallow with cover crops showed following legume green manure crops, yields were 10% lower as compared to conventionally fertilized crops, though, when the legume green manure crops produced a biomass of 110 kg N ha^{-1} yields were not significantly different between the two systems (Tonitto et al., 2005). Mixed results have also occurred in close proximity. In Garden City, KS (mean annual precipitation of 489 mm) Holman et al. (2012) found that winter and spring cover crops in a no-till winter wheat–fallow system did not reduce the wheat yield, but a winter triticale cover crop did reduce yields compared with the fallow plots. Similarly, fall planted legumes in semiarid regions of Canada had mixed effects, where winter pea reduced winter wheat yield by 23 to 37%, however, alfalfa added 18 to 20 kg ha^{-1} of soil N and increased the following canola crop yield (Blackshaw et al., 2010). Geographic/climate regions will have a significant effect on the results outcome to cash crop yield by cover crops (Marcillo and Miguez, 2017). Similarly, it was suggested by Blanco-Canqui et al. (2015) that the main factors effecting subsequent cash crop yield from cover crops is precipitation and evapotranspiration.

Through a meta-analysis of winter cover crop (WCC) impact on corn yields, Marcillo and Miguez (2017) made several observations: 1) yield response to WCC in the Great Plains, Canada, and North Central U.S. was not significant, 2) Southeast and Northeast U.S. showed positive and significant impacts by WCC on yield and 3) grass WCC neither increased or decreased yield 4) mixture WCC displayed an overall positive effect on yield 5) legume WCC contribute to higher yields when N fertilizer rates are low, or tillage systems shift from conventional till to no-till. With the mix of results on crop yield by use of cover crops Blanco-Canqui et al. (2015) determined that annual precipitation, cover crop species, growing season, tillage system, and number of years of cover crops all have an impact on the following cash crop yields. In semi-arid regions, it is suggested that cover crops can be grown as forage crops for hay or grazing to provide an economic return (Blanco-Canqui et al., 2015).

One potential reason that cash crop yield may be reduced is the moisture consumption of cover crops. Alvarez et al. (2017) found through their meta-analysis that no significant effect of cover crops was detected when available water stored in the upper meter of the soil profile was considered. However, from 1 to 2.5 m depth, the stored available water decrease ranged from 15% to 30% depending on the depth taken into account. This is more problematic in drier regions, such as semi-arid climates where timing of cover crop termination to allow for recharge of soil moisture reserves can be important (Unger and Vigil,1998).

Water is not the only potential factor that can have a negative effect on the following cash crop. Ketterings et al. (2015) found that in northeastern U.S. cereal cover crops returned lower nitrogen fertilizer replacement values (NFRV) than legumes after corn silage. Cereal rye was even found to produce insignificant or negative NFRV values indicating immobilization. Through a review of literature on cover crops effect on soil N, Dabney at al. (2001) also found several examples of literature concluding some immobilization of N. Immobilization or depleting of available soil N will occur at a C to N ratio of 25 to 1, due to the microbial needs of carbon and nitrogen, therefore, a C to N ratio of less than 24 to 1 has the potential to increase soil N (Weil and Brady, 2016). Kaspar et al. (2011) made the observation that "in addition to changing the composition of cover crop residues, terminating a cover crop significantly before planting the cash crop allows more time for decomposition of cover crop residues and mineralization of residue N". Therefore, the composition of the cover crop (C to N ratio) and timely termination of a cover crop can affect whether or not N is mineralized or immobilized.

The cost to seed a cover crop should not be forgotten. Mixes can be formulated to be cheaper or more expensive. Though, purchased seed is not the only cost associated with planting cover crops. Other costs that can accumulate are planting costs, inoculation of legumes, hay/grazing costs, and spray to terminate cover crop. Return on investment of cover crops can be quite variable for a both positive and negative return. Ultimately, the return on investment of a cover crop will last through the duration of the following cash crop, if not longer.

1.5. Cover Crops in Western South Dakota

In western (Missouri River to western border) South Dakota, there lies a great opportunity for cover crops to be utilized. From wheat harvest to first frost is typically about 2 months in western South Dakota (mid-July to mid-September). In these two months, current common practice is to fallow after wheat harvest until the coming spring. It is thought that cover crops in this time period could be used to increase following cash crop yield, recycle nutrients, and provide forage for livestock.

While all soil nutrients are of interest, nitrogen is generally the nutrient of focus. This is due to the high level of nitrogen that is used by crops. In theory, cover crops should take up the excess nitrogen from the previous wheat crop and possibly “release” lightly bound nitrogen from the soil. The following spring, the nitrogen has the potential to be released back into the soil through decomposition, which would partially offset the need for fertilizer-N.

However, the availability of nitrogen turnover from the residue is of concern. When the cover crop ceases, it will begin to release the nitrogen back into the soil.

However, the amount and speed of this nitrogen release is a question to be answered. Another concern is in regards to moisture. Moisture is often the first limiting factor for crop production in the semi-arid climate of western South Dakota. It is uncertain if cover crops will leave more, less, or the same amount of soil moisture leftover for the following cash crop. Moisture and nutrient cycling will therefore be the focus of the study.

Cover crops have been observed to have a wide range of potential benefits and drawbacks. With the variability in results, the overall impact of a cover crop will need to be examined over several years and varying conditions. The lack of research specific to cover crops in western South Dakota provide a large avenue of research. In hopes of beginning to understand the value of cover crops in western South Dakota, research will be performed on their affects on nitrogen cycling and soil moisture.

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Chapter 2. Replacement of Summer Fallow with Cover Crops in Western South Dakota

2.1. Introduction

Many farmers and ranchers are in a continuous search to enhance their operation in a manner that supports better economic returns, production, and labor efficiency among other reasons. A strategy that has continued to increase in popularity is the use of cover crops. These cropping systems involve a single or mix of plant species that are intended to be used outside of regular crop production periods to build soil health. They are also commonly used as a forage source on cropland. While being used as a forage source, they can double to provide a number of soil benefits such as increased organic matter, reduced leaching and erosion, and increase biological activity (Kaspar and Singer, 2011; Blanco-Canqui et al, 2015). The benefits to the soil can encompass many physical, chemical, and biological factors.

Benefit from the use of cover crops is not however a guarantee. Problems such as reduced soil moisture, nutrient immobilization, and lower cash crop yields can occur (Allen et al, 2011; Dabney et al, 2001; Nielsen et al, 2016; Wagger, 1989). Some producers have the desire to utilize cover crops in crop fields to provide forage yet leave the opportunity open to raise a cash crop. This is done often with a full season cover crop that is planted in spring or early summer. Harvest of the cover crop can be through haying or grazing or left as catch crop/green manure crop. In many regions with a semi-arid climate, summer fallow has been been common practice in the Great Plains over the twentieth century (Hansen et al, 2012), primarily, to build soil moisture levels during the fallow period (Greb et al, 1970). Though this practice may reduce risk of failure of the successive crop, it does not come without any risk or problems. Some reported concerns include poor precipitation use efficiency, increased soil erosion, and decreased soil organic C and N (Hansen et al. 2012). Returns to cropping can also be negatively affected by cover crops, though forage crops have been observed to increase returns (Holman et al, 2018). The purpose of this study is to evaluate the effect of summer cover crops in western SD crop rotations as a replacement for summer fallow on forage production and quality, as well as on soil nutrient and physical factors.

2.2. Materials and Methods

2.2.1. Location and Treatment Details

A two-year (2018 - 2019) study was established in western South Dakota at two sites: Pleasant Valley and Caputa in the spring of 2018. The Pleasant Valley site was established at a farm southeast of Sturgis, SD (44°20'34.7"N 103°26'00.0"W). The Caputa site was established at a farm east of Rapid City, SD (43°58'38.2"N 102°57'17.6"W). Each site began in the spring when a cover crop was planted by the producer. Both CC mixes contained: forage sorghum (*Sorghum bicolor*), pearl millet (*Pennisetum glaucum*), german millet (*Setaria italica*), rapeseed (*Brassica napus*), turnip (*Brassica rapa subsp. rapa*), collards (*Brassica oleracea var. viridis*), and cowpea (*Vigna unguiculata*). Caputa additionally contained sorghum-sudangrass (*Sorghum bicolor x S. bicolor var. Sudanes*), hybrid brassica, mustard (*Brassica sp. L.*), sunflower (*Helianthus annuus L.*), buckwheat (*Fagopyrum esculentum*), okra (*Abelmoschus Esculentus*), and sunn hemp (*Crotalaria juncea L.*). Pleasant valley also contained oats (*Avena sativa*), barley (*Hordeum vulgare L.*), radish (*Raphanus sativus*), soybeans (*Glycine max*), berseem clover (*Trifolium alexandrinum L.*), and lentil (*Lens culinaris Medikus*).

2.2.2. Layout

Cover crops at Pleasant Valley and Caputa were drilled using a no-till drill on June 1st and June 29th, respectively. Cereal Rye (*Secale cereal)* was additionally aerial seeded into the existing cover crop at Caputa in mid-September. At each site, three plots, 15 feet by 30 feet wide, were sprayed out using Roundup Powermax (Glyphosate, non-residual herbicide) shortly after emergence of the cover crop and designated as the control plots. The control plots could also be considered a summer fallow, for nothing was planted or allowed to grow until 2019. Each location of the control plot was chosen at random in the field. The rest of the field, particularly close to the control plots, was designated as the cover crop “plots”.

2.2.3. Sample Analysis

Soil and forage samples were taken at the end of the growing season to detect any differences from cover crop use. In the spring of 2019, a grain or another cover crop was planted into the field. Forage/grain and soil samples were again taken in the fall. In 2019, no plots were sprayed out, for the purpose of seeing if cover crop had an effect on the year following its growth and to determine yield/production differences the year following a cover crop versus no cover crop. Soil sampling was completed on both the control plots from the previous season as well as in the treatment areas for comparison of residual effects from the previous season’s cover crop. Dates of sampling are listed below in Table 1. Soil samples were separated into three depths; 0-3”, 3-6”, and 6-12”. Any surface organic residue was removed from the surface and excluded from the soil sample.

2.2.4. Statistical Methods

Statistical Analysis was performed in RStudio. Two-way ANOVA was performed with cover crop and soil depth as the two factors. ANOVA was performed for site and year individually due to the nature of the variability by site and the different treatments analyzed each year. Assumptions of normality and homogeneity were met or data was transformed to meet assumptions. Normality and homogeneity were assessed using the Shapiro-Wilk and Levene`s test, respectively. An alpha of 0.05 was chosen to determine significance for all tests. Mean separations were determined using Tukey multiple comparison.

Table 2.1: Dates and actions taken for Caputa and Pleasant Valley, SD cover crop trials occurring in 2018 and 2019.

Location	Date	Action Taken
Pleasant Valley	6/1/2018	Cover crop planted
Caputa	6/29/2018	Cover crop planted
Caputa	September-2018	Cereal rye aerial broadcasted
Pleasant Valley	9/26/2018	Forage samples
Caputa	10/12/2018	Soil samples
Pleasant Valley	10/18/2018	Soil samples
Pleasant Valley	4/01/2019	Barley planted
Pleasant Valley	8/06/2019	Barley hayed
Pleasant Valley	8/13/2019	Soil samples
Caputa	9/29/2019	Forage samples
Caputa	10/09/2019	Forage samples
Caputa	10/28/2019	Soil samples

2.3. Results

Table 2.3: Average soil values for fall Caputa (CA) and Pleasant Valley (PV) locations separated by year, location, cover crop treatment, and soil depth in regards to nitrogen, phosphorus, potassium, zinc, sulfur, organic matter, ph and electrical conductivity levels. Values for significance are also presented with bold formatting representing 95% significance and underline values representing 90% significance.

Year	Location	Cover Crop	Soil Depth	NO3-N	Olsen P	K	Zn	S	OM	pH	EC
			Inches	**ppm**					**%**		**mmhos/cm**
2018	CA	Cover Crop	0-3"	13.6	10.0	719.3	0.8	24.4	5.6	7.8	0.6
			3-6"	7.0	4.3	341.3	0.4	30.5	3.8	7.9	0.5
			6-12"	3.0	4.3	235.3	0.2	45.7	2.7	8.4	0.4
		Control	0-3"	54.2	21.7	573.0	0.7	31.0	5.2	8.0	0.5
			3-6"	71.0	9.3	317.0	0.5	35.4	4.3	8.0	0.6
			6-12"	35.4	6.3	264.0	0.4	46.9	2.9	8.3	0.6
	PV	Cover Crop	0-3"	17.7	38.0	666.7	2.7	10.4	7.9	6.7	0.2
			3-6"	30.9	14.3	456.3	1.3	14.4	5.1	6.5	0.3
			6-12"	12.6	6.7	426.0	0.6	9.8	3.4	6.8	0.2
		Control	0-3"	26.9	56.7	573.7	2.5	12.9	7.2	6.4	0.3
			3-6"	41.0	26.7	518.0	1.3	15.4	4.7	6.5	0.4
			6-12"	28.6	11.7	475.0	0.6	18.8	3.6	6.8	0.3
2019	CA	Cover Crop	0-3"	8.7	10.7	586.7	1.2	36.8	5.9	7.7	0.8
			3-6"	4.0	4.0	309.7	0.5	71.1	4.1	7.7	1.0
			6-12"	2.0	1.7	246.3	0.3	103.2	2.8	7.9	1.0
		Control	0-3"	9.3	15.3	592.3	1.3	40.5	5.8	7.8	1.0
			3-6"	5.0	6.0	326.3	0.6	72.7	4.2	7.8	1.1
			6-12"	2.7	3.0	271.3	0.3	92.8	2.9	7.9	1.5
	PV	Cover Crop	0-3"	8.3	38.7	508.7	2.4	10.3	7.3	6.6	0.4

			3-6"	6.0	19.3	415.7	1.4	8.9	5.1	6.6	0.3
			6-12"	4.0	21.7	400.7	0.5	8.0	3.5	6.7	0.4
		Control	0-3"	10.7	44.3	470.3	2.3	12.0	7.5	6.8	0.5
			3-6"	8.0	27.3	411.0	1.6	9.5	4.6	6.7	0.4
			6-12"	5.0	10.0	412.3	0.6	8.2	3.1	6.8	0.4
		Factor		p-values as produced by ANOVA							
		Year		**0.000**	0.726	**0.036**	0.228	0.073	0.919	**0.040**	**0.000**
		Location		0.389	**0.000**	**0.002**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
		Treatment		**0.000**	**0.007**	0.706	0.757	0.818	0.518	0.363	**0.006**
		Depth		**0.000**	**0.000**	**0.000**	**0.000**	0.160	**0.000**	**0.001**	0.417
		Year:Location		0.053	0.324	0.189	0.154	**0.023**	0.325	**0.001**	**0.000**
		Year:Treatment		**0.000**	0.055	0.625	0.792	0.778	0.919	0.363	0.563
		Location:Treatment		**0.000**	0.620	0.778	0.503	0.940	0.325	0.555	0.426
		Year:Depth		**0.000**	0.384	0.417	0.695	0.673	0.821	**0.049**	0.097
		Location:Depth		0.145	**0.000**	**0.000**	**0.000**	0.155	**0.007**	0.451	0.133
		Treatment:Depth		0.157	0.062	0.217	0.584	0.984	0.728	0.867	0.529
		Year:Location:Treatment		**0.000**	0.310	0.407	0.572	0.938	0.811	0.262	0.324
		Year:Location:Depth		0.329	0.396	0.984	0.069	0.492	0.849	0.898	0.058
		Year:Treatment:Depth		0.191	0.773	0.497	0.768	0.971	0.446	0.867	0.563
		Location:Treatment:Depth		0.057	0.427	0.961	0.901	0.942	0.602	0.451	0.148
		Year:Location:Treatment:Depth		**0.049**	0.724	0.943	0.777	1.000	0.747	0.579	0.759
		LSD (Year)		3.098	-	47.781	-	-	-	0.103	0.081
		LSD (Location)		-	3.810	47.781	0.147	16.319	0.326	0.103	0.081
		LSD (Treatment)		3.098	3.810	-	-	-	-	-	0.081
		LSD (Depth)		3.794	4.666	58.519	0.180	-	0.399	0.127	-

