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Influence of Cover Crops on Water and Nutrient Cycles in South Dakota

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INFLUENCE OF COVER CROPS ON WATER AND NUTRIENT CYCLES IN SOUTH DAKOTA

BY

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THESIS ACCEPTANCE PAGE

Sam Ireland

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.

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ABSTRACT

INFLUENCE OF COVER CROPS ON WATER AND NUTRIENT CYCLES IN SOUTH DAKOTA

SAM IRELAND

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A major concern of farmers implementing cover crops into a crop rotation is a potential reduction in soil moisture and nutrients available for the following cash crop. If soil moisture or nutrients are limited, the following cash crop yield suffers. One option to conserve soil moisture is to terminate cover crops with herbicides prior to a killing freeze. The purpose of this study is to develop a better understanding of the impact of cover crops and termination timing to the water and nutrient cycles and furthermore, the agronomic impact to the following cash crop (corn). Field experiments were conducted in 2019 through 2020 at the Dakota Lakes Research Farm (Pierre, SD) and on a producer's field near Canning, SD. Three different cover crop mixes (Grass-M1 (grass dominated blend), Brdlf-M2 (broadleaf dominated blend), and Blend-M3 (equally weighted by rate of grass and broadleaves)) were planted on 2019-07-25 at Dakota Lakes and 2019-08-08 at Canning. A chemical fallow treatment was implemented as a control. Cover crops were terminated with herbicides at different times in the fall of 2019. Plant available water (PAW) was calculated using field gravimetric soil moisture percentage measurements for the 0-90 cm soil profile. At Canning, on 2019-11-15 PAW was impacted by cover crop mixture ($p=0.086$) with Grass-M1 containing 62 mm, Blend-M3 containing 59 mm, and Brdlf-M2 containing 49 mm. This difference was not present in the spring. The Control

treatment contained significantly more PAW than the cover cropped treatments at Dakota Lakes and Canning in the fall of 2019 and again in April 2020. By June, when the corn crop is starting to use a significant amount of soil water, the Control contained more PAW than all other cover cropped treatments at Canning, but not at Dakota Lakes. At Dakota Lakes, spring soil nitrate-nitrogen was numerically lower in the cover cropped treatments than the Control. At Canning, spring soil nitrate-nitrogen was significantly lower in the cover cropped treatments than the Control ($p<0.001$). Corn grain yield was higher in the Control treatment than most cover cropped treatments at both locations. It is likely that the reduction in corn grain yield is a function of both reduced soil moisture and nitrogen. Earlier terminated cover crops resulted in a higher yielding corn crop as compared to those last terminated. The cover crops terminated later in the season produced more cover crop biomass but reduced the corn grain yield the following year. Terminating cover crops proved to be an effective practice. This approach saved a portion of the grain yield in the following cash crop, while still accomplishing some of the benefits from cover cropping. Drawbacks of early termination are reduced cover crop biomass production and reduced length of time that a living root is in place.

INTRODUCTION

Some monocultures grown in annual cropping systems do not utilize the entire growing season. As a result, a fallow period ensues in which no crop is grown, and plant growth is controlled chemically or mechanically (Haas et al., 1974). Minimizing fallow periods increases the intensity of an agroecosystem and is a method of fine tuning the water, nutrient, and energy cycles (Beck et al., 1998).

An important difference between annual cropping systems and the prairie is the prevalence of perennial grasses and forbs in the prairie. These plants have deep, extensive root systems in place year-round that play a key role in water and nutrient cycling (Glover, 2003). Randall et al. (1997) conducted a study in southwestern Minnesota analyzing the amount of soil water percolating through a soil profile in an annual cropping system compared to a system with established perennials. It was found that the amount of soil water percolating through a soil profile consisting of annual crops exceeded five times the amount flowing through a soil profile consisting of perennials (Randall et al., 1997).

The water cycle strongly influences the nutrient cycle. An imbalance in the former creates inefficiency in the latter. A system with an insufficient water use, relative to precipitation, tends to leach nutrients through the soil profile with the excess moisture (Cichota et al., 2016). In an annual cropping system, once nutrients move beneath the reach of annual crop roots, they are lost from the system. Some of these nutrients find their way into groundwater or surface water sources. This has become a major environmental and health concern (Masters, 1998). The native prairie leached very few nutrients. A system that leaches a nutrient for a long enough period without replacing it becomes a desert (Beck, 2014). In contrast, a system that utilizes too much moisture will encounter a soil water-deficit that instead can decrease nutrient uptake (Al-Karaki & Al-Raddad, 1997).

Tile drainage is one approach to treat the symptom of a system with insufficient water use intensity. By draining the gravitational water from a soil, tile drainage artificially alters the soil-water matric potential (plant available soil moisture). It has become apparent that this practice contributes significantly to water pollution and is therefore an unacceptable long-term solution (Howarth et al., 2000; Billen et al., 2013).

A practice that has been used to increase agroecosystem water use intensity is the use of cover crops. Cover cropping can be an important tool in managing the water and nutrient cycles within agroecosystems. A short-term benefit is an increase in biological activity and diversity (Finney et al., 2017) as well as economic value if the crop is used as forage (Tobin et al., 2020). Some long-term benefits to the soil are an increase in soil organic carbon, reduced compaction, increased infiltration, and increased water-holding capacity (Chalise et al., 2019; Folorunso et al., 2012).

A common practice in cropping systems in central South Dakota is to follow wheat (*Triticum aestivum*) with corn (*Zea mays*) in a crop rotation (Clay et al., 2016; Sexton, 2012). This transition results in a fallow period from mid-summer (wheat harvest) until the following spring (corn plant). Cover crops are a tool used to replace part of this fallow period. Post-wheat harvest, the amount of time remaining in the growing season is limited. This necessitates planting cover crops as soon as the wheat crop is harvested to take full advantage of this window of opportunity. As the planting date is delayed, potential biomass production decreases (Sexton, 2012).

The question that must be addressed is this: Does adding cover crops into an annual cropping system in central South Dakota use more soil moisture than can be replenished by precipitation? The answer must consider historical precipitation (as this is a probability game), water holding capacity of the soil profile and soil moisture at time of cover crop planting. Web soil survey is a resource that provides the water holding capacity of the soil profile (Web Soil Survey, 2020). This metric can be used to obtain an estimate of the amount of water a soil can hold. A field estimate of soil moisture at time of cover crop planting may be sufficient to determine soil moisture condition. This estimate can be used to assist producers in matching their cover crop management to the variable conditions as they occur. If the available time for a soil to recharge with soil moisture after a cover crop is grown is insufficient, a moisture deficit is likely to occur (Unger & Vigil, 1998). If a soil moisture deficit does occur, the cover crop is a potential detriment to the producer's economic enterprise. The objective of this study is to find the middle ground between utilizing the benefits of cover crops and conserving enough soil moisture for the following cash crop.

There have been contradicting findings with regards to the effect of cover crops on the following cash crop yield. Some studies have shown that cover crops increase the yield of the following cash crop (Blanco-Canqui et al., 2012; Chalise et al., 2019; Miguez & Bollero, 2006), while others have observed negative impacts to yield (Kuykendall et al., 2015; Reese et al., 2014; Hively & Cox, 2001). Several studies have shown that cover crops do not have a significant impact on following cash crop yields (Henry et al., 2010; Duiker & Curran, 2005; Acuña & Villamill, 2014). One trend that has been documented is the decrease in crop yields following cover crops in drier than normal growing seasons (Nielsen & Vigil, 2005). Cover crops have been found to decrease soil moisture and, in some cases, short-change the following cash crop moisture (Kahimba et al., 2008; Nielsen & Vigil, 2005; Lu et al., 2000). If limited soil moisture becomes a concern during the cover crop's lifespan, an option may be to use herbicides to terminate the growing cover crop (Legleiter et al., 2012).

Terminating cover crops prior to maturity is one option to conserve soil moisture (Nielsen & Vigil, 2005). This is carried out by reducing moisture use late in the fall, while still producing a surface residue that would reduce soil evaporation. The earlier the termination date, the less soil moisture used by the cover crop. Earlier terminations in the fall also leads to reduced biomass production which could lead to less surface residue and increased soil evaporation. From a farmer's perspective, transpiration of water through a plant is a positive endeavor, while evaporation from the soil is not (Kite, 2000). To optimize the water use efficiency of a system, transpiration must be maximized, and evaporation minimized.