2.3.1. Macronutrients

2.3.1.1 Nitrate-N (N)

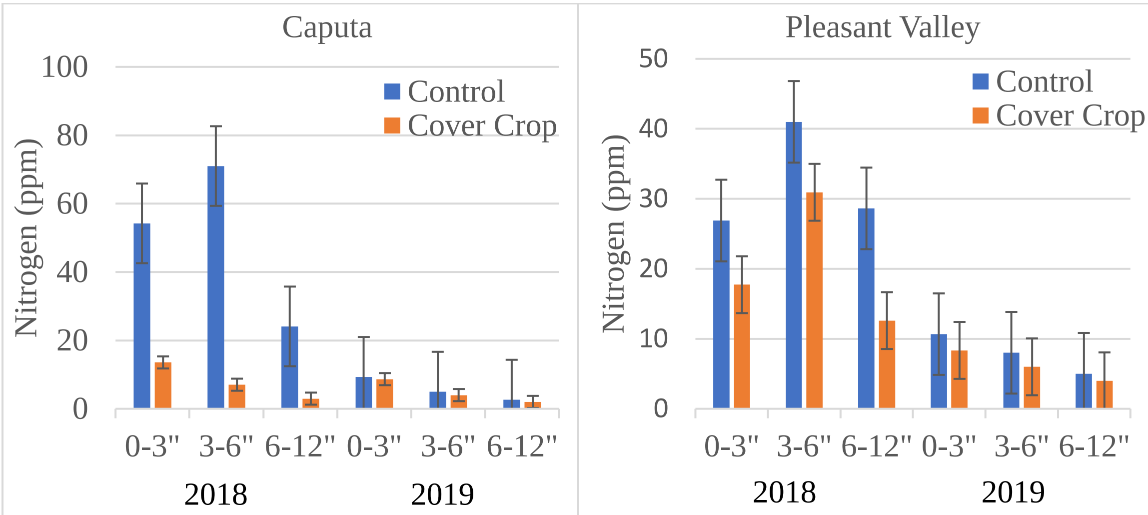

Figure 2.7: Nitrogen concentration in fall soil for both control (fallow) and cover crop treatments across measured soil depths (0-3", 3-6", 6-12") in both 2018 and 2019. Error bars represent standard error.

Of the nutrients measured, N was found to be the most influenced by the use of cover crops. This is not necessarily surprising given that N is consumed in large quantities by plants. In 2018 the Caputa cover crop reduced amount of soil N by 84% as compared to the control plot for 0-12” (Figure 1). A reduction in N was also observed in 2019 at Caputa in the cover crop plots, however, a reduction of 14% was observed as compared to the control plot. Treatment and interaction were found to be significant through the ANOVA test for Caputa in 2018, however, only depth was significant for Caputa in 2019. In the 3-6” and 6-12” soil depths for 2018 Caputa, cover crop plots had less N by 44% and 58% respectively as compared to the control. This did change at the 0-3” depth where an increase in N by 31% was seen from cover crop over the control. In 2019 Caputa soil depths tell a similar story, except that N was less following the cover crop than the control in all depths. N was reduced by 7%, 20%, and 25% for 0-3”, 3-6”, and 6-12” respectively as compared to the control. In 2018 and 2019, Caputa N levels were greatest in the 0-3” soil depth then dropped at relatively similar rates to 3-6” and to 6-12”.

Pleasant Valley N in 2018 and 2019 was significantly different by treatment and depth, with non-significant interaction (Figure 1). In 2018, the cover crop reduced N by 37% and by 23% in 2019 across all depths combined. When evaluating soil depth as a factor, similar results appear as compared to Caputa. In 2018 cover crop produced lower N results as compared to the control by 34%, 25%, 56% for 0-3”, 3-6”, and 6-12” soil depth respectively. In 2019, a similar reduction from the cover crop as compared to the control was observed resulting in a reduction of 22%, 25%, and 20% in the 0-3”, 3-6”, and 6-12” soil depth, respectively. In 2018 Pleasant Valley N was greatest in the 3-6” depth, while the 0-3” and 6-12” soil depths N levels were lower, but similar to each other. In 2019 this changed to where 0-3” soil depth had the greatest levels of N then reduced at a relatively constant rate to 3-6” and further reduced in the 6-12”.

Both sites had much higher levels of N in 2018 versus 2019 (Table 2). Caputa 2018 values ranged from 2.97 to 71.00 ppm N, but 2019 ranged from 2.00 to 9.33 ppm N. Pleasant valley in 2018 had values ranging from 12.60 to 41.00 ppm N, but a range of 4.00 to 10.67 ppm N. All ranges just stated were considering means with both cover crop treatment and soil depth as factors.

2.3.1.2. Phosphorus (P)

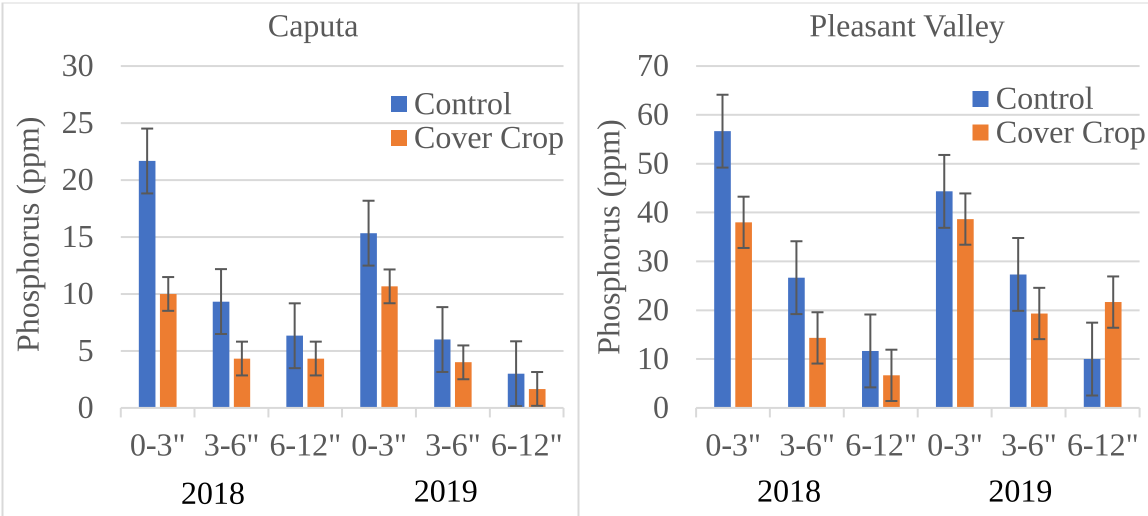

Figure 2.8: Phosphorus concentration in fall soil for both control (fallow) and cover crop treatments across measured soil depths (0-3", 3-6", 6-12") in both 2018 and 2019. Error bars represent standard error.

On average, both sites had higher concentrations of soil P in 2018 than in 2019. Caputa 2018 values ranged from 4.33 to 21.67 ppm P, and 2019 ranged from 1.67 to 15.33 ppm P (Table 2). Pleasant Valley in 2018 ranged in soil P from 6.67 to 56.67, and 2019 ranged from 10.00 to 44.33 ppm P (Table 2).

Caputa and Pleasant Valley in 2018 and 2019 displayed the same pattern of results for P levels. For Caputa the ANOVA test revealed significance for treatment, depth and interaction in 2018, and significance for depth in 2019. At Caputa, P levels dropped with cover crop as compared to control by 50% and 33% in 2018 and 2019, respectively when depths were not separated. Cover crop again produced lower soil P concentrations at Caputa in 2018 by 54%, 54%, and 32% for 0-3”, 3-6”, and 6-12” respectively (Figure 2). Results for 2019 at Caputa displayed a 30%, 33%, and 44% decline in soil P concentration from cover crop as compared to control.

An ANOVA test found significance in treatment and depth for Pleasant Valley in 2018, but significance only in depth in 2019 (Table 2). Over the full soil profile sampled, Pleasant Valley experienced a 38% and 2% decline in soil P concentration from cover crop in 2018 and 2019, respectively. When depth is considered, Pleasant Valley in 2018 experienced declines in soil P concentrations from cover crop at 0-3”, 3-6” and 6-12” soil depth by 33%, 46%, and 43% respectively, as compared to the control (Figure 2). In 2019, however, a decline in soil P concentration was seen from cover crop at 0-3” and 3-6” soil depth by 13% and 29% respectively, as compared to the control. However, an increase of 217% was observed at 6-12” soil depth from cover crop at Pleasant Valley.

2.3.1.3. Potassium (K)

Statistically significant differences were found for depth in both 2018 and 2019 at Caputa but not at Pleasant Valley (Table 2). In 2018, Caputa cover crop resulted in 12% greater soil K concentration, however, in 2019 a decrease of 4% in soil K concentration was seen as compared to control across all soil depths. Increases in soil K concentration occurred from cover crop by 26% and 8% in 0-3” and 3-6” soil depth respectively, but a decrease of 11% was observed in the 6-12” soil depth. In 2019 only decreases were observed from cover crop in soil K concentration by 1%, 5%, and 9% in the 0-3”, 3-6”, and 6-12” soil depths respectively.

At Pleasant Valley, no factors were determined to be significant in either 2018 or 2019. In 2018, the Pleasant Valley cover crop trends in a decrease of 1% and an increase of 2% in K concentration as compared to control when soil depth was not separated. In 2018 trending increases in soil K concentration from cover crop were seen in the 0-3” soil depth by 16%, whereas, a 12% and 10% decrease trends were seen in 3-6” and 6-12” soil depth respectively as compared to control. This changes slightly in 2019 where a trending increase in soil K concentration of 8% and 1% were seen in the 0-3” and 3-6” soil depth respectively, but a trending decrease occurred in the 6-12” soil depth of 3% from cover crop as compared to control.

2.3.2. Micronutrients

2.3.2.1. Sulfur (S)

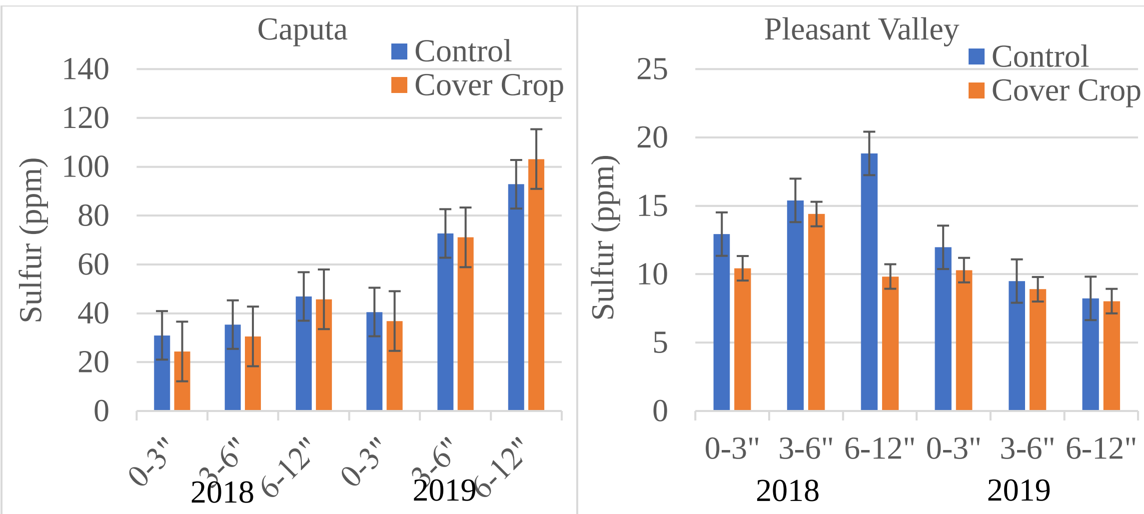

Figure 2.9: Sulfur concentration in fall soil for both control (fallow) and cover crop treatments across measured soil depths (0-3", 3-6", 6-12") in both 2018 and 2019. Error bars represent standard error.

Sulfur was found to have less of a significant change from cover crops than that of N, P, and K. No significance was found in treatment, depth or interaction for S at Caputa in 2018 or 2019 (Table 2). Cover crops in 2018 trended to an 11% decrease in S concentration, where 2019 led to a trending increase of 2% as compared to control. Pleasant Valley trends in decreases from cover crop in both 2018 and 2019 by 27% and 8% respectively, as compared to control. Caputa in 2018 showed trending decreases in soil S at 0-3”, 3-6” and 6-12” by 21%, 14%, and 2% respectively from cover crop as compared to control (Figure 3). This pattern changes in 2019 where trending decreases are seen from cover crops in the 0-3” and 3-6” soil depths by 9% and 2% respectively. However, an 11% trending increase from cover crops is seen in the 6-12” soil depth as compared to control.

Pleasant Valley location did reveal significance for S with treatment in 2018 and depth in 2019. A decrease of soil S from the cover crop occurred in 2018 by 19%, 6%, and 48% in the 0-3”, 3-6”, and 6-12” soil depths respectively, as compared to control (Figure 3). In 2019 cover crops decrease S supply in 0-3”, 3-6” and 6-12” by 14%, 6% and 2% respectively, as compared to the control.

A consistent pattern is evident in which cover crop trends in lower soil S concentrations than that of the control. This happens in all soil depths and averaged across soil depths, except for that of 2019 Caputa in the 6-12” soil depth where a trending increase is seen from cover crops. In 2018 at this location, soil S values ranged from 24.37 to 46.90, where 2019 ranged from 36.83 to 103.17 ppm S. Pleasant valley had a smaller range where in 2018 soil S values ranged from 9.83 to 15.40 and in 2019 ranged from 8.03 to 11.97 ppm S. All ranges just discussed include soil depth and treatment separation.

2.3.2.2. Zinc (Zn)

Zinc as a micronutrient would not be expected to show unique or dynamic changes, though this was not quite the case. For the Caputa location, both 2018 and 2019 led to significant differences in soil depth, but not cover crop treatment (Table 2).

Averaged across all soil depths, soil Zn at Caputa in 2018 and 2019 revealed a decrease from cover crop use by 17% and 7% respectively, as compared to Control. When depths are separated, several differences appear that were not evident in the averages. An increase of 14% occured in the 0-3” soil depth in 2018 from cover crops as compared to control. Moving deeper into the soil, the 3-6” and 6-12” produce a decrease of 32% and 52% respectively, from cover crop use. In 2019, an opposite trend appears where a decrease from cover crops occur by 10% in both the 0-3” and 3-6”, but an increase of 9% occurs in the 6-12”.

The Pleasant Valley location also showed significant differences in soil depth rather than cover crop treatment in both 2018 and 2019 (Table 2). Results in Zn concentration from cover crop use averaged across tested soil depths varied for Pleasant Valley depending on year as well. In 2018 cover crops trended increasing Zn soil concentration by 6%, however, a trending decrease of 2% in the cover crop occurred as compared to control in 2019. Interesting results again appear when soil depths are separated. In 2018, Pleasant Valley trended with an increase in soil Zn from cover crop by 9% and 5% in the 0-3% and 3-6” soil depths respectively, as compared to control. This changes in the 6-12” soil depth, where a trending decrease of 4% from cover crop occurs. Similar to the Caputa location, this flips in 2019 for the Pleasant Valley location. A trending increase was still seen in the 0-3” soil depth by 6% as compared to control from cover crop. However, a trending decrease by 11% was observed in both the 3-6” and 6-12” soil depth from cover crop.

When soil depths were averaged, a trend appeared that Zn soil level concentrations decreased with cover crop use. When soil depths were separated, results become more scattered even within location. In 2018 Caputa soil Zn levels ranged from 0.20 to 0.83, where 2019 ranged from 0.32 to 1.28 ppm Zn. Pleasant Valley ranged in soil Zn levels in 2018 from 0.57 to 2.69 and in 2019 ranged from 0.54 to 2.38 ppm Zn.

2.3.2.3 Soluble Salts (EC)

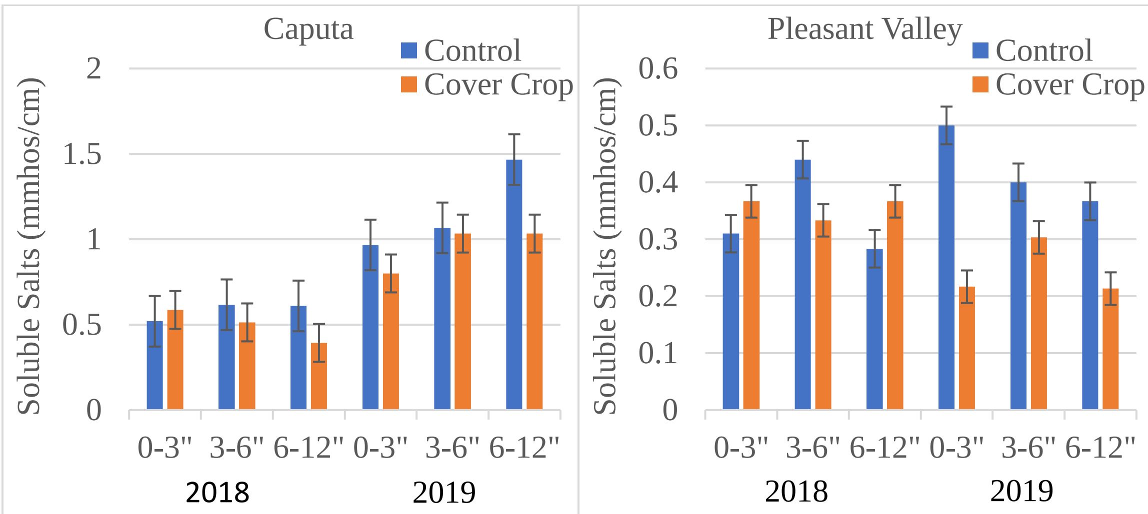

Figure 2.10: Soluble Salts concentration in fall soil for both control (fallow) and cover crop treatments across measured soil depths (0-3", 3-6", 6-12") in both 2018 and 2019. Error bars represent standard error.

Soluble Salt levels were not significantly affected at Caputa in 2018 or 2019 (Table 2). A trending decrease in soluble salt levels from cover crop use was seen in both 2018 and 2019 by 15% and 18% respectively when depth was not considered. A slight deviation occurs when soil depth is considered. Cover crop use trended toward an increase in soluble salt levels by 13% in 2018 at the 0-3" depth (Figure 4). However, a trending decrease from cover crop occurs by 17% and 36% in the 3-6" and 6-12" soil depths respectively in 2018. A trend of decreasing levels from cover crop use in soluble salt levels were again seen in 2019 in the 0-3", 3-6" and 6-12" soil depths by 17%, 3%, and 30% respectively as compared to control.

The Pleasant Valley location in 2018 revealed significance in cover crop treatment and soil depth, however, no significance in either factors were found to be significant in 2019 according to an ANOVA test (Table 2). Without considering depth, a decrease from cover crop use was seen in 2018 by 29% and a trending decrease of 16% in 2019 in soil soluble salt levels. When soil depth is considered, a trending decrease still occurs at most soil depths in both 2018 and 2019 in soluble salt levels. In 2018, a decrease of 30%, 31%, and 25% were seen in the 0-3”, 3-6” and 6-12” soil depths respectively (Figure 4). Results change slightly in 2019 where a trending decrease from cover crop use was seen in soluble salt levels by 27% and 17% in the 0-3” and 3-6” soil depths respectively. No percent change was seen from cover crops, though in the 6-12” soil depth in 2019.

Control levels in 2018 at Caputa trended with an increase as soil depth increases where cover crops lead to a trending decrease as soil depth depths increase in soluble salt levels. A range in values of 0.39 to 0.62 mmho/cm was seen. In 2019, both control and cover crop treatments trend with an increase in soluble salt levels as soil depth increases. Values double in 2019 where a range of 0.8 to 1.47 mmho/cm is observed. Values in 2018 at Pleasant Valley were greater at 3-6” soil depth, but lower in the 0-3” and 6-12”. Control soluble salt values decrease as soil depth increases in 2019, where cover crop values were greater in the 0-3” and 6-12” as compared to the 3-6”. A range of 0.21 to 0.44 mmho/cm was seen in 2018 and a range of 0.33 to 0.50 mmho/cm in 2019 at Pleasant Valley.

2.3.3. Soil Properties

2.3.3.1. Organic Matter (OM)

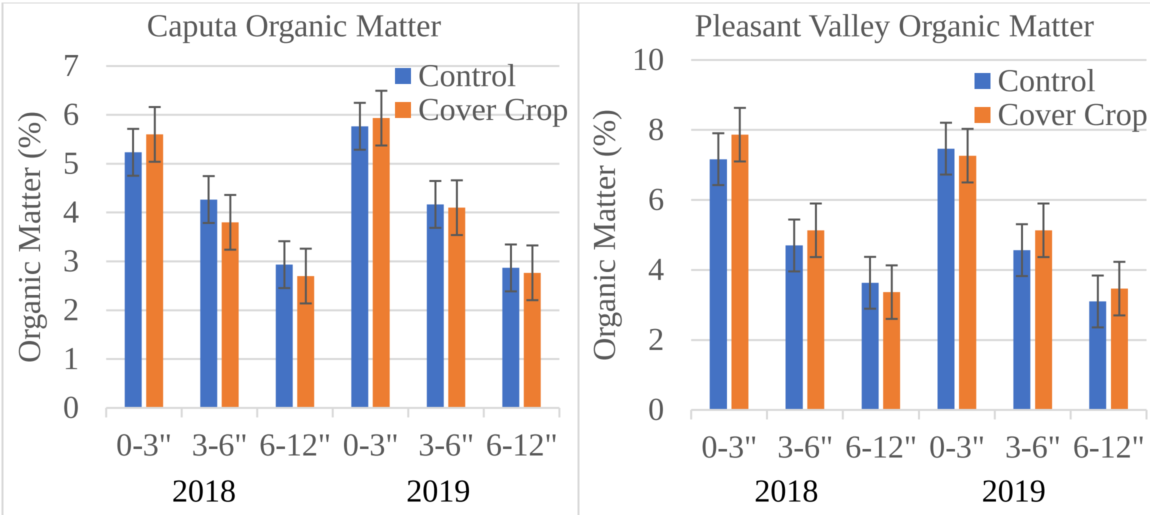

Figure 2.11: Organic matter concentration in fall soil for both control (fallow) and cover crop treatments across measured soil depths (0-3", 3-6", 6-12") in both 2018 and 2019. Error bars represent standard error.

OM would not be expected to change drastically due to the nature in how it is built. Significance for OM was found for the soil depth factor in both 2018 and 2019 at Caputa (Table 2). When soil depth is not considered, a trending decrease from 4.1 to 4.0 % OM with cover crops in OM was found in 2018 at Caputa, where no difference was found in 2019. When soil depth is considered, a trending increase was found in the 0-3” depth from 5.2% to 5.6% OM when cover crops were included in 2018 at Caputa (Figure 5). As for the 3-6” and 6-12” soil depths, a decreasing trend from 4.3% to 3.8% OM and from 2.9% to 2.7% OM, respectively was seen in OM values by cover crops. Caputa in 2019 also saw a trending increase in the 0-3” soil depth from 5.8% to 5.9% OM from cover crop use. The 3-6” and 6-12” soil depths trended with a decreased from 4.2% to 2.8% OM and from 2.9% to 2.8% OM, respectively through cover crops.

Significance for the soil depth factor was detected for both 2018 and 2019 at Pleasant Valley (Table 2). Opposite to that of Caputa, an increase in soil OM values was found in both 2018 and 2019 from 5.2 to 5.5% OM and 5.0 to 5.3% OM, respectively at Pleasant Valley when soil depth was not considered. Increasing trends appeared in both the 0-3" and 3-6" from 7.2 to 7.9% OM and from 4.7 to 5.1% OM respectively, occurred through cover crops in 2018 at Pleasant Valley (Figure 5). A decreasing trend, however, occurred from 3.6 to 3.4% OM with cover crops at the 6-12" soil depth. This switches in 2019 where a trending decrease was seen in the 0-3" from 7.5 to 7.3% OM from cover crops. Trending increases occurred through cover crop use at both the 3-6" and 6-12" soil depth from 4.6 to 5.1 %OM and from 3.1 to 3.5% OM, respectively, as compared to control.

A consistent trend occurs at both Caputa and Pleasant Valley in 2018 and 2019 in OM values. From the 0-3" to the 6-12" soil depths, OM values continue to decrease in trend. OM at Caputa in 2018 ranges from 2.70 to 5.60 % OM and from 2.77 to 5.93 in % OM respectively when means are separated by depths. Pleasant valley in 2018 ranged from 3.37 to 7.87 % OM and from 3.10 to 7.47 % OM respectively when means are separated by depths.

2.3.3.2. Soil pH

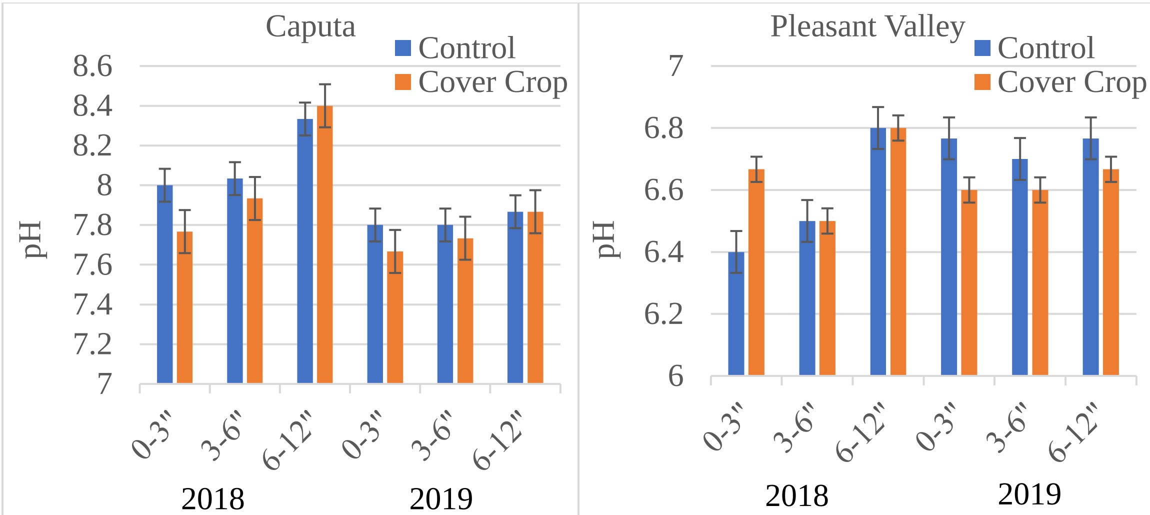

Figure 2.12: Soil pH values in fall for both control (fallow) and cover crop treatments across measured soil depths (0-3", 3-6", 6-12") in both 2018 and 2019. Error bars represent standard error.

Soil pH is a measure that also can take time to change, though not typically thought to take as long as OM. Through ANOVA tests, significance was found in cover crop treatment, soil depth and interaction for Caputa in 2018 (Table 2). Though, Caputa in 2019 showed no significance for any factors or interaction. When soil depth at Caputa was not considered a decrease was seen from cover crop use in both 2018 and 2019 by 1% for both years. Depth did show some influence to soil pH at Caputa. Cover crop use trended toward decreasing soil pH by 3% and 1% in the 0-3" and 3-6" soil depths respectively in 2018 (Figure 6). However, a trending increase of 1% was seen in the 6-12" soil depth from cover crops. A trend of decreasing soil pH also occurred in 2019 from cover crops in the 0-3" and 3-6" soil depth by 2% and 1%. This time, no percent change was observed in the 6-12".

Pleasant Valley regardless of year did not show significance in either factors or interaction through ANOVA tests (Table 2). Without considering soil depth, cover crops trended an increase in soil pH by 1% in 2018 and trending decrease in soil pH by 2% in 2019 at Pleasant Valley. When depth is considered, an increasing trend of 4% is seen from cover crops at the 0-3" soil depth in 2018 (Figure 6). No percentage difference is found though in the 3-6" and 6-12" soil depths in 2018 for pH at Pleasant Valley. 2019, however, shows a trending decrease in soil pH from cover crops by 2%, 1%, and 1% in the 0-3", 3-6", and 6-12" soil depths.

For much of the data, a trend of increasing pH as soil depth increases is present. Values of pH ranged at Caputa in 2018 from 7.77 to 8.40 and ranged from 7.67 to 7.87 in 2019. Pleasant valley had pH ranges of 6.40 to 6.80 in 2018 and from 6.60 to 6.77 in 2019. All ranges are using average values of depth and treatment.

2.3.4. Forage

Table 2.3: 2018 Caputa and Pleasant Valley Average Cover Crop Production and Forage Analysis - Reported on a Dry Basis

	Biomass Production Dry (ton/acre)	Crude Protein %	ADF %	NDF %	RFV	TDN % (ADF)	P %	K %	Total Carbon % C	NE/Maint Mcal/cwt (ADF)	NE/Gain Mcal/cwt (ADF)	NE/Lact Mcal/cwt (ADF)
Pleasant Valley	5.57	10.47	39.87	62.03	87.00	57.10	0.29	3.16	43.20	55.01	29.37	59.58
Caputa	3.44	12.23	32.47	53.17	112.67	65.57	0.18	2.75	42.77	67.65	40.84	68.77

Table 2.4: 2019 Caputa Average Cover Crop Production and Forage Analysis - Reported on a Dry Basis

	Biomass Production Dry (ton/acre)	Crude Protein %	ADF %	NDF %	RFV	TDN % (ADF)	P %	K %	Total Carbon % C	NE/Maint Mcal/cwt (ADF)	NE/Gain Mcal/cwt (ADF)	NE/Lact Mcal/cwt (ADF)
Cover Crop (CC)	6.55	4.43	37.83	49.13	128.67	59.37	0.19	1.38	44.50	58.50	32.57	62.07
Control (CO)	5.49	4.90	37.77	60.43	91.67	59.50	0.16	1.38	44.07	58.66	32.71	62.19

Forage production and quality on a dry matter basis was recorded for Caputa in 2018 and 2019, however, just 2018 at Pleasant Valley. The crop at Pleasant Valley in 2019 was hayed early due to disease, without notice. A large difference in production amount by the cover crop mixtures appears in 2018 between the two study sites. Pleasant Valley produced statistically significant more biomass by 62% than Caputa with production of 5.57 tons/A dry and 3.44 tons/A dry respectively (Table 3). Average production at Caputa did increase in 2019 to 6.02 tons/A dry. In 2018 feed quality differences do occur between the two study sites as shown in Figure 5. Measures that resulted in statistically significant differences are ADF%, RFV, TDN%, P%, and all net energy (NE) types measured. In 2019, some differences appear in cover crop forage quality between treatments (Table 4). Production in the cover crop plot was numerically 19% greater than the control plots with productions of 6.55 tons/A dry and 5.49 tons/A dry matter respectively, though not statistically significant. A large difference also occurs in the NDF values where cover crop returned 49.13% NDF and control returned 60.43 NDF %. These values then carry the effect into the RFV values, where cover crop saw a 128.67 RFV and control saw a 91.67 RFV, a 40% increase in cover crop as compared to control. Other feed quality measures were similar and are reported in Figure 6. Statistically significant differences did not appear for any measures in 2019.