A function of cover crops is to use excess soil water and sequester soil nutrients. Potential drawbacks of cover cropping include reduced soil moisture and reduced soil nutrient availability to the following cash crop (Holman et al., 2018). Cash crops planted the following spring would likely experience drier soil conditions and have access to fewer available soil nutrients. As a result, cash crop yields may suffer, especially in drier than normal years. This begs the question, is this reduction in yield a function of soil moisture or soil nitrogen?

It was hypothesized that a higher carbon to nitrogen (C:N) ratio cover crop would conserve soil moisture versus a lower C:N ratio cover crop. Higher C:N crop residue decomposes slower than lower C:N crop residue (USDA-NRCS, 2011). As a crop residue decomposes, soil evaporation increases due to reduced soil cover. Another hypothesis of this experiment is that early fall termination of cover crops will conserve soil moisture. The last hypothesis was a lower C:N ratio will likely have a quicker release of nutrients and therefore more of these nutrients may be available for the following cash crop.

MATERIALS AND METHODS

Site Descriptions

Effects of different cover crop mixes and herbicide termination timing were evaluated at two locations. The first location was at the Dakota Lakes Research Farm (44°17’33N, 100° 00’ 22W) located 18 miles east of Pierre, SD on a Dorna silt loam soil (coarse-silty over clayey, mixed over smectite, superactive, mesic Fluventic Haplustolls.) The second location was located approximately six miles north of the Dakota Lakes Research Farm on a producer’s field near Canning, SD. The soil type at this location was a Hurley silt loam (very-fine, smectitic, mesic Leptic Natrustolls). Both fields have been under no-till management for over 25 years. The current crop rotation at the Dakota Lakes site is winter wheat (*Triticum aestivum*) – corn (*Zea mays*) or sorghum (*Sorghum bicolor*) – cool-season broadleaf. Current crop rotation at the Canning site is spring wheat-winter wheat-corn-sunflower (*Helianthus annuus*) or soybean (*Glycine max*). Both locations produced winter wheat in 2019.

Experimental Design

The experimental setup consisted of a randomized complete block split plot design containing four replications. Three different cover crop mixes were seeded, each consisting of the same eight species. The contrast in mixes was due to the differing amounts of species within each cover crop mix. Mix 1 (Grass-M1) is a grass dominant blend. Mix 2 (Brdlf-M2) is a broadleaf dominant blend. Mix 3 (Blend-M3) is an equally weighted blend containing 50% grass and 50% broadleaves by seeding rate (Table 1.1). In addition to the cover crop mixes, a control treatment was utilized where no cover crops were planted, and stubble was left mechanically undisturbed. In the fall, the cover crops were terminated at four different times. This further split the design setup into 12 m by 6 m treatments. The Control did not receive any termination treatments; therefore, the size of this experimental unit was 12 m by 24 m.

Cover Crop Planting

At the Dakota Lakes site, winter wheat harvest took place on 2019-07-24. A 6 m (20-foot) Shelbourne stripper head was used to harvest the small grain crop. This operation left the remaining stubble standing vertically in the field. Cover crops were planted the day after wheat harvest, on 2019-07-25. A 3 m (10-foot) John Deere 750 drill was used to plant each mixture of cover crops. Seed was placed at a 4 cm (1.5 in) depth and the closing wheels were lifted to the frame to be bypassed. The idea behind this approach is to place the seed relatively deep to access soil moisture, while leaving the furrow open. This practice enables the seedlings to emerge without having to push through a significant amount of soil. For the Canning site, wheat harvest took place on 2019-07-30. A Shelbourne stripper head was also utilized for this operation. Cover crops were planted on 2019-08-08 with a 6 m (20-foot) John Deere 750 drill. Seed was placed at a depth of 5 cm (2 in). Closing wheels were utilized in this plot and therefore the furrows were closed during the seeding operation. No inoculant was used with the seeding mix. No herbicide or fertility applications occurred at this time. Plant species implemented in each cover crop mixture and seeding rates are shown in Table 1.1.

Herbicide Applications

No pre-plant burndown herbicide was applied at either site. The Control treatments received multiple herbicide applications during the fall of 2019 to control weed pressure. The first herbicide application to the Control occurred on 2019-08-28.

Glyphosate (N-(phosphonomethyl)glycine)) was applied at a rate of 0.79 kg ai ha^{-1}, and 2,4-D (2,4-Dichlorophenoxyacetic Acid) at 0.62 kg ai ha^{-1}. On 2019-09-27 volunteer wheat was sprayed in the Control treatment. Glyphosate (N-(phosphonomethyl)glycine)) was applied at a rate of 0.95 kg ai ha^{-1}, and 2,4-D (2,4-Dichlorophenoxyacetic Acid) at 0.62 kg ai ha^{-1}, thifensulfuron-methyl (Methyl 3-[[[[(4-methoxy-6-methyl-1,3,5- triazin-2-yl) amino]carbonyl]amino] sulfonyl]-2-thiophenecarboxylate) at 17 g ai ha^{-1}, and tribenuron-methyl (Methyl 2-[[[[N-(4-methoxy-6-methyl-1,3,5- triazin-2-yl) methylamino]carbonyl] amino]sulfonyl]benzoate) at 8.4 g ai ha^{-1}.

Cover crops were terminated with herbicides at different times (Table 1.2). A UTV-mounted sprayer with a 6 m (20 ft) coverage span was utilized for the herbicide application. Glyphosate (N-(phosphonomethyl)glycine) was applied at a rate of 1.9 kg ai ha^{-1}, 2,4-D (2,4-Dichlorophenoxyacetic Acid) at 1.2 kg ai ha^{-1}, and clopyralid (3,6-dichloro-2-pyridinecarboxylic acid) at 1.5 kg ai ha^{-1}. Target pressure setting was 276 kpa (40 psi).

At both sites on 2020-05-06 an herbicide application was made across the entirety of the plots. Glyphosate (N-(phosphonomethyl)glycine)) was applied at a rate of 0.95 kg ai ha^{-1}, 2,4-D (2,4-Dichlorophenoxyacetic Acid) at 0.83 kg ai ha^{-1}, thifensulfuron-methyl (Methyl 3-[[[[(4-methoxy-6-methyl-1,3,5- triazin-2-yl) amino]carbonyl]amino] sulfonyl]-2-thiophenecarboxylate) at 13 g ai ha^{-1}, tribenuron-methyl (Methyl 2-[[[[N-(4-methoxy-6-methyl-1,3,5- triazin-2-yl) methylamino]carbonyl] amino]sulfonyl]benzoate) at 6.3 g ai ha^{-1}, atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine) at 0.47 kg ai ha^{-1}, S-metolachlor (2-Chloro-N-(2-ethyl-6-methylphenyl)-N-[(1S)-2-methoxy-1-methylethyl]acetamide) at 3.2 kg ai ha^{-1}, and octanoic acid ester of bromoxynil (3,5-

dibromo-4-hydroxybenzonitrile) at 0.31 kg ai ha^{-1}. An herbicide application was made at the Canning site on 2020-05-29. Glyphosate (N-(phosphonomethyl)glycine)) was applied at a rate of 0.79 kg ai ha^{-1}, 2,4-D (2,4-Dichlorophenoxyacetic Acid) at 0.62 kg ai ha^{-1}.

Soil Sampling and Corresponding Calculations

Soil samples were obtained periodically from the time cover crops were planted until corn harvest the following fall. A Giddings soil probe (Giddings Machine Company Windsor, CO) mounted on a trailer was used to obtain soil cores to depths of 120 cm (48 in). Prior to splitting the experiment into individual treatments (2019-09-27) by herbicide termination, five to six cores were composited for each sample. After the experimental setup was split into individual treatments, two to three cores were composited for each sample out of practicality.