2.4. Discussion

Table 2.5: Means across all soil depths measured (0-3", 3-6", 6-12") separated by year, location and cover crop treatment for Nitrate Nitrogen, Olsen Phosphorus, Potassium, Zinc, Sulfate Sulfur, Organic Matter, pH, and Electrical Conductivity. Locations shown are Caputa (CA) and Pleasant Valley (PV). Letters denote statistical mean separations.

Year	Location	Cover Crop	NO3-N		Olsen P		K		Zn		S		OM		pH		EC	
			ppm										%				mmhos/cm	
2018	CA	Cover Crop	7.9	d	6.2	c	432.0	a	0.5	b	33.5	ab	4.0	d	8.0	ab	0.5	bc
		Control	53.5	a	12.4	bc	384.7	a	0.6	b	37.7	ab	4.1	cd	8.1	a	0.6	b
	PV	Cover Crop	20.4	c	19.7	ab	516.3	a	1.5	a	11.6	b	5.5	a	6.7	c	0.2	c
		Control	32.2	b	31.7	a	522.2	a	1.4	a	15.7	b	5.2	abc	6.6	c	0.3	bc
2019	CA	Cover Crop	4.9	d	5.4	c	380.9	a	0.7	b	70.4	a	4.3	bcd	7.8	b	1.0	a
		Control	5.7	d	8.1	bc	396.7	a	0.7	b	68.7	a	4.3	bcd	7.8	ab	1.2	a
	PV	Cover Crop	6.1	d	26.6	a	441.7	a	1.4	a	9.1	b	5.3	ab	6.6	c	0.4	bc
		Control	7.9	d	27.2	a	431.2	a	1.5	a	9.9	b	5.0	abcd	6.7	c	0.4	bc

In the Northern Great Plains (NGP) yearly precipitation remains a leading factor in the success or failure of a crop. To reduce the risk of crop failure and attempt to store moisture, the practice of summer fallow was widely adopted in semi-arid climates (Greb, 1979; Nielsen and Calderón, 2011). In South Dakota peak cultivated summer fallow acres was in 1987 with 2,208,134 acres (USDA NASS, 1987 Census of Agriculture). Since the 1920s increasing use of the fallow practice occurred until 1987 when it then began to decrease to a low of 301,562 acres (0.7% of SD cropland acres) in 2017 (USDA NASS, 2017 Census of Agriculture).

Transition away from the use of summer fallow has been due to adoption of no-till and negative impacts of tillage practices including; soil organic carbon (SOC) losses (Peterson et al., 1998; Sherrod et al., 2003), increased wind and water erosion (Merrill et al., 1999; Sharratt and Feng, 2009) , and destruction of soil properties (Shaver et al., 2003). The advent of no-till has been shown to decrease these negative effects and even provide opportunity for crop intensification. In a 33-year study, it was found that rotations that did not include a fallow period as compared to ones that did, increased soil physical properties and SOC with greater results in the no-till treatments than in reduced till (Blanco-Canqui et al., 2010). However, greater water content of fallow versus a fallow replacement crop has been observed along with reduction in yield of subsequent crops (Holman et al, 2018; Pikul et al, 1997). On the other hand, yields have also been unaffected by the use of a summer fallow replacement crop (Burgess et al., 2014; Holman et al., 2017). Arguments have been presented that a reduction in moisture and subsequent crop yield still resulted in greater profitability of a summer fallow replacement crop

(Holman et al., 2018). Part of this is due to the low moisture storage efficiency of 10 to 40% that is found in summer fallow (Nielsen and Vigil, 2010; Hansen et al. 2012).

This study evaluated the effects of summer crops in lieu of a summer fallow or as an addition to a crop rotation. June terminated summer cover crops found similar N results where 1.7 to 4.8 times greater nitrate levels in fallow versus a CC (Housman, 2016). Legume green manure crops have also been studied where nitrate N levels were still greater in fallow as compared to pea or lentil green manures (John et al, 2017; Campbell et al, 1992; Pikul et al, 1997). The differences in nitrate N can arise from uptake by growing crops, and mineralization of residue and organic matter during fallow periods. No increase in N by cover crop was seen in this study. Often, an increase in N can arise from decay of early senesced legumes or increased biological activity mineralizing other sources of N. Greater N values were observed following fallow than a wheat-lentil and continuous wheat rotation by Zentner et al. (2001), though significantly higher N-supplying capacity of winter-lentil and continuous wheat rotations than rotations including fallow was also found.

At nearly all soil depths in both years and at both locations, the fallow treatment contained noticeably larger values of soil P (Table 5). The one exception to this occurred at Pleasant Valley in 2019 with the 6-12" soil depth where control treatment was now noticeably lower than that of cover crop. Soil P levels increased in cover crop when moving from 2018 to 2019, especially in the 6-12" soil depth. However, Caputa soil P levels remained approximately the same in cover crop moving from 2018 to 2019 except for a small decrease in the 6-12" soil depth. Both sites, particularly Pleasant Valley, suggest greater soil P cycling and availability due to growth and decay of CC, also with the assumable greater microbial activity.

2.5. Conclusion

Several differences did appear in the use of cover crops replacing a summer fallow. Though some of the differences are profound, most are inconsistent. A small number of observations and large variability add to the difficulty in discussion and conclusions as well as only having two years of data that cover one full cycle. Cover crops have a potential to affect soil nutrient cycling in western South Dakota. More time may be needed to develop consistency and to make other differences appear. The use of cover crops also appears to be a useful source of livestock forage in a crop rotation cycle.

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Chapter 3. Cover Crop Effects on Soil Properties and Value as A Forage Source in Western South Dakota

3.1. Introduction

Planted cover crop (CC) acreage increased by 50% in the US and by 89% in SD from 2012 to 2017 (2017 Census of Agriculture – USDA (USDA-NASS, 2017). This largely stems from the benefits that can arise after the use of a cover crop, which include reduced erosion, increase in soil carbon, increase of biological activity, and greater subsequent cash crop yields (Kaspar and Singer, 2011; Dabney et al., 2001; Moore et al., 2014). Though benefits are often observed, they are not a guarantee from the use of cover crops. Semi-arid climates are especially concerning for the use of cover crops where soil moisture is a major concern. (Unger and Vigil, 1998). Nielsen et al (2016) found a trend for average winter wheat yield reduction of 10% due to spring planted CC, though not significant. Conversely soil water is depleted while the cover crop is growing, but conserved after cover crop termination (Frye et al. 1988). Both reductions and no difference in yield have been observed from CC/green manure crop use in semi-arid climates (Nielsen and Vigil, 2005; Holman et al., 2012; Holman et al., 2018; Obour et al., 2019). Along with soil moisture, northern states must also consider the shorter growing season relative to that of more southern U.S. states.

Western SD is both semi-arid and a northern state, therefore must consider both moisture and growing season factors. Spring and winter wheat are prominent crops grown in the region. After wheat harvest, the fields are typically left as fallow until the following spring. Alternatively, CCs may be utilized during this brief window, which may allow for improvement in soil qualities and provide additional livestock forage. With the growing season that remains after wheat harvest, the potential to reduce nitrate leaching is of promise. A meta-analysis by Tonitto et al. (2005) that reported a 40% and 70% reduction in nitrate leaching from leguminous and non-leguminous winter CCs, respectively. Growing cover crops have the potential to take in residual N from the previous wheat crop. When taken into plant tissue, it can be stored until later decay and release when cash crops may be available to utilize the available N. This creates a greater N synchrony with residue N mineralization during N uptake by cash crops versus receiving only N fertilizer at time of planting (Zentner et al., 2001). In addition, CCs can support an increasing microbial community to recycle nutrients and stabilize soil carbon (Kim et al., 2020).

While CCs have broad potential, research of CCs in western South Dakota is limited. Therefore, this study will begin to provide information to producers in the area. Two main objectives were determined: 1) influence of CC compositions on nutrient cycling and availability for subsequent cash crops in South Dakota, 2) CC nutrient compositions, decomposition and carbon/nitrogen ratio effect on following cash crop nutrient uptake and yield in western South Dakota.

3.2. Materials and Methods

3.2.1. Location

The research study was established in 2018 at the South Dakota State University (SDSU) West River Research Farm (44°25'32.0"N 103°22'51.4"W). This research farm is approximately 7 miles East of Sturgis, SD. Soils at this site are a Nunn clay loam and classified as a fine, smectitic, mesic Aridic Argiustoll. With a semi-arid climate, the average annual precipitation is approximately 21 inches (533 mm) (30-year average from 1981-2010). A second site near Scenic, SD was established in 2019. The site is located on a producer's farm approximately 16 miles NE of Scenic, SD (43°55'32.3"N 102°29'59.1"W). Soils at this site are Nunn-Beckton complex loam and classified as Fine, montmorillonitic, mesic Aridic Argiustolls. Average annual precipitation is approximately 17 inches (432 mm) (30-year average from 1981-2010).

3.2.2. Cover Crop Treatments and Layout

This project was designed to examine the biomass production and nutrient uptake of a Fall CC along with the effects on N uptake in a subsequent sorghum crop. In the Fall of 2018, three cover crop mixes and a control were established in a randomized split block design with four replications. The CCs planted in 2018 were preceded by another cover crop. This was due to the research farms establishment in 2018 where a wheat crop was not attainable due to time constraints. In 2019, CCs were planted into wheat stubble at both sites. In 2019, grass CC plots at Sturgis were replanted due to grasshopper destruction of plots. To compensate for the lateness of the replanted CC species winter-hardy species including: winter wheat (*Triticum aestivum)*, winter triticale (×*Triticosecale*), and winter rye (*Secale cereale*) all planted at 20 pounds per acre, resulting in a seeding rate of 60 pounds per acre. Planting was completed with a 5' no-till drill on 10" row spacing. The size of each CC block was 30` by 180`. Each mix contained the same eight plant species, but varied in percentage of the mix (Table 6). The variance in composition allowed for differing Carbon to Nitrogen ratios of the CC. A grass (high C/N), broadleaf (low C/N) and 50/50 (medium C/N) CC mix was planted, along with an unplanted control that mimics the traditional fallow period after wheat harvest.

3.2.3. Cover Crop Sampling and Analysis

To examine CC production and forage quality, biomass samples were taken from the CC in late fall just before the first killing frost of each year. All samples were taken in fall with a 2.4 ft^2 square cut at the soil surface. Biomass samples were replicated a minimum of three times per CC plot. Replication of four times was utilized in low biomass conditions to gather enough material for quality analysis. Samples were dried in an oven at 135°F for 72 hours. All forage and biomass values are reported on a dry weight basis. With N as the primary nutrient of focus in this study, total nitrogen uptake ($N_{upt,}$ lbs ac^{-1}) was calculated as a function of crude protein as presented by Sigua et al (2012).

$$Nupt = \frac{CP}{6.25} * DM$$

Where, CP is crude protein (%) and DM is the total aboveground dry matter (lbs ac^{-1}). Nitrogen uptake in the roots was not calculated. Residue of the CC was sampled shortly before planting of the cash crop.

3.2.4. Grain Sorghum Treatments and Layout

In the following growing season, grain sorghum (*Sorghum bicolor* (L.) Moench) was planted at 80,000 pure live seed per acre across all CC plots. Within each CC plot, subplots were established consisting of six N rates applied as stabilized urea granules (SuperU) shortly after sorghum emergence at 0, 40, 80, 120, 160, and 200 lbs N $acre^{-1}$.

Each subplot measured 30` by 30` and was replicated four times. Tissue samples of the grain sorghum were taken for each N rate and CC treatment at the 5 to 7 leaf stage.

3.2.5. Grain Sorghum Sampling and Analysis

Harvest was performed with a small plot combine, which measured yield, moisture, and test weight. After harvest of the grain sorghum, post N soil samples were taken for each N rate and CC treatment. All soil samples taken were separated into 0-6" and 6-24" depths and tested for Nitrogen (N), Phosphorus (P), Potassium (K), Sulfur (S), Zinc (Zn), Electrical Conductivity (EC), Organic Matter (OM), and pH. Due to tough soil conditions at sampling time for 2019 spring at Sturgis, the 0-6" and 6-18" soil depths were sampled.

Table 3.1: Cover crop mixes and associated lbs (%) planted for each species, along with CC mix seeding rate.

Crop Species	Grass CC Lbs	Broadleaf CC Lbs	50/50 CC Lbs
Oat	70 (34.8%)	12 (6.0%)	48 (23.9%)
Forage barley	76 (37.8%)	12 (6.0%)	50 (24.9%)
German millet	20 (10.0%)	4 (2.0%)	10 (5.0%)
Sorghum sudangrass	23 (11.4%)	4 (2.0%)	15 (7.5%)
Radish	1 (0.5%)	12 (6.0%)	5 (2.5%)
Turnip	1 (0.5%)	6 (3.0%)	5 (2.5%)
Forage pea	5 (2.5%)	106 (52.7%)	48 (23.9%)
Lentil	5 (2.5%)	45 (22.4%)	20 (10.0%)
Seeding Rate (Lbs/A)	45.1	29.9	37.5

3.2.6. Statistical Methods

Statistics were performed using RStudio and mixed model ANOVA through the use of lme4 package. Significance was set to be an 0.05 for the alpha value. Assumptions for normality and homogeneity were evaluated and met, unless otherwise noted.

3.3. Results

3.3.1. Weather

Temperatures in 2018 and 2019 (Figure A1) at Sturgis were similar to average except for being below average in February for both years. Precipitation at Sturgis (Figure A1) received in 2018 was well above average in June and well below average in October. This changes slightly in 2019 where May and July more than twice the average and slightly above average moisture in August. March was below average in precipitation in 2019.

Temperatures at Scenic (Figure A2) in 2019 were near average throughout the year, except for February, which was half of average in both years. Rainfall at Scenic (Figure A2) in 2019 was near normal except for May and July where more than twice the average was received. Below average precipitation was also received in June and October.

3.3.2 Sturgis Fall Soil

Results from Sturgis displayed minimal significance in the parameters measured for CC treatment. Only N and Zn were found to be significant for CC (Table 7). Interaction of CC and year was significant for N, potentially displaying the differences in

CC mix growth that between years. Soil depth was significant for N, K, Zn, EC, OM and pH. Values of K and OM were consistently greater in the 0-6" soil depth as compared to the 6-24" depth. For the values of EC and pH, lower values were observed in the 0-6" soil depth as compared to the 6-24" soil depth. All other variables were inconsistent or insignificant for depth.