Soil samples were placed in plastic bags and weighed immediately. The soils were then moved into paper bags to air dry. Because gravimetric moisture content was a critical parameter in the soil analysis, the samples were oven-dried at 104°C (220°F) in a Stabil-Therm Oven (Blue M Electric Company). Plant available water (PAW) for the 0-90 cm soil profile was calculated using gravimetric soil moisture samples measured periodically in 2019 and 2020. Gravimetric soil moisture was converted to volumetric moisture using Equation 1. Gravimetric soil moisture was multiplied by soil bulk density to obtain a volumetric soil moisture content. The volumetric soil moisture content was then multiplied by the depth of the soil profile to calculate total soil water in the soil profile. Lastly, the amount of water in the soil profile present at permanent wilting point (according to web soil survey) was subtracted from the total soil water to estimate PAW.

$$VMC = [(wet\ soil\ wt. - dry\ soil\ wt.)/dry\ soil\ wt.)] * 100 * Bd \qquad \textbf{Eq. (1)}$$

The term VMC corresponds to volumetric moisture content, wet soil wt. to the weight of the soil immediately after sampling (grams), dry soil wt. to the oven dried soil weight (grams) and Bd to bulk density (g cm^{-3}). All soil nutrient analysis was completed by Ward Laboratories Inc. (Kearney, NE). Soil nitrate-nitrogen and ammonium-nitrogen was measured by the cadmium reduction procedure using a flow injection analyzer. Soil sulfate-sulfur was measured by implementing a calcium phosphate extraction procedure. Specific methodology for each analysis can be found in the WARD guide (Ward, 2019).

Consumptive water use (mm) was calculated using gravimetric soil sample measurements and precipitation records. At Dakota Lakes total soil water measured on 2019-07-26 was added to the precipitation received from 2019-07-26 through 2020-06-16. The total soil water measured on 2020-06-16 was then subtracted from this sum. At Canning total soil water measured on 2019-08-09 was added to the precipitation received from 2019-08-09 through 2020-06-17. The total soil water measured on 2020-06-16 was then subtracted from this sum.

Water use efficiency was calculated using gravimetric soil samples measurements and precipitation records. At Dakota Lakes total soil water (mm) measured on 2019-07-26 was subtracted from the total soil water (mm) measured on 2020-10-02. Total evapotranspiration (mm) was calculated by adding the precipitation received (mm) from 2019-07-26 through 2020-10-02 to the difference in total soil water (mm). Corn grain yield (kg ha^{-1}) was divided by total evaporation to arrive at the water use efficiency metric (kg ha^{-1} mm^{-1}). The calculations for Canning were performed identical to Dakota Lakes except that the time frame considered was 2019-08-09 through 2020-10-15.

Phospholipid-derived fatty acid (PLFA) samples were taken on 2019-09-17 at Canning, and on 2019-09-18 at Dakota Lakes. This sampling was done prior to any herbicide desiccations of the individual treatments; therefore, the only comparison is between the different cover crop mixes and the control. A 1.2 m stainless steel hand probe was used to obtain the soil cores. No lubricant was applied in order to maintain the integrity of the biological sample. Ten cores from the 0-20 cm soil depth were composited for each sample. This depth was chosen based upon Ward Laboratories Inc. (Kearney, NE) recommendation. The samples were shipped in a Styrofoam cooler to Ward Laboratories Inc. for analysis (Ward, 2019).

Cover crop biomass and biomass C:N

During the cover crop's growing season (the fall of 2019), aboveground biomass samples were taken by harvesting a 0.5 m by 0.5 m quadrat (0.25 m^2). A serrated sickle knife was used to cut the biomass 2 cm above the soil surface. For the Dakota Lakes site, samples were obtained on September 27, October 7, and November 2. For the Canning site, samples were obtained on September 27, October 14, and November 2. Samples were air-dried at 60°C (140°F) until the weight of the samples stabilized (approximately 10 days). Carbon and nitrogen contents were analyzed by Ward Laboratories Inc. (Kearney, NE) (Ward, 2019).

Surface Residue

Surface residue samples were obtained from both the Dakota Lakes and Canning sites on 2020-04-30 (same day as corn planting, but prior to the planting operation). This procedure was accomplished by harvesting all aboveground attached and loose residue material in a 0.5 m by 0.5 m quadrat area (0.25 m^2). Samples were air-dried at 60°C

(140°F) until the weight of the samples stabilized (approximately 7 days). Effort was made to exclude any material that was contaminated with soil. Due to the management of both plots (continuous no-till with residue remaining in the field), the soil-residue interface was very difficult to distinguish.

Corn Planting

Corn was planted at Dakota Lakes on 2020-04-30. A 12 row 50 cm (20 in) row spacing no-till planter was used to plant Pioneer P9998AM hybrid at a depth of 5.7 cm (2.25 in). This 99-day maturity hybrid was planted at a seed population of 55,700 seeds ha^{-1} (22,500 seeds ac^{-1}). At the Canning site corn was planted on 2020-04-30. A 76 cm (30 in) row no-till planter was used to plant Dekalb DKB45-66 at a depth of 5.1 cm (2 in). This 95-day maturity hybrid was planted at a seed population of 45,800 seeds ha^{-1} (18,500 seeds ac^{-1}).

Fertility Applications

For the Dakota Lakes site, 28 kg of N ha^{-1} (25 lbs of N ac^{-1}) in the form of urea ammonium nitrate (UAN) was banded into the soil 7 cm from the seed furrow during the corn planting operation 2020-04-30. During the same operation, a mixture of monoammonium phosphate (MAP) and potassium chloride (KCl) was banded into the soil 7 cm from the seed at a rate such that the individual nutrients applied were as follows: 5.9 kg of N ha^{-1} (5.25 lbs of N ac^{-1}), 27.8 kg of P_2O_5 ha^{-1} (24.8 lbs of P_2O_5 ac^{-1}), and 3.6 kg of K_2O ha^{-1} (3.2 lbs K_2O ac^{-1}).

At the Canning site, a liquid fertilizer (8-21-4-3S-0.5Zn) was placed in furrow during the corn planting operation at a rate of 46.8 L ha^{-1} (5 gal ac^{-1}). This resulted in a nutrient application rate of 5.0 kg of N ha^{-1} (4.5 lbs of N ac^{-1}), 13.3 kg of P_2O_5 ha^{-1} (11.9

lbs of P_2O_5 ac^{-1}), 2.6 kg of K_2O ha^{-1} (2.3 lbs of K_2O ac^{-1}), 1.9 kg of S ha^{-1} (1.7 lbs of S ac^{-1}), and 0.3 kg of Zn ha^{-1} (0.3 lbs of Zn ac^{-1}).

A fertility application of urea ammonium nitrate blended with ammonium thiosulfate (26.4-0-0-2.6S) was stream bar applied (12.7 cm spacing) at the Dakota Lakes and Canning sites on 2020-05-15. The UAN liquid fertilizer was diluted with water to a volumetric ratio of 2 units water to 1-unit fertilizer. Total nitrogen rates applied to the corn crop are shown in Table A.1. Nitrogen fertilizer application amounts were determined using Equation 2.

$$Nitrogen\ Fertilizer\ \left(\frac{kg\ of\ N}{ha}\right) = (0.014 * YG) - STN - N\ applied\ @\ Plant \quad \textbf{Eq. (2)}$$

A yield goal (YG) of 8,810 kg ha^{-1} (8.81 Mg ha^{-1}) was used for both Dakota Lakes and Canning. Soil test nitrogen (STN) in kg of N ha^{-1} was determined from fall soil nitrate-nitrogen samples. Only the Term 4 termination timing within each mixture as well as the Control were sent for soil nitrate-nitrogen analysis. Because of this, the corn crop following each cover crop mixture received the same amount of nitrogen fertilizer (it was not split amongst termination timing). This resulted in some variability in soil nitrogen within the experiment. N applied at planting (kg of N ha^{-1}) was applied during the planting operations on 2020-04-30.

Corn Stand Counts

Stand counts for the 2020 corn crop were obtained by counting the number of plants emerged in a 3 m by 2 row area. The same area within each plot was counted each time as spray paint was used to mark the exact location. Counts were made at the Dakota Lakes plot on May 26, June 1, and June 8 (Table 1.22). Counts were made at the Canning plot on May 27, June 2, and June 15 (Table 1.23). A wind/hail event damaged the plot at Canning on June 7, and therefore pushed the count back one week, which resulted in some of the counts on June 15 being lower than the previous count (June 2).

Stomatal Conductance

A SC-1 Leaf Porometer (METER Group Inc.) was used to measure stomatal conductance of the corn crop. One plant was randomly selected for measurement within each plot. The abaxial side of the ear leaf was measured on each plant. The plots at the Dakota Lakes location were measured on 2020-07-23. Measurements were taken between 2 p.m.-5 p.m. (CST). The weather conditions were sunny with intermittent clouds. Temperature ranged from 33-35°C (91-95°F), relative humidity from 44-48%, and wind speed from 24-48 kph (15-30 mph). Corn at Dakota Lakes was at the VT (tasseling) stage. The plots at Canning were measured on 2020-07-24. Measurements were taken between 12 p.m.-3 p.m. (CST). The weather conditions were mostly sunny. Temperature ranged from 31-34°C (87-94°F), relative humidity from 52-55%, and wind speed from 24-32 kph (15-20 mph). The corn crop at the Canning site was at the V12/VT stage.

Remote Sensing

A DJI Phantom 4 Pro V2.0 unmanned aerial vehicle (UAV) (Shenzhen DJI Sciences and Technologies Ltd.) was used as the carrier for remote sensing equipment. The DJI Phantom 4 Pro V2.0 UAV was equipped with a camera using a 2.54 cm (1-inch) 20 MP CMOS sensor. This camera was utilized to capture red, green, and blue (RGB) wavelengths. A High-Precision NDVI single sensor (Sentera) was attached to the UAV as an aftermarket addition. The Sentera High-Precision camera utilizes a 1.2 MP CMOS sensor. This camera captured red and near-infrared (NIR) wavelengths.

The drone flew at an elevation of 61 m aboveground and at a speed of 5.4 m s^{-1}. Effort was made to conduct flights as close to solar noon as possible.

Image Processing

Individual images were stitched using Open Drone Map application (GitHub Inc.). This application produces an orthophoto as a .tif file. The file can be imported as a raster layer into GIS software. QGIS (Open Source Geospatial Foundation (OSGeo)) was the platform used to analyze the stitched NDVI orthophotos. Each image was georeferenced using ground control points to align the images. A vector layer was created containing a grid of the plots (12 m by 6 m). The layer was buffered 1.5 m on all sides to be positioned in the center (9 m by 3 m) of the plots. NDVI values were extracted from this buffered layer and are shown in Table 1.23 for Dakota Lakes and Table 1.24 for Canning. The size of the pixels extracted was 5 cm by 5 cm. NDVI was calculated using Equation 3.

$$NDVI = (1.236 * DN_{ch3} - 0.188 * DN_{ch1})/(DN_{ch3} + 0.044 * DN_{ch1}) \qquad \textbf{(Eq. 3)}$$

Channel 1 (DN_{ch1}) contains both red and NIR light, while Channel 3 (DN_{ch3}) contains only NIR light. The equation isolates the red light from NIR light in Channel 1 while simultaneously accounting for unequal irradiance in the NIR and red bands.

Remote-sensing drone flights were conducted throughout the corn crop’s growing season (2020) to evaluate NDVI. At Dakota Lakes, the dates flown were June 11, June 19, July 01, July 13, and August 03. At Canning, the dates flown were June 23, July 07, July 24, and August 03.

Corn Tissue Analysis

Corn tissue samples were obtained at the V5-V6 stage and again at the R1 stage. At V5-V6, the top leaf with collar was removed from 15-20 randomly selected plants within each plot. At R1, the ear leaf was removed from 15-20 randomly selected plants within each plot. At the Dakota Lakes site sampling for V5-V6 and R1 stages (Table A.2) took place on 2020-06-24 and 2020-07-27, respectively. At the Canning site sampling for V5/V6 and R1 stages (Table A.2) took place on 2020-06-29 and 2020-07-28, respectively. Ward Laboratories Inc. (Kearney, NE) measured concentration of nitrogen and sulfur in leaf tissue (Ward, 2019).

Corn Grain Yield/Analysis

A Zern 150 plot combine with a 3 row 50 cm Franco Fabril Evolution corn head was used to harvest the plot at Dakota Lakes. The same combine with a 2 row 76 cm Franco Fabril Evolution corn head was used to harvest the plot at Canning. Corn was harvested at the Dakota Lakes plot on 2020-10-01. Corn was harvested at the Canning plot on 2020-10-09. The harvested area was identical at Dakota Lakes and Canning (0.001626 ha) as 3 rows were harvested at Dakota Lakes with row spacing of 50 cm, and 2 rows were harvested at Canning with row spacing of 76 cm. Corn grain yield is presented on a standard corn moisture (15.5%) basis. This was determined by the combine's grain moisture analyzer.

Ward Laboratories Inc. used near infrared spectroscopy (NIRS) method to measure grain crude protein (Ward, 2019).

Statistical Analysis

Statistical analysis was performed in R programming language using the "agricolae" package to conduct analysis of variance. Because the control treatment did not include the termination date factor, multiple statistical analyses were run. To test the effect of seeding mixtures and termination dates, cover crop seeding mixture was considered the whole plot factor and termination timing was considered the subplot factor. Control treatments were not included in this analysis. Blocks (replications) were treated as random effects.

To compare all treatments to the Control, a transformation was performed on these data to allow for a contrast to the Control. Each response was divided by the mean of the Control from their respective block. The transformation performed expresses the response as a proportion of the Control treatment for each of the four blocks. By construction, the Control responses are equal to one and excluded from the analysis. After the transformation, a one-way ANOVA was performed on each of the 12 treatments. A hypothesis test was performed for each treatment mean to determine if it was different from the Control (1) at $\alpha = 0.10$.

Cover crop biomass, cover crop carbon content, cover crop nitrogen content, and cover crop C:N ratio data were sampled without considering the termination factor, as the terminations had not been applied as an experimental factor at the time of sampling. These data were analyzed as a one-way ANOVA at $\alpha = 0.10$. Bulk density was also analyzed as a one-way ANOVA at $\alpha = 0.10$ as termination timing was not considered. PLFA data was analyzed as a one-way ANOVA at $\alpha = 0.10$. PLFA data considered the Control treatment as a mixture factor as the termination treatments had not yet been applied when sampling took place (September 2019). Fisher's LSD method was utilized as the post hoc test following ANOVA when the F-test was significant (α =0.10).

A linear regression analysis was used to determine if there was a correlation between variables (Figures 1.14, 1.15, 1.18, 1.19). The analysis determined if the slope was different from 0 at α =0.10. If the slope was different from 0, this indicated that there was a significant relationship between the dependent and independent variables.

RESULTS AND DISCUSSION

Weather

The SDSU Mesonet weather station located at the Dakota Lakes Research Farm was used as the primary weather record (Mesonet at SDSTATE 2020). At Dakota Lakes, the mean monthly temperature in 2019 was cooler than normal (2000-2019 mean) for 9 out of the 12 calendar months (Table 1.3). The cover crop grown in the fall of 2019 experienced below normal temperatures for much of its growing season. Mean monthly temperature in 2020 deviated less from normal (2000-2019 mean) compared to 2019.

2019 monthly precipitation, 2020 monthly precipitation, and historical average monthly precipitation at Dakota Lakes data are shown in Table 1.4 and at Canning in Table 1.5. Figure 1.1 presents a plot of normal precipitation (mean) versus the season precipitation at Dakota Lakes for July 2019 through October 2020. Figure 1.3 presents the same data as Figure 1.1 for a shortened time frame (January 2020 through October 2020). Figure 1.2 presents a plot of normal precipitation (mean) versus the season precipitation at Canning for July 2019 through October 2020. Figure 1.4 presents the same data as Figure 1.2 for a shortened time frame (January 2020 through October 2020).

Precipitation at Dakota Lakes in 2019 was characterized by a wetter than normal late summer carrying into the fall. Early spring 2020 was abnormally dry. On 2020-06-07, a large precipitation event delivered 50.8 mm at Dakota Lakes. Canning received even more precipitation during this rainfall event. Unfortunately, rain gauges were not installed at the Canning site to record this event. Precipitation measurements from producers near the Canning site were used to estimate this precipitation event at 102 mm. This storm also brought damaging hail and winds at Canning. At the V3 stage, the corn crop was stripped and tattered, with some plants being killed. Fortunately, the thin stand of corn recovered quite well.

The cool wet fall in 2019 was advantageous for the cover crop and contributed to the production of biomass. When corn was planted in 2020, the weather conditions made for a dry seed bed. Late spring 2020 brought substantial precipitation which carried the corn crop into the summer months. In July 2020, corn began showing signs of stress due to lack of moisture. This stress was exacerbated by the lack of precipitation in the late summer carrying into the fall.