Table 3.2: Average soil values for fall Sturgis, SD separated by year, cover crop, and soil depth for Nitrogen, Phosphorus, Potassium, Sulfur, Zinc, EC, Organic Matter, pH and Chloride levels. Values for significance are also presented with bold formatting representing 95% significance while underline only represents 90% significance.

Year	**Soil Depth**	**Cover Crop**	**NO3-N**	**Olsen P**	**K**	**Sulfur SO4-S**	**Zn**	**EC**	**O.M.**	**pH**	**Chloride**
					ppm			**mmhos/cm**	**%**		**ppm**
2018	0-6"	Broadleaf	3.82	2.25	262.50	5.94	0.70	0.20	3.28	6.20	3.11
		Control	10.89	2.25	251.25	5.66	0.43	0.28	3.45	6.10	4.53
		Grass	2.55	2.25	249.25	5.37	0.66	0.23	3.28	6.15	3.68
	6-24"	Broadleaf	4.31	2.25	176.25	5.94	0.28	0.43	2.50	7.50	4.67
		Control	6.08	2.25	172.75	7.64	0.25	0.48	2.55	7.38	3.39
		Grass	4.10	2.75	178.25	8.48	0.35	0.43	2.50	7.38	2.55
2019	0-6"	Broadleaf	6.50	3.50	191.75	4.68	0.72	0.33	3.68	6.65	1.00
		Control	5.50	3.00	195.75	4.78	0.47	0.33	3.58	6.78	4.00
		Grass	7.00	3.25	200.25	4.68	0.57	0.33	3.70	6.53	1.00
	6-24"	Broadleaf	5.00	2.25	123.25	2.90	0.15	0.58	2.28	7.40	1.00
		Control	3.75	1.75	129.50	3.18	0.14	0.58	2.28	7.53	1.00
		Grass	3.75	1.75	130.25	3.45	0.16	0.60	2.38	7.53	1.25
			p-values as produced by ANOVA								
	Cover Crop		**0.001**	0.690	0.950	0.228	**0.009**	0.162	0.904	0.680	0.200
	Soil Depth		**0.013**	0.065	**0.000**	0.138	**0.000**	**0.000**	**0.000**	**0.000**	0.268
	Year		0.841	0.538	**0.000**	**0.000**	**0.000**	**0.000**	0.410	**0.000**	**0.000**
	CC*Depth		0.251	0.803	0.873	0.090	0.363	0.734	0.949	0.680	0.082
	CC*Year		**0.000**	0.951	0.547	0.990	0.707	0.117	0.353	0.153	0.526
	Depth*Year		**0.021**	**0.002**	0.353	**0.000**	**0.000**	0.845	**0.000**	**0.000**	0.513
	CC*Depth*Year		**0.016**	0.951	0.822	0.667	0.913	0.705	0.776	0.345	0.372
	LSD (Cover Crop)		0.091	-	-	-	0.206	-	-	-	-
	LSD (Soil Depth)		0.075	-	11.316	-	0.168	0.017	0.134	0.103	-
	LSD (Year)		-	-	11.316	0.113	0.168	0.017	-	0.103	1.059

Table 3.3: Average fall soil effects at Sturgis, SD of study year on N, P, K, S, Zn, EC, OM, pH, and Cl. Values are averaged across both of the soil depths measured, therefore represent the 0-24" soil profile.

Year	NO3-N	Olsen P	K	Sulfur SO4-S	Zn	EC	O.M.	pH	Chloride
			ppm			mmhos/cm	%		ppm
2018	5.29	2.33	215.04	6.50	0.44	0.34	2.93	6.78	3.65
2019	5.25	2.58	161.79	3.94	0.37	0.45	2.98	7.07	1.54

Table 3.4: Average fall soil effects at Sturgis, SD of cover crop treatment on N, P, K, S, Zn, EC, OM, pH, and Cl. Values are averaged across both of the soil depths measured, therefore represent the 0-24" soil profile.

Cover Crop	NO3-N	Olsen P	K	Sulfur SO4-S	Zn	EC	O.M.	pH	Chloride
			ppm			mmhos/cm	%		ppm
Broadleaf	4.91	2.56	188.44	4.86	0.46	0.38	2.93	6.94	2.44
Control	6.55	2.31	187.31	5.31	0.32	0.41	2.96	6.94	3.23
Grass	4.35	2.50	189.50	5.50	0.43	0.39	2.96	6.89	2.12

Soil Nitrate N ranged from 3.82 to 10.89 ppm N in 2018 and from 3.75 to 7.00 ppm N in 2019 at Sturgis (Table 8). Interaction was found in CC and year, which was created from broadleaf and grass plots being similar in nitrate N values, though control being largely greater in 2018 and lower in 2019 as compared to the broadleaf and grass plots. Interaction was also found with soil depth and year, where 2019 had a greater range of values, along with a higher average in the 0-6" and lower average in the 6-24" creating interaction across the 2018 range. Year did show significance in soil Nitrate N, though the means are rather similar, with means of 2018 and 2019 as 5.29 and 5.25 ppm N respectively. Cover crop treatment was also found to be significantly different with respect to soil nitrate N where averaged across 0-24", broadleaf equaled 4.91 ppm N, control equaled 6.55 ppm N and grass equaled 4.35 ppm N (Table 9).

Zinc was the only soil nutrient examined to be significant across year, cover crop and soil depth. In fact, Zn concentrations increased in CCs. Across both years broadleaf CC contained the greatest concentration of Zn with 0.71 ppm in the 0-6” depth. The grass CC had a concentration of 0.62 ppm and Control had an average concentration 0.45 ppm. At the lower depth, concentrations were 0.25, 0.21 and 0.19 ppm Zn for the grass CC, broadleaf CC and control, respectively. These differences were not statistically different.

3.3.3. Sturgis Spring Soil

Table 3.5: Average values for spring soil at Sturgis, SD soil and ANOVA results when considering both soil depth and cover crop factors. Bolded values indicate significance at the 95% level.

Soil Depth	Cover Crop	NO3-N	Olsen P	K	Sulfur	Zn	EC	OM	pH	Chloride
		ppm					mmhos/cm	%		ppm
0-6"	Broadleaf	3.75	3.00	242.25	5.00	0.33	0.30	3.08	6.23	2.00
	Control	3.75	2.75	278.25	5.63	0.33	0.25	3.25	6.18	1.25
	Grass	4.75	3.00	242.75	5.35	0.35	0.30	3.35	6.20	1.50
6-24"	Broadleaf	3.50	1.25	161.50	4.53	0.42	0.53	2.53	7.55	1.50
	Control	3.50	1.25	170.50	5.08	0.38	0.50	2.53	7.40	1.25
	Grass	3.75	1.25	149.25	5.15	0.55	0.48	2.48	7.25	2.75
		p value as produced by ANOVA								
	Cover Crop	**0.020**	0.711	**0.006**	0.284	0.723	0.303	0.795	0.603	0.085
	Soil Depth	**0.018**	**0.000**	**0.000**	0.207	0.251	**0.000**	**0.000**	**0.000**	0.357
	CC*Depth	0.245	0.711	0.348	0.898	0.831	0.303	0.647	0.694	0.089
	LSD (Cover Crop)	0.550	-	19.819	-	-	-	-	-	-
	LSD (Soil Depth)	0.449	0.304	16.182	-	-	0.043	0.303	0.283	-

Table 3.6: Average spring soil effects at Sturgis, SD of cover crop treatment on N, P, K, S, Zn, EC, OM, pH, and Cl. Values are averaged across both of the soil depths measured, therefore represent the 0-18" soil profile.

Cover Crop	NO3-N	Olsen P	K	Sulfur	Zn	EC	OM	pH	Chloride
	ppm					mmhos/cm	%		ppm
Broadleaf	3.63	2.13	201.88	4.76	0.37	0.41	2.80	6.89	1.75
Control	3.63	2.00	224.38	5.35	0.36	0.38	2.89	6.79	1.25
Grass	4.25	2.13	196.00	5.25	0.45	0.39	2.91	6.73	2.13

Nitrogen (N) concentration in the soil was significantly different for both cover crop and soil depth (Table 10). Grass cover crops contained the greatest level of N for both the 0-6” and 6-18” with 4.75 and 3.75 ppm N respectively. Broadleaf and control cover crop treatments were equal with both soil depths measured containing 3.75 ppm N in the 0-6” and 3.50 ppm N in the 6-18” depth. Grass CC contained greater N values in both soil depths with 4.75 and 3.75 ppm N in the 0-6” and 6-18” depths respectively.

Potassium (K) also displayed significance for both cover crop and soil depth (Table 10). Control contained the greatest K levels in both the 0-6” and 6-18” soil depths with 278.25 and 170.50 ppm K respectively. At the 0-6” depth broadleaf and grass cover crops had nearly the same K levels at 242.25 and 242.75 ppm K respectively. A separation in values forms between the two cover crops in the 6-18” soil depth where broadleaf contained more soil K at 161.50 ppm K as compared to grass containing 149.25 ppm K.

Soil depth values in the spring was found to be significant for N, P, K, EC, OM, and pH. Soil S, Zn and Cl were not found to be significant for either CC or soil depth in the spring (Table 10). Soil P values were just over twice as great in the 0-6” depth than the 6-24” soil depth. Greater “surface” values also occur with K and OM. Lower values appeared in the 0-6” soil depth with EC and pH. Soil values of S, Zn and Cl were very similar between both soil depths measured.

3.3.4. Sturgis Forage

Table 3.7: Average fall forage values for Sturgis, SD separated by cover crop in regards to Biomass production, crude protein, acid detergent fiber, neutral detergent fiber, relative feed value, total digestible nutrients, total Carbon and Carbon to Nitrogen ratio. Values for significance are also presented with bold and underline representing 95% significance while underline only represents 90% significance.

Year	**Cover Crop**	**Biomass**		**Crude Protein**	**ADF**	**NDF**	**RFV**	**TDN**	**Total Carbon**	**C:N Ratio**
		lbs/acre	**ton/acre**	**% dry basis**				**% dry basis**		
2018	Broadleaf	466.35	0.23	24.35	23.63	37.55	175.00	75.63	46.65	11.98
	Grass	877.14	0.44	20.33	23.58	38.85	169.25	75.70	45.80	14.09
2019	Broadleaf	99.98	0.05	34.25	27.35	26.30	240.75	71.40	45.85	8.37
	Grass	103.59	0.05	24.85	29.65	40.08	153.50	68.75	44.83	11.32

p-values as produced by mixed model anova

Cover Crop	**0.000**	**0.000**	**0.000**	0.173	**0.000**	**0.000**	0.172	0.054	**0.000**
Year	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.002**	**0.000**	0.068	**0.000**
CC*Year	**0.000**	**0.000**	**0.000**	0.155	**0.000**	**0.000**	0.148	0.857	**0.007**
LSD (Cover Crop)	119.843	0.060	1.340	-	2.635	18.298	-	-	0.562
LSD (Year)	119.843	0.060	1.340	1.868	2.635	18.298	2.132	-	0.562

Biomass production at Sturgis, SD was statistically significant for both year and cover crop treatment (Table 12). In 2018 greater biomass was achieved overall with broadleaf producing 466 lbs/acre (0.23ton/acre) and the grass producing 877 lbs/acre (0.44 ton/acre). Overall production was decreased due to late planting in 2019 with broadleaf averaging 100 lbs/acre (0.05 ton/acre) and grass being 104 lbs/acre (0.05 ton/acre).

Crude protein (CP) was also found to be statistically significant for both CC and year (Table 12). Broadleaf CP was greater overall with an average of 24.35 % in 2018 and 34.25 % in 2019. Grass CCs was lower averaging 20.33 % and 24.85 % in 2018 and 2019 respectively.

Acid Detergent Fiber (ADF) was significantly increased in the low production year but did not different between cover crops (Table 12). Neutral Detergent Fiber (NDF), on the other hand, was found to be significant with CC and year. Average NDF values of 2018 were 38.20% compared to 33.19% in 2019. Broadleaf CC was lower than that of grass cover crop each year where averages were 31.93 and 39.46 % NDF for broadleaf and grass CC, respectively.

Relative Feed Value (RFV) significance was found in both year and cover crop (Table 12). Lower RFV values were found in 2018 with 172.13 as compared to 2019 with 197.13 on average. The broadleaf CC had a higher RFV compared to the grass CC with the disparity inversely related to production.

Total Digestible Nutrients (TDN) resulted in significance with year only (Table 12). Values of TDN on average were 75.66 % in 2018 and 70.08 % in 2019. When comparing cover crops differences were small with grass trending 0.07 percentage points greater in 2018 and broadleaf being 2.65 percentage points greater in 2019.

Total Carbon (TC) was not found to be significant for either year or cover crop (Table 12). However, the carbon to nitrogen ratio (C:N) was significantly different in both year and cover crop. Values were found to trend generally greater in 2018 with an average of 13.04 as compared to 9.85 in 2019. Broadleaf cover crops had a lower C:N ratio of 10.18 compared 12.70 in the grass cover crop.

3.3.5. Sturgis Spring Residue

Table 3.8: Residue composition of 2018 fall cover crop measured in spring of 2019.

Year	Cover Crop	Biomass		Crude Protein	P	K	Total Carbon	C:N Ratio
		lbs/A	ton/A	% dry basis				
2019 Residue	Broadleaf	160.80	0.08	17.97	0.25	0.20	44.20	15.42
	Grass	311.52	0.16	18.01	0.27	0.26	45.02	15.67
		p-values as determined by ANOVA						
Cover Crop		**0.000**	**0.000**	0.828	0.108	**0.000**	**0.047**	0.318
LSD		100.994	0.051	-	-	0.027	1.307	-

Table 3.9: Change in composition of cover crop residue, comparing 2019 spring to 2018 fall forage. Values are the difference between 2019 and 2018 (2019 - 2018).

Cover Crop	Biomass		Crude Protein	P	K	Total Carbon	C:N Ratio
	lbs/A	ton/A	% dry basis				
Broadleaf	-305.55	-0.15	-6.38	-0.02	-2.19	-2.45	3.43
Grass	-565.63	-0.28	-2.32	-0.04	-2.60	-0.78	1.58

Cover crop spring residue was significant in biomass, potassium (K) and total carbon (TC) (Table 13). Biomass of the grass residue was roughly twice that of the broadleaf with 312 and 161 lbs/A (0.16 and 0.08 ton/A) respectively. Crude protein (CP) showed minimal differences in cover crop residue with a difference of 0.04 between the broadleaf (17.97 %CP) and grass (18.01 %CP) CC residue. Phosphorus (P) levels too were minimally different with broadleaf being 0.25 % P and grass being 0.27 % P. concentration of K was 0.06 % K greater in the grass (0.26 %K) CC residue than that of the broadleaf (0.20 %K). TC of the grass CC was minimally greater at 45.02 %C, where broadleaf CC were 44.20 %C. When evaluating the C:N ratio of the CC residues, both CC`s were very similar with broadleaf and grass at 15.42 and 15.67 respectively.

3.3.6. Scenic Soil

Table 3.10: Average soil values for Scenic, SD separated by cover crop, and soil depth in regards to Nitrogen, Phosphorus, Potassium, Sulfur, Zinc, EC, Organic Matter, pH and Chloride levels. Values for significance are also presented with bold and underline representing 95% significance while underline only represents 90% significance.