Plant Available Water (calculated from gravimetric moisture measurement)

At Dakota Lakes on 2019-09-24, prior to any termination factor being applied, PAW was estimated between the different cover crop mixes and Control (Table 1.6). Cover crops utilized soil moisture in the fall of 2019 resulting in all cover cropped treatments containing less plant available water than the Control on 2019-11-08. In November 2019, the mixture and termination factors had no statistical difference amongst cover cropped treatments. On 2020-04-08 all cover cropped treatments contained less PAW than the Control remaining consistent with the November 2019 PAW. In April, the mixture and termination factors had no statistical difference amongst cover cropped treatments. On the June sampling date, a trend showed the Brdlf-M2 mixture had less plant available water than the other cover crop mixes, while the Grass-M1 mixture had the most plant available water. Following corn harvest, on 2020-10-02, fewer than half of the cover cropped treatments differed from the Control with no trend present. In October, there was no difference amongst cover cropped treatments.

At the Canning site on 2019-09-27, prior to any termination factor being applied, PAW was estimated between the different cover crop mixes and Control (Table 1.7). On 2019-11-08, all cover cropped treatments contained less PAW than the Control except for the Grass-M1 Term 1 treatment. In November 2019, there was no difference amongst cover cropped treatments. On 2020-04-17, all cover cropped treatments contained less PAW than the Control except for the Brdlf-M2 Term 1 treatment. In April, the mixture and termination factors had no statistical difference amongst cover cropped treatments. On 2020-06-17, no significant difference was found when comparing the cover cropped treatments to the control. In June, the mixture and termination factors had no statistical difference amongst cover cropped treatments. Following corn harvest on 2020-10-15, only the Grass-M1 Term 3 and Brdlf-M2 Term 3 treatments contained less PAW than the Control. Mixture and termination factors had no statistical difference amongst cover cropped treatments at this sampling date.

The cover cropped treatments at Dakota Lakes contained less soil moisture than the Control from 2019-09-24 through 2020-04-08. On 2020-06-16, the Grass-M1 contained more PAW than the Brdlf-M2 and Blend-M3. An explanation for this is due to the lower carbon to nitrogen ratio of the surface residue produced by broadleaves compared to grasses. Broadleaf residue typically has a lower C:N ratio which causes the residue to decompose quicker and leave the soil surface with less cover (USDA-NRCS, 2011). Reduced soil surface cover results in increased evaporation from the soil surface (Klocke et al., 2009).

The cover cropped treatments at the Canning site showed no statistical differences from the Control in 2020-06-17, despite all cover cropped treatments having numerically less soil moisture than the Control. This is the time at which the corn crop starts to use a significant amount of soil moisture (approximately V5/V6 stage) (Trooien et al., 2009). If every cover cropped treatment contained the same amount of soil moisture as the Control at the V5/V6 stage, it would indicate that the corn crop was not affected by the soil moisture usage from the fall cover crop.

Termination timing did not affect plant available water significantly at any sampling date for either site. The fall of 2019 was wetter than normal which may have prevented the soil profile from becoming depleted. The cover crops did not establish deep extensive root systems because their active growing season was limited. This would mean that the cover crops predominantly accessed the soil moisture in the shallow depths of the soil profile.

Consumptive Water Use

At Dakota Lakes, the Control treatment consumptive water use was less than six of the eight Brdlf-M2 and Blend-M3 treatments (Table 1.8). None of the Grass-M1 treatments consumed significantly more water than the Control. The Grass-M1 biomass had a higher C:N ratio (Figure 1.12). The higher the C:N ratio of surface residue, the slower it decomposes (USDA-NRCS, 2011). This may have reduced evaporation from the soil surface and reduced the water consumption.

At Canning, the Control consumed numerically less water than all cover cropped treatments; however only one treatment (Blend-M3 Term 1) was significantly different from the Control (Table 1.9).

Water Use Efficiency

At Dakota Lakes, the Control produced the highest water use efficiency and was significantly higher than seven of the cover cropped treatments (Table 1.10). At Canning, the Control again produced the highest water use efficiency and was significantly higher than most cover cropped treatments (Table 1.11). This water use efficiency only accounted for corn grain yield. If cover crop biomass were to be considered as well, it would likely cause a drastic change as the Control produced no cover crop biomass.

Soil Nutrients

Excluding the Control treatment, soil nitrate-nitrogen at Dakota Lakes (Table 1.12) was not affected by mixture or termination on any sampling date. On 2020-04-08, all cover cropped treatments contained numerically less soil nitrate-nitrogen than the Control; however, only four treatments were significantly different from the Control. On 2020-06-15, soil nitrate-nitrogen in cover cropped treatments were not significantly different than the Control except for the Brdlf-M2 Term 3 treatment (p=0.084). On 2020-10-02, none of the cover cropped treatments were significantly different from the Control.

On 2020-04-17 at the Canning site, soil nitrate-nitrogen showed statistical differences amongst the different termination timings (p=0.100) (Table 1.13). Term 1 contained the most soil nitrate-nitrogen (45 kg ha^{-1}) while Term 2 (36 kg ha^{-1}), Term 3 (37 kg ha^{-1}), and Term 4 (38 kg ha^{-1}) were not statistically different from one another. All treatments from the April sampling were significantly less than the Control treatment. On 2020-06-16, soil nitrate-nitrogen was numerically higher in the Control treatment than all other treatments, with Grass-M1 Term 2 (p=0.104) and Grass-M1 Term 3 (p=0.689) being not significantly different. Excluding the control, mixture and termination factors had no significant effect in June. On 2020-10-02, Grass-M1 Term 4 ($p=0.041$) was the only treatment significantly different from the Control. Excluding the Control, mixture and termination factors again had no significant effect.

Considering both sites, soil nitrate-nitrogen was not consistently affected by cover crop mixture or termination timing. In early spring (April 2020), soil nitrate-nitrogen was lower in the cover cropped treatments than the Control. At this same sampling date, soil ammonium-N was higher in the cover cropped treatments than the Control. This indicates that more net nitrogen mineralization had taken place in the Control than in the cover cropped treatments throughout the fall and winter. Growing a cover crop in the fall immobilized some soil nitrogen.

By June, the cover cropped treatments at Dakota Lakes had no less soil nitrate-nitrogen than the Control. November soil nitrate-nitrogen soil tests were used for nitrogen fertilizer application calculations. Nitrogen fertilizer was split applied at Dakota Lakes on 2020-04-30 and 2020-05-15. The June soil nitrate-nitrogen sampling at Dakota Lakes shows that fertility applications replenished the soil nitrate-nitrogen in the cover cropped treatments. For the June soil nitrate-nitrogen measurements at Canning, all cover cropped treatments were lower than the Control. This introduced variability into the experiment with the cover crops having less soil nitrate-nitrogen available.

Soil ammonium-N at Dakota Lakes was measured on 2020-04-08 and 2020-10-02. Excluding the Control treatment, soil ammonium-N at Dakota Lakes was not affected by mixture or termination on either sampling date. In April, all cover cropped treatments contained more soil ammonium-N than the Control; however, only the Brdlf-M2 Term 1 (p=0.004) and Brdlf-M2 Term 3 (p=0.045) treatments were statistically significant. The Brdlf-M2 Term 4 (p=0.016) treatment was the only treatment significantly different from the Control post-harvest in October.

Soil ammonium-N at Canning was measured on 2020-04-17 and 2020-10-15. On 2020-04-17, soil ammonium-N was higher in the cover cropped treatments than in the Control treatment, with Blend-M3 Term 3 (p=0.180) and Blend-M3 Term 4 (p=0.178) being not significantly different. Mixture (p=0.070) had a significant impact on soil ammonium-N in April with Brdlf-M2 containing the most soil ammonium-N (370 kg ha^{-1}), followed by Blend-M3 (330 kg ha^{-1}), and Grass-M1 (290 kg ha^{-1}). On 2020-10-15, soil ammonium-N in cover cropped treatments were not significantly different than the Control except for the Brdlf-M2 Term 2 (p=0.018) treatment.