Soil Depth	Cover Crop	NO3-N	Olsen P	K	Sulfur SO4-S	Zn	EC	O.M.	pH	Chloride
		ppm					mmhos/cm	%		ppm
0-6"	Broadleaf	1.25	12.25	414.25	3.70	0.79	0.20	2.55	6.13	1.25
	Control	1.75	13.75	443.75	3.40	0.68	0.20	2.48	6.13	1.00
	Grass	2.00	13.25	466.75	4.65	0.84	0.20	2.53	6.10	1.00
6-24"	Broadleaf	1.00	2.50	260.75	3.10	0.13	0.35	2.18	7.25	1.25
	Control	1.00	1.75	274.25	3.23	0.09	0.33	2.15	7.23	1.25
	Grass	1.00	1.75	287.75	3.30	0.09	0.33	2.20	7.15	1.00

p-values as produced by mixed model anova

	NO3-N	Olsen P	K	Sulfur SO4-S	Zn	EC	O.M.	pH	Chloride
Cover Crop	0.226	0.929	0.122	**0.013**	**0.012**	0.741	0.809	0.478	0.351
Soil Depth	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	0.555
CC*Depth	0.226	0.492	0.802	0.051	**0.044**	0.741	0.948	0.782	0.706
LSD (Cover Crop)	-	-	-	0.520	0.067	-	-	-	-
LSD (Soil Depth)	0.066	1.725	33.740	0.425	0.055	0.032	0.154	0.095	-

Sulfate Sulfur (S) was one of two measures that was found to be significant in both CC and soil depth at Scenic (Table 15). The top soil layer measured higher S levels with an average of 3.92 ppm S where the lower layer averaged 3.21 ppm S. The grass CC contained the greatest S soil concentration in both soil layers measured as compared to broadleaf and control, with an average across both layers of 3.98 ppm S. Broadleaf and control were fairly similar in values at both soil depths and again were similar in full profile average with control at 3.31 ppm S and broadleaf at 3.40 ppm S.

Zinc (Zn) was the second soil measure that significance appeared in both CC and soil depth (Table 15). The 0-6" layer averaged 0.77 ppm Zn and a decrease is seen in the 6-24" depth with an average of 0.10 ppm Zn. Smaller differences are seen among the CCs and no consistent trend is seen. When averaging 0-24" for control, broadleaf and grass CCs concentrations of 0.38, 0.46, and 0.47 ppm Zn respectively are seen.

3.3.7. Scenic Forage

Table 3.11: Average forage values for Scenic, SD separated by cover crop in regards to Biomass production, crude protein, acid detergent fiber, neutral detergent fiber, relative feed value, total digestible nutrients, total Carbon and Carbon to Nitrogen ratio. Values for significance are also presented with bold and underline representing 95% significance while underline only represents 90% significance.

Cover Crop	Biomass		Crude Protein	ADF	NDF	RFV	TDN	Total Carbon	C:N Ratio
	lbs/A	tons/A	% dry basis				% dry basis		
Broadleaf	411.56	0.21	17.83	28.53	38.23	164.25	70.03	41.98	14.77
Control	277.45	0.14	22.55	29.68	39.65	154.75	68.73	42.33	11.75
Grass	366.99	0.18	17.98	29.30	42.38	146.25	69.13	42.43	14.90
Mix	370.61	0.19	18.25	27.68	38.45	163.00	71.00	42.25	14.70
	p-values as produced by mixed model anova								
Cover Crop	0.067	0.067	**0.000**	0.597	**0.042**	0.077	0.597	0.881	**0.001**
LSD	-	-	2.747	-	3.691	-	-	-	2.138

At Scenic in 2019, a late flush of volunteer spring wheat grew in the control plots. To capture the values of the wheat that grew in the CC plots, the control was allowed to remain, as the first killing frost was to come within 10 days.

Biomass produced at Scenic, SD was not found to be significant with CC treatment (Table 16). A range of CC treatments from 277 to 412 lbs/A (0.14 to 0.21 ton/A) was found. Significance was found in CP with average values of 17.83 and 17.98 %CP for broadleaf and grass, respectively. An increase in CP occurred in the control to 22.55 %CP. No significance was found in ADF. However, NDF was found to be significant with CC treatment, where grass contained higher NDF at 42.38% followed by the control, mix, and broadleaf CC with 39.65, 38.45 and 38.23 %NDF, respectively. Relative feed value, TDN and TC did not reveal significance in CC treatment. Each had small ranges in average values as well with RFV ranging from 146.25 to 164.25, TDN ranging from 68.73 to 71.00 %TDN, and TC ranging from 41.98 to 42.43 %C. The carbon to nitrogen ratio (C:N) though was lowest in the Control at 11.75 with broadleaf, grass and mix with values of 14.77, 14.90, and 14.70, respectively.

3.4. Discussion

Statistical significance of CC in soil nutrients/qualities was variable between sites and time of year sampled. In the fall, N was significantly different at Sturgis while S was significantly different at Scenic. Both sites in the fall also found Zn to be significant for CC treatment.

The lack of significance in soil nutrients/qualities observed in this study may be due to the limited growth in the fall where Sturgis averaged 0.43 Mg ha^{-1} and Scenic averaged 0.40 Mg ha^{-1}. Climate and pests had a large effect on the biomass production at Sturgis where a longer growing period did provide more biomass in 2018 with an average of 0.75 Mg ha^{-1} as compared to an average of 0.114 Mg ha^{-1} in 2019. Other production values have been reported by Andraski and Bundy (2005) in Wisconsin who averaged 1.16 +- 0.86 Mg ha^{-1}, and Marcillo and Miguez (2017) through a meta-analysis found an average of 1.2 Mg ha^{-1} (range of 0.6 to 3). Greater biomass and root production would likely lead to greater soil activity and nutrient acquisition/exchange. Establishment of fall CCs may prove to be difficult in the semi-arid climate of western SD. Persistence and continued testing of CC use may be necessary in order for significant differences to develop as the soil ecology adapts and changes with the new management practice.

It was of surprise that soil N levels was significant for CC treatment at Sturgis in both fall and spring, though not significant at Scenic in fall. This may be due to the amount of volunteer wheat that arose in each of the CC plots at Scenic that made each CC treatment more similar in composition. A lack of difference in soil N results may suggest that composition of CC mixes may be less important in semi-arid regions. Soil results were quite variable and had a lack of consistent trends, though this would likely change with more years and locations of CC studies. Only soil inorganic nitrate-N was measured, however results from this study may have been different if organic N was measured as well (Chu et al., 2017).

The impact of cover crops on Zn is not well studied in current literature, however, the findings here agree with some available literature. Beck et al. (2016) found that summer CCs increased mean soil levels of Zn as compared to no CC in strawberries. A possible explanation may be from the involvement of arbuscular mycorrhizal fungi

(AMF). The presence of AMF can increase availability and uptake of Zn (Begum et al., 2019; Hamilton et al., 1993; Smith and Read, 2008). It was suggested that differences in Zn availability were caused by differences in biological activity rather than chemical availability (Hamilton et al., 1993). In SD, fall CCs have been shown to increase the number of AMF in soils by up to three times that of no CC (Lehman, 2013). Species differences in AMF association exist where oat was found to provide the greatest number of AMF by Lehman (2013). The mixture used in this study contained oats, which may also be of influence to the Zn availability.

Forage quality is of importance to many aspects of crop production and CC use. The quality of forage will not only affect performance of grazing animals, but also soil "performance" and decomposition of CC residue (Kuo et al., 1997). Significance was consistently found in CP, NDF, and C:N ratio in the CC forage with CC treatment for both Sturgis and Scenic. Additionally, significance was found in RFV for CC treatment at Sturgis. Crude protein at Sturgis was greatest in the broadleaf plots by an average (2 year) of nearly 7%. This did change at Scenic, where volunteer wheat (control) had the greatest CP at 22.55 % CP compared to broadleaf and grass at 17.83 and 17.98 % CP, respectively. Even though the volunteer wheat produced approximately 0.10 Mg ha^{-1} less per acre than grass CC (second lowest biomass yield), the CP value and no associated planting cost with volunteer wheat could be considered an option for short-term cover cropping, as long as related crop disease is not of concern. This idea has been trialed in North Dakota with field peas, where a light tillage pass after pea harvest is used to promote germination and growth of volunteer field pea from seeds lost from combine or in-season. Schatz (2015) documented above-ground biomass yields of 1.96 Mg ha^{-1} dry matter with yields ranging from 1.02 to 2.50 Mg ha^{-1}. Nitrogen contribution from biomass ranged from 40.31 to 98.54 kg ha^{-1}, not including N contribution from active nodules (Schatz, 2015). Another potential option to be tested is other CC species planted with volunteer allowed to grow.

NDF values are an important measure of feed quality as they pertain to the intake potential by livestock (Ball et al, 2001). Values of NDF were not separated by large differences, though a consistent trend did appear. Broadleaf CC was lower in each instance than that of the grass CC for both Sturgis and Scenic. As the forages mature, it would be expected that a larger difference would appear between the broadleaf and grass CCs, where broadleaf CC may be more desired from an intake of livestock perspective. At young growth stages, the CCs are very comparable.

Carbon to nitrogen ratio (C:N) was significant for both Sturgis and Scenic for CC treatment. In general, the broadleaf CC had a lower C:N ratio than the grass CC. The C:N is often used as an evaluation of the rate of residue decomposition. This is important to feed soil microbes, drive soil N dynamics and estimate the amount of cover or residue left in the field after a time period. All C:N values at both sites are well below the threshold (24:1) for ideal microbial activity (Weil and Brady, 2016). The residues therefore should decompose rather quickly and promote N cycling within the soil.

Cover crop residue remaining in 2019 at Sturgis was significantly different among CC treatments. The biomass remaining was 34% for broadleaf and 35% for grass CC of the measured CC fall biomass. This similarity in decomposition percentage is not necessarily surprising with the similar C:N ratios of CC forage observed and discussed earlier. What is surprising with similar decomposition percentages, is that total C change was greater in broadleaf CC with a decrease by 2.45 % C, but only a loss of 0.78 % C in the grass CC (Table 14). This may suggest other forage quality differences that affect residue decomposition. More recalcitrant carbon compounds such as cellulose and lignin can inhibit microbial attack, reducing decomposition rates (Sievers and Cook, 2017). Grasses typically contain more recalcitrant carbon sources (Ghimire et al., 2017), whereas legumes and brassicas contain more N and more readily available/decomposable carbon sources such as lower cellulose, hemicellulose, and acid soluble lignin (Johnson et al., 2017). In addition to biomass, both total C and K of residue was significant. Change in K composition of residues was more similar with a loss of 2.19 and 2.60 % K for broadleaf and grass CC, respectively.

3.5. Conclusion

Cover Crops have been proven to provide a multitude of benefits to cropping systems. These benefits include, but are not restricted to: reduction in erosion, increased soil biology activity/population, greater nutrient cycling and supply, and production of livestock forage. Studies of cover crop use, however, are currently limited in drier climates. This study aimed to observe the effects from the use of cover crops after wheat harvest in western SD. A grass, broadleaf, and 50/50 CC mix were planted along with a fallow control. Results were variable, where one site found N and another found S to be significant for CC treatment. Both sites, though found Zn to be significant for CC treatment. Biomass produced by the CC was also variable and generally low. Year had a large effect on CC biomass due to climatic conditions, length of growing season, pest issues and species traits within CC mix. Forage quality varied by CC with CP, NDF, and C:N ratio to be significantly different for all locations and years. RFV was only found to be significant with CC treatment at one location. Residue left in the spring as a percentage was similar across CC treatments, but total C and K were observed to be different between CC treatments, despite a lack of significance in the fall. The implementation of CCs in western SD shows slight promise in regards to soil and forage qualities. It should be kept in mind this study spans only 2 years while longer use of CCs, especially in the same field/spot, could provide new and different insights to the effects of CCs in western SD.

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Chapter 4. Sorghum Yield and Nitrogen Use Evaluation Following Cover Crops in Western South Dakota

4.1. Introduction

Cover Crops (CC) have been increasingly utilized in recent years as a primary component of the soil health movement and a mix of new and old discovered benefits from CC use. Benefits can encompass a wide range of aspects including biological, chemical, and physical properties of both soil and crops. For example, introducing CCs have been found to reduce N leaching and P runoff, promote biological population/activity, and build soil organic C (Kaspar and Singer, 2011; Blanco-Canqui et al, 2015).

However, the effects of CCs on subsequent crop yields remains unresolved. Increases in yield have been observed (Andraski and Bundy, 2005; Hively and Cox, 2001; Kuo and Jellum, 2000). However, decreases in crop yield have also been observed through different mechanisms such as N immobilization (Wagger, 1989; Dabney et al, 2001), moisture consumption (Nielsen et al, 2016; Allen et al, 2011), and potential allelopathic effects (Raimbault et al, 1990). The resulting cash crop yields from CC use will depend on annual precipitation, CC species, time of year grown, tillage system, number of years of CC management (Blanco-Canqui et al, 2015), along with termination date and method (Clark et al, 1997; Unger and Vigil, 1998).

Precipitation is a leading factor in the success of CCs and subsequent crop yields, particularly in semi-arid climates. Unger and Vigil (1998) assert that CCs are more suited for sub-humid to humid climates where precipitation is greater and more reliable than that of semi-arid regions. Due to its semi-arid climate and short time period to establish and/or decompose a CC, western South Dakota is likely to face challenges with moisture consumption and nutrient immobilization. To address these issues, a study was conducted to evaluate the yield of sorghum (*Sorghum bicolor*) following a fall cover crop. Cover crop species composition was arranged with increasing rates of applied nitrogen (N) fertilizer to examine N immobilization and the subsequent effects on sorghum grain yield following the CC. The hypothesis is that sorghum yields will be increased or unaffected by the CC if moisture is not a limiting factor. If moisture is not adequate, CC use is hypothesized to decrease sorghum yield. With sufficient growth, CCs may increase biological activity and increase nutrient cycling, especially in higher legume CCs where N addition through fixation is possible.

4.2. Materials and Methods

4.2.1. Location and treatments

This research was conducted in Sturgis, SD on the South Dakota State University (SDSU) West River Research Farm (44°25'32.0"N 103°22'51.4"W). The soil at this site is a Nunn clay loam (fine, smectitic, mesic Aridic Argiustoll). The semi-arid climate produces an average annual precipitation of approximately 21 inches (533mm) (30-year average from 1981-2010). Fall cover crops were planted on August 16, 2018, where three mixes were used and each contained the same eight cover crop species, but in varying amounts. A grass, broadleaf and 50/50 mix were used. Species and CC planting rate are further detailed in Table 17, below.

Table 4.1: Cover crop mixes and associated lbs (%) planted for each species, along with CC mix seeding rate.