At both Dakota Lakes and Canning, the April sampling date showed less soil ammonium-N in the Control than the cover cropped treatments. As discussed above, in the early spring soil nitrate-nitrogen was higher in the Control treatment. This indicates that nitrogen mineralization occurred, converting soil ammonium-N to soil nitrate-nitrogen during the time at which the Control did not have a living crop (August 2019-April 2020). In April at Canning, soil ammonium-N was affected by mixture with Brdlf-M2 having the most, followed by Blend-M3, and Grass-M1. This contradicts the findings of Wei et al., (2019) who found that a higher broadleaf percentage by species in a polyculture resulted in lower soil ammonium-N concentrations.

Cover crops appeared to have no impact to soil sulfate at the Dakota Lakes site (Table 1.14). Mixture and termination factors had no effect at any sampling date. The only measurement significantly different from the control was the Grass-M1 Term 1 (p=0.013) treatment sampled on 2020-10-02.

Excluding the control, soil sulfate was not affected by mixture or termination timing factor at any sampling date. On 2020-04-17, Brdlf-M2 Term 4 (p=0.082) treatment was significantly higher than the Control. On 2020-06-17, Brdlf-M2 Term 1 (p=0.089) treatment was significantly higher than the Control. On 2020-10-15, half of the cover cropped treatments were significantly different than the Control, but no trend was present.

Cover cropped treatments did not have a consistent impact to the availability of soil sulfate at either site. Soil sulfate at Canning (Table 1.15) was much higher than at Dakota Lakes (Table 1.14). This is due to a difference in soil types. The Dorna silt loam soil at Dakota Lakes contains 1% hydrated calcium sulfates in the <20 mm soil fraction, while the Hurley silt loam at Canning contains 9% hydrated calcium sulfates (Web Soil Survey, 2020).

Phospholipid-derived Fatty Acid (PLFA)

At Dakota Lakes none of the functional groups were significantly different at α=0.1 (Table 1.16). Arbuscular mycorrhizal fungi were numerically lower in the Control than in the cover cropped mixtures. Fallow syndrome is likely to be the cause of this disparity (Thompson, 1987). At Dakota Lakes and Canning (Table 1.17) the total living microbial biomass was numerically lower in the Control than the cover cropped mixtures.

Cover Crop biomass, carbon content, nitrogen content and C:N ratio

Cover crop biomass, biomass carbon content, biomass nitrogen content, and biomass C:N ratio at Dakota Lakes (Table 1.18) were sampled at three different dates in the fall of 2019. At Dakota Lakes, date was a significant factor for cover crop biomass (p<0.001), biomass carbon content (p<0.001), biomass nitrogen content (p<0.001) and insignificant for biomass C:N ratio (p=0.709). Mixture was a significant factor for biomass nitrogen content (p<0.001) and biomass C:N ratio (p<0.001) and insignificant for cover crop biomass (p=0.633) and biomass carbon content (p=0.785). The date*mixture interaction term was significant for biomass carbon content (p=0.036).

Data for Canning cover crop biomass, biomass carbon content, biomass nitrogen content, and biomass C:N ratio is presented in Table 1.19. Date was a significant factor for cover crop biomass (p<0.001), biomass carbon content (p<0.001), biomass nitrogen content (p<0.001) and biomass C:N ratio (p=0.025). Mixture was a significant factor for cover crop biomass (p<0.001), biomass carbon content (p<0.001), and biomass C:N ratio (p=0.025) while insignificant for biomass nitrogen content (p=0.656). The date*mixture interaction term was significant for cover crop biomass (p=0.062), biomass carbon content (p=0.031), and biomass nitrogen content (p=0.025).

At Dakota Lakes and Canning, date significantly impacted cover crop biomass, biomass carbon content, and biomass nitrogen content as they all increased over time. Date was significant for biomass C:N ratio at Canning, but not Dakota Lakes. Mixture impacted biomass C:N ratio at both sites with Grass-M1 having the highest ratio, followed by Blend-M3, and lastly Brldf-M2. These results follow the expected outcome as grasses typically have a higher C:N ratio than broadleaf plants (NRCS-USDA, 2011). At Dakota Lakes and Canning, the interaction term was significant for carbon and nitrogen.

Surface Residue

Surface residue samples were obtained on 2020-04-30 at the Dakota Lakes and Canning sites. At Dakota Lakes, excluding the Control, mixture and termination had no significant effect on surface residue biomass (Table 1.20). All but one cover cropped treatment, Grass-M1 Term 1, had numerically more surface residue biomass than the Control treatment. Only one treatment, Blend-M3 Term 3 (p=0.077), was significantly different from the Control.

At Canning, excluding the Control, mixture (p=0.119) showed a trend and termination (p=0.066) was significant (Table 1.21). The Grass-M1 mixture contained the most surface residue biomass (4040 kg ha^{-1}), Blend-M3 had (3660 kg ha^{-1}), and Brdlf-M2 had (3430 kg ha^{-1}). Surface residue biomass content by Termination timing were Term 3 (4260 kg ha^{-1}), Term 2 (3570 kg ha^{-1}), Term 1 (3520 kg ha^{-1}), Term 4 (3500 kg ha^{-1}). All but one cover cropped treatment, Brdlf-M2 Term 4, had more surface residue biomass than the Control treatment.

At Canning, the surface residue biomass was higher in the Grass-M1 followed by Blend-M3, and lastly Brdlf-M2. Broadleaves have a lower C:N ratio which results in faster decomposition (Brady & Weil 1999).

Corn Stand Counts

Corn stand counts were made on three separate dates at Dakota Lakes (Table 1.22) and Canning (Table 1.23). At Dakota Lakes, mixture (p=0.064) was a significant factor on 2020-06-01. On the first stand count at Dakota Lakes on 2020-05-26, the Control was the highest stand count treatment. This was the case at the Canning site as well on 2020-05-27 and 2020-06-02. At Canning, mixture (p=0.083) was a significant factor on 2020-06-15.

At both sites, corn plants emerged quicker in the Control (wheat straw) compared to the cover cropped treatments. This could be explained by the higher surface residue biomass content in the cover cropped treatments. Less residue causes the soil to warm up sooner in the spring and furthermore causes quicker emergence (Alessi & Power, 1971). This difference in stand counts was negligible at both sites by the last stand count date (2020-06-08 at Dakota Lakes and 2020-06-15 at Canning).

Stomatal Conductance

At Dakota Lakes and Canning, excluding the Control treatment, mixture and termination had no significant effect on stomatal conductance. When comparing to the Control, Brdlf-M2 Term 1 (p=0.027) and Brdlf-M2 Term 2 (p=0.029) were significantly higher at Dakota Lakes (Table 1.24), while Blend-M3 Term 1 (p=0.098) was significantly higher at Canning (Table 1.25).

At Dakota Lakes, a trend existed in which the Control treatment was lower than all other cover cropped treatments except for Blend-M3 Term 1. This suggests that soil water in the Control treatment is lower than in cover cropped treatments (Urban et al., 2017). Plant available water estimates showed otherwise. Arbuscular mycorrhizal fungi (AMF) were numerically higher in the cover cropped treatments than in the Control (p=0.151) (PLFA Table). Arbuscular mycorrhizal fungi (AMF) act as an extension of the root system and assist in water and nutrient uptake (Birhane et al., 2012). A larger population of arbuscular mycorrhizal fungi in the cover cropped treatments may have contributed to the higher stomatal conductance readings.

Corn Normalized Difference Vegetation Index (NDVI)

Excluding the Control, termination (p=0.033) timing was a significant effect for NDVI on 2020-06-11 at Dakota Lakes (Table 1.26). The NDVI values for this flight shown in decreasing order were Term 4, Term 3, Term 2, Term 1. Termination timing for NDVI at Canning (Table 1.27), excluding the Control, was significant every date NDVI was analyzed. At Canning the order was reversed from Dakota Lakes, as the NDVI values for each date in decreasing order were Term 1, Term 2, Term 3, Term 4. On 2020-06-11 most cover cropped treatments NDVI values were significantly higher than the Control. This trend disappeared on the flights later in the season. At Canning, most cover cropped treatment NDVI values were significantly lower than the Control on 2020-06-23, 2020-07-07, and 2020-08-03. The NDVI results at Canning indicate that the earlier termination timings in the fall increased the amount of live green vegetation in the corn crop.

Corn Tissue

Nutrient sufficiency ranges for nitrogen in corn at V6 are 3.5-4.5% and at R1 are 2.76-3.75% (Clay, 2016). At Dakota Lakes, corn tissue nitrogen was sufficient at V5/V6 (2020-06-24) for all treatments (Table 1.28). At R1 (2020-07-27), corn tissue nitrogen was deficient in approximately half of the cover cropped treatments. The Control was numerically higher than or equal to all cover cropped treatments at the V5/V6 stage, and numerically higher than most cover cropped treatments at the R1 stage. At Canning, corn tissue nitrogen was deficient at V5/V6 (2020-06-29) for all treatments (Table 1.29). The Control and Brdlf-M2 Term 1 treatments were sufficient at R1 (2020-07-28) while all other cover cropped treatments were deficient of corn tissue nitrogen. At V5/V6, tissue nitrogen was numerically less in the Control than all other cover cropped treatments. Conversely, at R1, tissue nitrogen in the Control was numerically higher than all other cover cropped treatments.

Dakota Lakes data showed the Control treatment had higher tissue nitrogen content than cover cropped treatments at V5/V6. The opposite of this was true at Canning, with the Control having numerically less tissue nitrogen at V5/V6. Interestingly at the R1 stage at Canning, the tissue nitrogen in the Control shifted from being the lowest numerically at V5/V6 to being the highest at R1. It is possible that early in the season (V5/V6) the cover crop residue was supplying additional nitrogen to the corn crop. Nitrogen was side banded at Dakota Lakes at a rate of 28 kg of N ha^{-1}. At Canning, no N was side banded, which could explain the deficiency at the vegetative stage (V5/V6).

Sulfur sufficiency ranges for sulfur in corn at V5/V6 are 0.18-0.40% and at R1 are 0.16-0.40% (Clay, 2016). At Dakota Lakes, corn tissue sulfur was sufficient at V5/V6 and R1 for all treatments (Table 1.28). The Control was numerically higher than most cover cropped treatments at the V5/V6 and R1 stage. At Canning, corn tissue sulfur was sufficient at V5/V6 and R1 for all treatments (Table 1.29). The Control was numerically higher than all cover cropped treatments at the R1 stage.

Corn tissue sulfur was not deficient at either site. At Dakota Lakes, corn tissue sulfur was numerically higher in the Control at both the V5/V6 and R1 stages. At Canning, corn tissue sulfur was numerically higher in the Control at the R1 stage. Soil sulfate was not significantly impacted by cover crop mixture or termination timing (see

Table 1.12 and Table 1.13) and therefore does not explain the difference in sulfur uptake by corn.

Corn Grain Yield/Analysis

Excluding the Control, at Dakota Lakes, termination (p=0.052) timing had a significant effect on corn grain yield (Table 1.30). The Control was significantly higher yielding than all treatments except Blend-M3 Term 1 (p=0.248). Each treatment's corn grain yield at Dakota Lakes is presented in Figure 1.16. Excluding the Control, at Canning, termination (p=0.011) timing had a significant effect on corn grain yield (Table 1.31). Each treatment's corn grain yield at Canning is presented in Figure 1.17. The Control was significantly higher yielding than most cover cropped treatments.

At Dakota Lakes, as cover crop biomass (kg ha^{-1}) increased later in the fall of 2019, the following corn grain yield (kg ha^{-1}) declined ($p<0.001$) (Figure 1.18). This same trend occurred at Canning (p=0.003) (Figure 1.19).

The grain yield data agrees with work done by Kuykendall et al., (2015); Reese et al., (2014); Hively & Cox, (2001) in showing that cover crops can have a negative impact on the following cash crop yield. 2020 was a below average precipitation year. This affirms Unger & Vigil, (1998) concerns of potential negative impacts of cover crops in semi-arid regions where precipitation is variable and inconsistent (Unger & Vigil, 1998).

Corn grain test weight at Dakota Lakes for most cover cropped treatments were not significantly different from the Control treatment (Table 1.30). Corn grain test weight at Canning for most cover cropped treatments were not significantly different from the Control treatment (Table 1.31).

For corn grain crude protein at Dakota Lakes, only the Grass-M1 Term 2 treatment was significantly different from the Control (Table 1.30); however, the Control was numerically greater than or equal to all cover cropped treatments. At Canning, all cover cropped treatments were significantly lower in corn crude protein percentage than the Control treatment (Table 1.31). Reduced grain crude protein percentage can be indicative of nitrogen deficiencies (Hammad et al., 2011). As shown in Table 1.9, soil nitrogen at Canning on 2020-06-17 was significantly higher in the Control than most cover cropped treatments. This nitrogen deficiency could explain the lower crude protein contents in the cover cropped treatments at Canning. A linear regression of total nitrogen (kg ha^{-1}) (spring soil nitrate-nitrogen plus nitrogen fertilizer applied) versus crude protein (%) showed total nitrogen had an impact on crude protein (%) at Canning ($p=0.004$) (Figure 1.15) and at Dakota Lakes ($p=0.171$) (Figure 1.14). Cover crops sequester soil nitrogen, and it is likely that some of this nutrient was still tied up in the surface residue throughout the corn’s growing season.

CONCLUSIONS

From 2019-11-01 until 2020-09-01 (months that impacted soil moisture available to the corn crop) 373 mm of precipitation was measured at Dakota Lakes. Considering precipitation data from 2002-2019, this precipitation record for the plot at Dakota Lakes ranked 8th wettest out of 16 years of data. For the same time frame and using the same historical weather data, the Canning site (423.8 mm) ranked as the 5th wettest year out of 16 years. 2020 was a drier than normal year in central South Dakota, however the time frame that impacted the soil moisture availability in the corn crop was not drier than normal.

Grain yield was significantly lower in most of the cover cropped treatments as compared to the Control. Cover crops reduced soil moisture in the fall of 2019 carrying through into spring 2020. This difference in soil moisture narrowed later in the 2020 corn growing season. Soil nitrate-nitrogen in early spring 2020 showed that fall cover crops sequestered a significant amount of nitrogen in the fall compared to the Control. At Dakota Lakes this difference was no longer present in June 2020, while at Canning it was still present.

At both locations, C:N ratio of the cover crops manifested an expected result as the mixtures shown in decreasing order were Grass-M1, Blend-M3, and Brdlf-M2. At Canning, the spring surface residue biomass shown in decreasing order were again Grass-M1, Blend-M3, and Brdlf-M2. More soil evaporation would be expected due to less soil cover; however, this difference was not observed in plant available water (PAW) data.

At Dakota Lakes, grain crude protein was numerically higher in the Control than cover cropped treatments, while at Canning the Control was significantly higher than other treatments. This suggests that the corn grain yield was impacted by differences in total soil nitrogen (Figure 1.15). It is difficult to pinpoint these differences in soil nitrogen to one specific factor. Fertilizer applications, differences in species composition between mixtures, and termination timing likely impacted the nutrient availability.

This experiment demonstrated one of the risks of sacrificing grain yield of the following cash crop following a cover crop in central South Dakota. It is likely that the reduction in corn grain yield is a function of both reduced soil moisture and nitrogen. Earlier terminated cover crops resulted in a higher yielding corn crop as compared to those last terminated. The cover crops terminated later in the season produced more cover crop biomass but reduced the corn grain yield the following year (Figure 1.18 and Figure 1.19). Terminating cover crops proved to be an effective practice. This approach saved a portion of the grain yield in the following cash crop while still accomplishing some of the benefits from cover cropping. Drawbacks of early termination include reduced cover crop biomass production and reduced length of time that a living root is in place. The different cover crop mixtures tested did not significantly impact corn grain yield.

Table 1.1. Plant species and seeding rate of cover crops seeded in summer 2019 following wheat harvest at Dakota Lakes Research Farm (18 miles east of Pierre, SD) and Canning (central South Dakota).

Common Name	Scientific Name	Grass-M1	Brdlf-M2	Blend-M3
		-------------kg ha^{-1}-------------		
Forage Peas	Pisum sativum L.	1.8	18.5	8.6
Indianhead Lentils	Lens cullinaris	0.8	8.0	3.8
Buster Radish	Raphanus sativus L.	0.2	2.1	1.0
Purple Top Turnips	Brassica rapa	0.1	1.0	0.6
Hayden Oats	Avena sativa	15.5	2.1	8.6
Lavina Barley	Hordeum vulgare	16.5	2.2	9.2
Golden German Millet	Setaria italica	4.5	0.6	2.5
Bunker Buster Forage Sorghum	Sorghum bicolor L. Moench	5.2	0.7	2.9
	Total Seeding Rate	44.5	35.2	37.2

Table 1.2. Cover crop herbicide termination operation timing and weather conditions for the fall of 2019 at Dakota Lakes Research Farm (18 miles east of Pierre, SD) and Canning (central South Dakota).