Crop Species	Grass CC Lbs	Broadleaf CC Lbs	50/50 CC Lbs
Oat	70 (34.8%)	12 (6.0%)	48 (23.9%)
Forage barley	76 (37.8%)	12 (6.0%)	50 (24.9%)
German millet	20 (10.0%)	4 (2.0%)	10 (5.0%)
Sorghum sudangrass	23 (11.4%)	4 (2.0%)	15 (7.5%)
Radish	1 (0.5%)	12 (6.0%)	5 (2.5%)
Turnip	1 (0.5%)	6 (3.0%)	5 (2.5%)
Forage pea	5 (2.5%)	106 (52.7%)	48 (23.9%)
Lentil	5 (2.5%)	45 (22.4%)	20 (10.0%)
Seeding Rate (Lbs/A)	45.1	29.9	37.5

4.2.2. Layout and sampling

In the spring following CC planting, grain sorghum (Sorghum Partners KS 310) was planted at 80,000 pure live seed per acre. The trial was arranged in a split-plot design with each CC as the whole plot factor. The subplot factor consisted of six N rates applied as urea (46-0-0) coated with a nitrification and urease inhibitor (SuperU containing dicyandiamide and N-[n-butyl] thiophosphoric triamide) shortly after emergence of the grain sorghum. Rates used were as follows: 0, 40, 80, 120, 160, and 200 lbs N per acre. Tissue samples of the grain sorghum were taken for each N rate and CC treatment at the 5 to 7 leaf stage. At grain maturity, plots were harvested with a small plot combine, recording yield, moisture, and test weight. Yields were adjusted to 13% moisture.

4.2.3. Optimum Yield and Economic Return Computation

Optimum yield was determined by the derivative of the yield curves generated from the NLS function in RStudio. Economic return curves were created using the steps in calculation of MRTN (maximum return to N) as detailed by Sawyer et al (2006). To summarize, yield curves generated from average sorghum yield at each N rate were created utilizing NLS to create the equation to form a best fit quadratic curve. From the yield curve, price per yield unit ($/bu) is multiplied by sorghum yield to give yield revenue. In addition, N rate is multiplied by cost per unit ($/lb N) to give an associated N cost component for each unit of grain yield. Cost of N is then subtracted from the yield revenue to give return to N curve in $/acre. Lastly, the return to N is plotted across N rates and a new curve is created. To find the economic optimum, the derivative is then taken which finds the peak in the return curve where adding additional N no longer returns an increase in revenue. Values of MRTN were based on an average urea price of $0.08/lb N and $2.81/bu as the local sorghum cash bid.

4.2.4. Statistical Methods

Statistics performed utilized RStudio software, where ANOVA and NLS (nonlinear least squares) were used under the stats package. The level of statistical significance was determined at $p < 0.05$ for all tests and comparisons.

4.3. Results

Comparing CC treatments across N rates (Figure 7), the broadleaf CC trended the highest sorghum yield at 59 bu/A on average. The grass, control, and 50/50 mix follow with average sorghum yields of 55, 53 and 51 bu/A respectively. When N rates are compared across all CC treatments, 160 lbs N/A trends the greatest sorghum yield with 58 bu/A on average closely followed by 40 and 120 lbs N/A with 57 bu/A average for both (Figure 8). Despite yield differences, particularly over the 0 N rate, these results were not statistically significant.

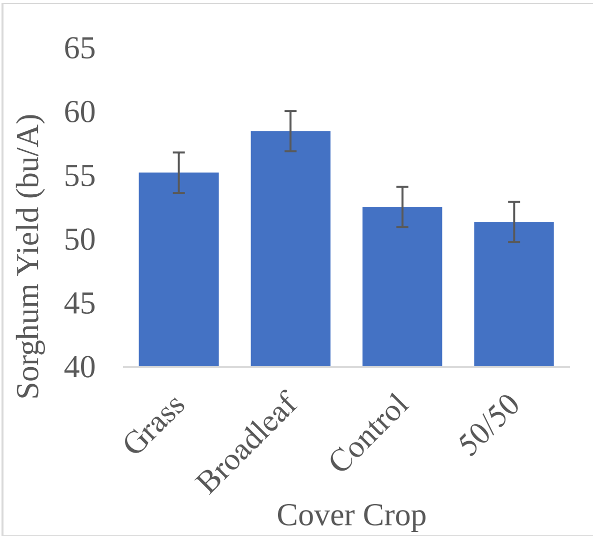

Figure 4.1: Average sorghum yields, in bu/A, for each cover crop treatment tested

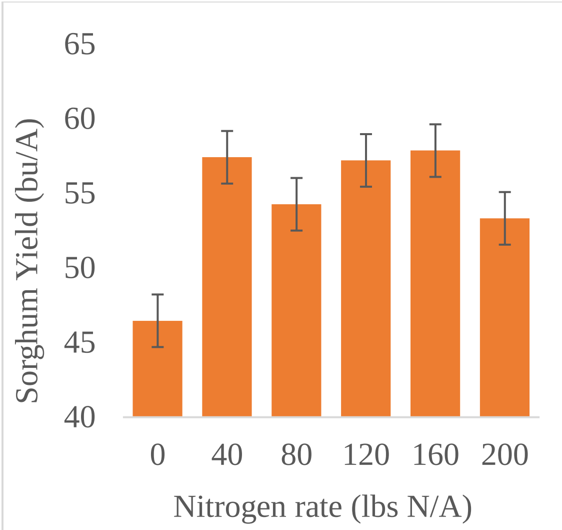

Figure 4.2: Average sorghum yields, in bu/A, for each applied N rate in lbs N/A.

When evaluating the N yield curves for CCs, the broadleaf, 50/50 and control showed a similar response whereas grass is visibly different (Figure 10). Correlations of data to the equation were weak with correlations of 0.43, 0.18, 0.32, 0.31 for grass, broadleaf, 50/50 and control treatments, respectively (Table 18). Optimum yield (Table 18) was obtained with the least N in the broadleaf CC with N applied at 99 lbs/A, corresponding to a sorghum yield of 61 bu/A. The NLS models for control and 50/50 CC were similar with N applied of 105 and 114 lbs/A leading to a yield of 57 and 60 bu/A, respectively. Grass CC NLS model had the greatest N applied of 237 lbs/A to achieve the optimum of 58 bu/A sorghum yield.

Based on the MRTN, the broadleaf CC had the greatest net return at 165 $/A with N applied at 74 lbs/A (Table 18 and Figure 11). Following in return, the 50/50 CC has a return of 160 $/A with 100 lbs N/A applied. Control and grass CC have similar returns of 157 and 151 $/A but very different N applied with 93 and 172 lbs/A respectively.

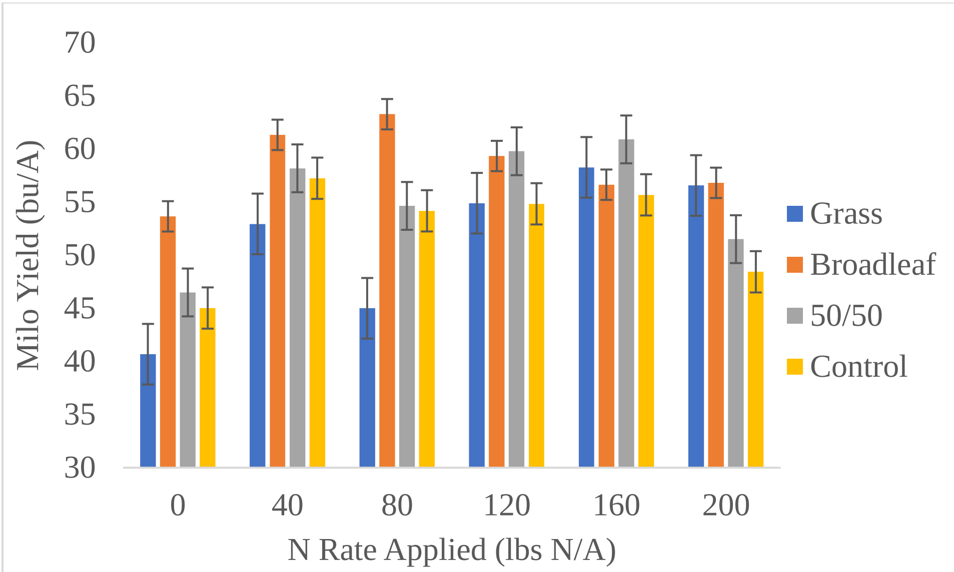

Figure 4.3: Resulting sorghum yield from multiple Nitrogen rates and four fall cover crop treatments, including control

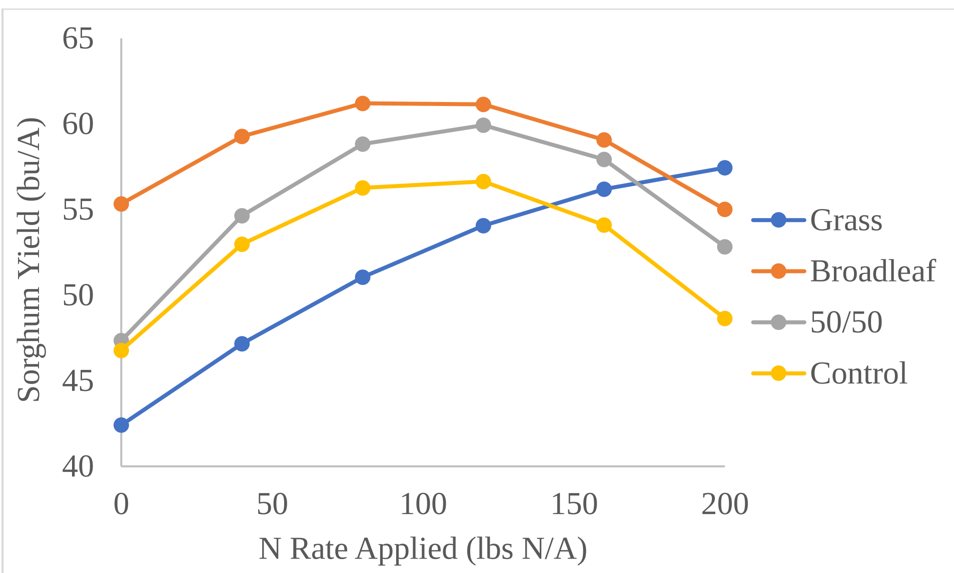

Figure 4.4: Sorghum yield curves from multiple Nitrogen rates and four fall cover crop treatments, including control. Curves were created with nonlinear least squares model for each cover crop treatment along with mean cover crop treatment values for each Nitrogen rate, and the observed optimum N rate and corresponding sorghum yield for each cover crop treatment

Table 4.2: NLS model data correlation, along with nitrogen curve optimum and associated optimum economic return using $0.08/lb N and sorghum cash bid price of $2.81/bu.

Cover Crop	Curve Correlation	Optimum fertilizer rate (lbs N/A)	Optimum sorghum yield (bu/A)	MRTN fertilizer rate (lbs N/A)	MRTN revenue ($/A)
Grass	0.44	237	58	178	145
Broadleaf	0.18	99	61	74	165
50/50	0.33	114	60	100	160
Control	0.34	105	57	88	151

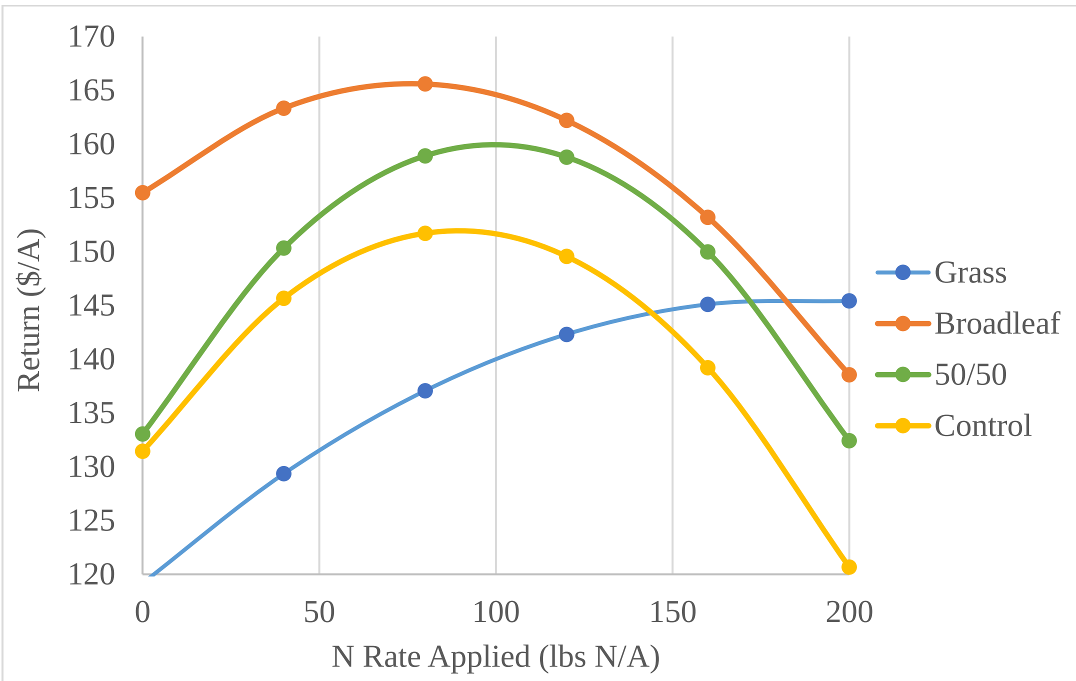

Figure 4.5: Economic return curves of Nitrogen rate following a fall CC, created through Nitrogen fertility NLS models using $0.08/lb N and sorghum cash bid price of $2.81/bu for each CC model curve.

4.4. Discussion

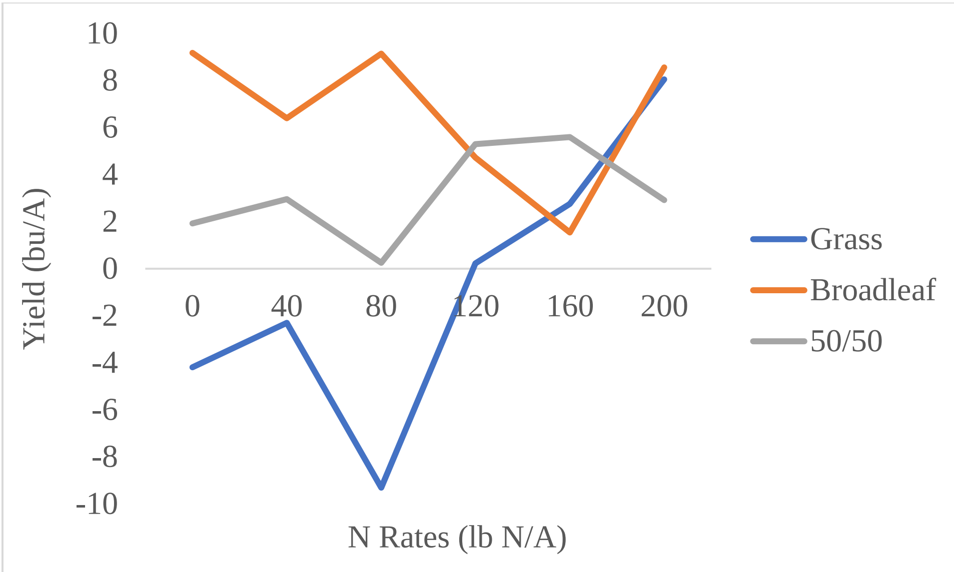

Figure 4.6: Yield difference compared to control over all N rates with yield presented on vertical axis in bushel per acre and N rate on horizontal axis as applied pounds N per acre.

Even though CC and N rate were not determined to be statistically significant for sorghum yield, certain trends and differences appear when evaluating sorghum yield following a winter cover crop. Broadleaf cover crop shows the greatest promise for use from this study. Not only did it produce the lowest optimum N rate for the greatest sorghum yield, but also the greatest revenue with the least applied N (cost of seed and planting not figured). Control (fall fallow) showed consistently lower yields and less economic return, without considering the cost of the cover crop. The addition of N by legume CCs to the soil has also been observed (Hargrove, 1986; Kramberger et al., 2014; Kuo et al., 1997; Mahama et al., 2016). However, benefits may not be seen in the first rotation cycle, where two or more cycles may be needed to see N benefits from CC use (Janke et al., 2002). One study found that less than 55% of N contained in roots of oat or rye CC will be available to the subsequent crop (Malpassi et al., 2000)

Yield in the grass CC was lower than that of all treatments until 120 lbs N/A were applied, where it then exceeded the yield of the control and continued to do so with increasing N applied. This suggests possible nitrogen immobilization that can often be attributed to non-legume CCs (Dabney et al, 2001). Immobilization, was overcome in this study with high rates of N applied. The stress brought on by lack of moisture was not apparent during this study due to the above average moisture received. A typical or below average precipitation year may change results seen in this study. Through a meta-analysis, Marcillo and Miguez (2017) found that corn yield was positively affected following a legume or mixture winter CC than that of grass CC, which was found not to be different than no CC. High sorghum yields were also seen following a winter CC that contained purely and predominantly crimson clover CC contrary to low yields seen after a pure and predominant Italian ryegrass winter CC (Kramberger et al. 2014).

Another measure to consider is simple N use efficiency by comparing sorghum bushels produced per lb N applied over each N rate and CC (Figure 13). A similar trend appears where broadleaf exceeds the other CCs and control in each N rate applied for N use efficiency, except at the 200 lb N rate. Following broadleaf CC, is the 50/50 CC and control even into the 200 lb N rate. Grass CC at the 40 lb N rate had a N use efficiency of 1.18 bu/lb N, compared to broadleaf at 1.48 bu/lb N. The difference between broadleaf and grass CC N use efficiency tapers lower until grass exceeds broadleaf. At 200 lbs N applied, grass N use efficiency was 0.29 bu/lb N compared to broadleaf at 0.28 bu/lb N.

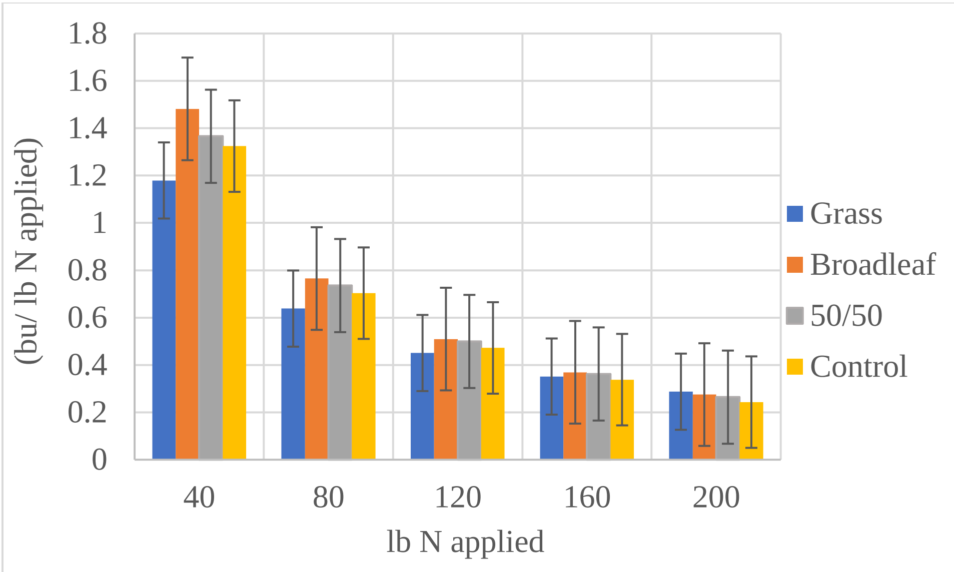

Figure 4.7: Nitrogen use efficiency for bushel of sorghum per pound N applied over all N rates applied and cover crops.

Timing of CC termination plays a large role in the effect on crop yield following a winter CC (Nielsen and Vigil, 2005). Ample time should be given for a CC to break down, begin recycling the nutrients that were once held in roots and shoot tissues and potentially recharge soil moisture. However, too early of termination will limit production of a CC and N fixation of legumes. Residues undecayed for subsequent cash crop will then decay and cycle nutrients the following year. This could create a nutrient cycling timeline of both immediate and long-term release and storage of nutrients. This also allows for the benefits of soil residue cover that are often seen (Blanco-Canqui et al, 2011; Blanco-Canqui et al, 2015). Yield is one component of CC implementation, but all factors will work together to create one final impact. This impact can be positive or negative depending on factors that are in and out of a producer's control. Adding to the difficulty in analysis of CC use impact, several results may not be seen immediately, but rather in the long term.

4.5. Conclusion

Sorghum yields were affected by CC use and N rates, as found in this study. In general, the broadleaf CC tended to increase sorghum yield over that of a fall fallow control as did a 50/50 CC mixture and tended to decrease the amount of N needed to reach the maximum economic yield. The grass CC trended in decreased sorghum yields as compared to a fall fallow control until approximately 140 lbs N/A was applied, which suggests that N immobilization occurred with the grass CC and that sorghum yield reduction needed to be overcome by increased rates of commercial N fertilization. Yield of a subsequent cash crop is important; however, it is not the only factor that can benefit a producer's bottom line. Reduction in leaching, increased biological activity, and livestock forage are a few of the positive effects that CC can result in. Therefore, in evaluating the results from CC use, all factors (positive and negative) should be considered. Results from a CC are diverse and ever changing according to climate, inherent soil factors, management and termination. From this study, positive results from certain CC mixtures was found, though more testing should be done to ensure consistency of results, particularly under diverse precipitation outcomes.

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Appendix

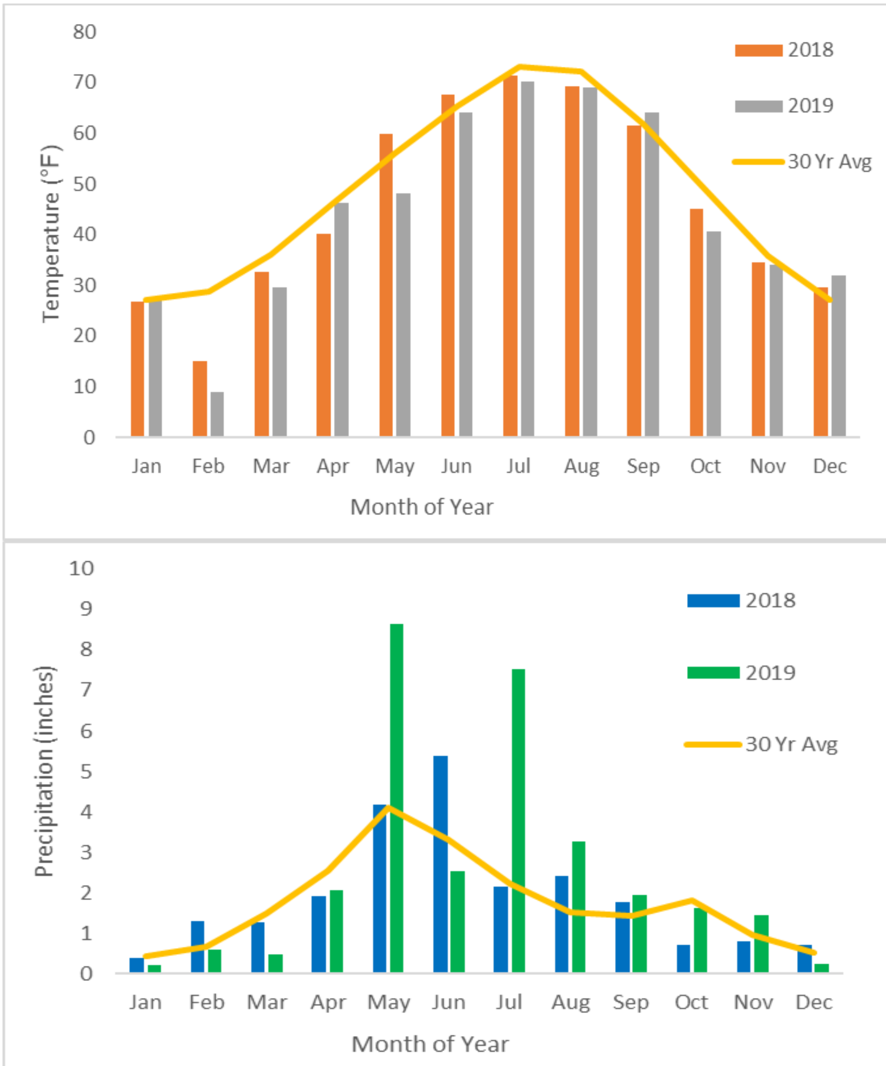

Figure A.13: *Weather for Sturgis, SD during study period as reported from Ft. Meade weather station (approximately 5 miles from study site). Temperature, in Fahrenheit, is reported as month average on the left. Precipitation, in inches, is reported as total precipitation received in that month on the right. Both the single years and 30-year (1981-2010) averages are reported for temperature and precipitation from NOAA.*

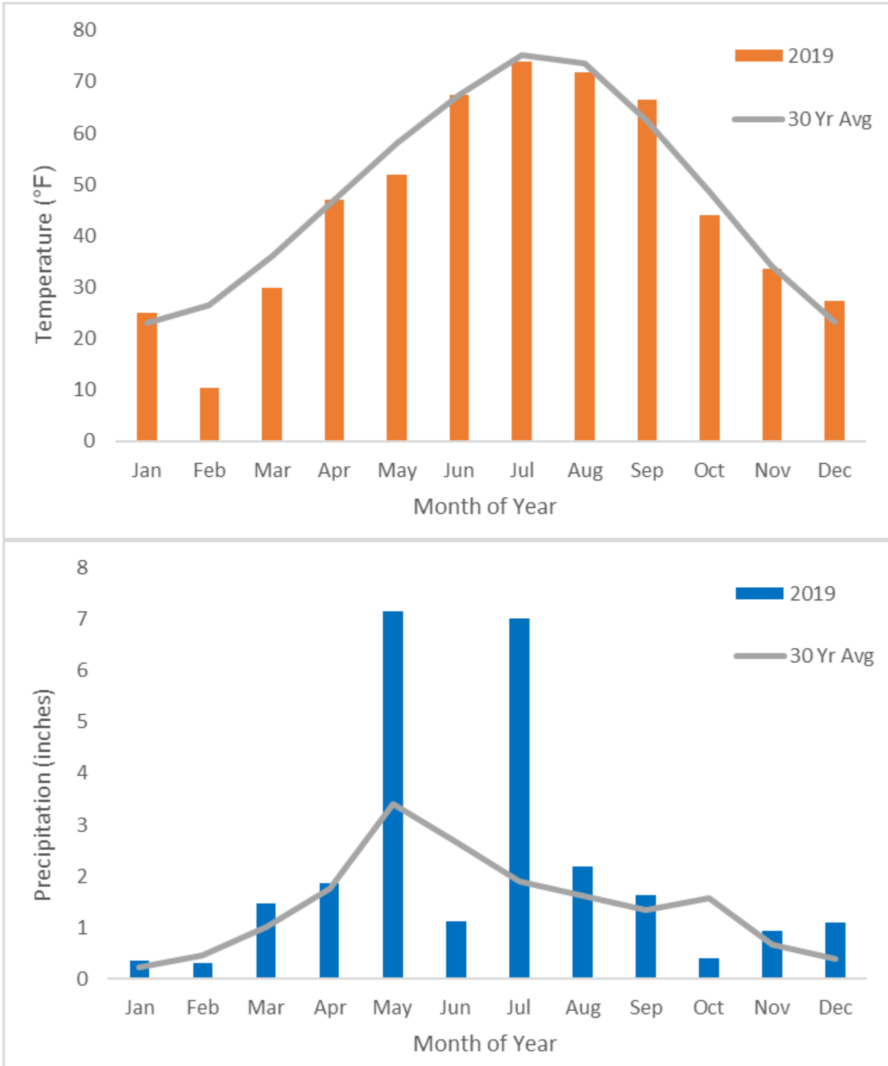

Figure A.14: *Weather for Scenic, SD during study period as reported from Wasta weather station (approximately 10 miles from study site). Temperature, in Fahrenheit, is reported as month average on the left. Precipitation, in inches, is reported as total precipitation received in that month on the right. Both the single years and 30-year (1981-2010) averages are reported for temperature and precipitation from NOAA.*

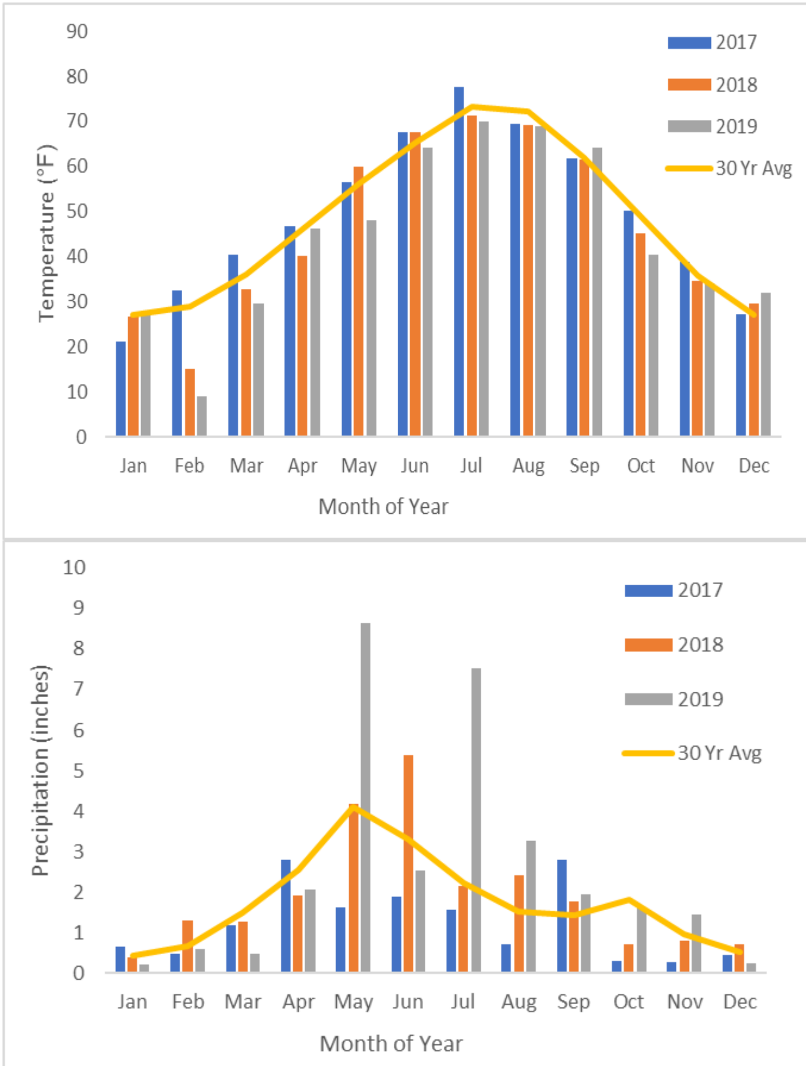

Figure A.3: *Weather for Sturgis, SD during study period as reported from Ft. Meade weather station (approximately 5 miles from study site). Temperature, in Fahrenheit, is reported as month average on the left. Precipitation, in inches, is reported as total precipitation received in that month on the right. Both the single years and 30-year (1981-2010) averages are reported for temperature and precipitation from NOAA.*