Plot	Termination	Date	Weather Conditions	Wind (m/s)
Dakota Lakes	Term 1	2019-09-27	Overcast 16°C	2.2-4.5 (North)
Dakota Lakes	Term 2	2019-10-07	Sunny 18°C	2.2-4.5 (South)
Dakota Lakes	Term 3	2019-11-02	Overcast 2°C	4.5-6.7 (Northwest)
Dakota Lakes	Term 4	2019-11-08	Sunny 5°C	2.2-4.5 (Southeast)
Canning	Term 1	2019-09-27	Overcast 16°C	2.2-4.5 (North)
Canning	Term 2	2019-10-17	Mostly Sunny 18°C	4.5-6.7 (East)
Canning	Term 3	2019-11-02	Overcast 2°C	4.5-6.7 (Northwest)
Canning	Term 4*	2019-11-09	Sunny 16°C	2.2-4.5 (North)

*Terminated by killing frost but was not sprayed with herbicides until 2020-05-06.

Table 1.3. Dakota Lakes Research Farm (18 miles east of Pierre, SD) monthly mean air temperature 2000-2019, 2019, 2020, 2019 difference from mean, and 2020 difference from mean.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						Temperature °C						
(2000-2019) Mean	-6.3	-5.7	1.3	7.9	14	20	24	23	18	8.8	1.5	-5.6
2019	-8	-14	-4	7	11	20	18	20	18	5	0	-5
2019 ± from (2000-2019) Mean	-1.7	-8.3	-5.3	-0.9	-3.0	0	-6.0	-3.0	0	-3.8	-1.5	+0.6
2020	-6	-3	3	7	13	22	24	23	17	6	4	-2
2020 ± from (2000-2019) Mean	+0.3	+2.7	+1.7	-0.9	-1.0	+2.0	0	0	-1.0	-1.8	+2.5	+3.6

Table 1.4. Dakota Lakes Research Farm (18 miles east of Pierre, SD) monthly precipitation data mean and median of 2002-2019, 2019, and 2020. Data source is South Dakota State University Mesonet supplemented by rain gauges at Dakota Lakes.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
						Precipitation (mm)							
(2002-2019) Mean	9.1	15	25	49	68	83	40	55	44	33	12	16	449
(2002-2019) Median	6.6	15	22	50	64	80	28	55	29	26	7.0	16	399
2019	13	30	39	55	82	15	85	97	83	29	33	26	587
2020	3.0	7.0	20	8.0	59	105	75	36	5.0	5.0	9.0	3.0	335

Table 1.5. Canning (central South Dakota) monthly precipitation data mean and median of 2002-2019, 2019, and 2020. Data source is South Dakota State University Mesonet weather station located at Dakota Lakes Research Farm supplemented by rain gauges at Canning.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
					Precipitation (mm)								
(2002-2019) Mean	9.1	15	25	49	68	83	40	55	44	33	12	16	449
(2002-2019) Median	6.6	15	22	50	64	80	28	55	29	26	7.0	16	399
2019	13	30	39	55	82	15	85	97	83	28	33	26	586
2020	3.0	7.0	20	8.0	59	144	74	36	5.0	5.0	9.0	3.0	373

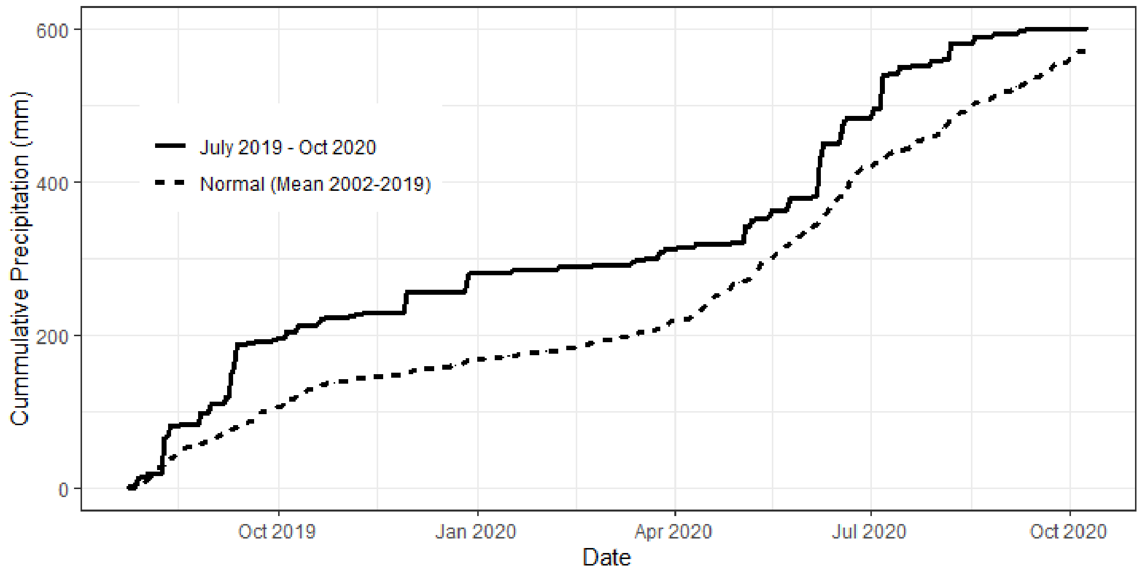

Figure 1.1. Dakota Lakes Research Farm (18 miles east of Pierre, SD) precipitation (July 2019-October 2020). Data source is South Dakota State University Mesonet weather station located at Dakota Lakes Research Farm supplemented by rain gauges.

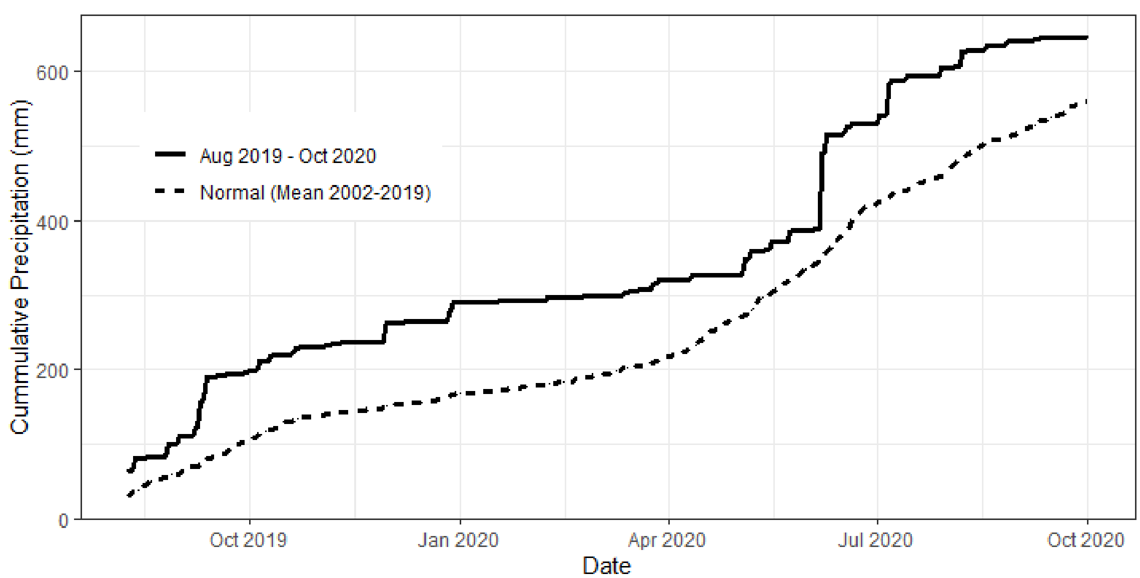

Figure 1.2. Canning (central South Dakota) precipitation (August 2019-October 2020). Data source is South Dakota State University Mesonet weather station located at Dakota Lakes Research Farm supplemented by rain gauges.

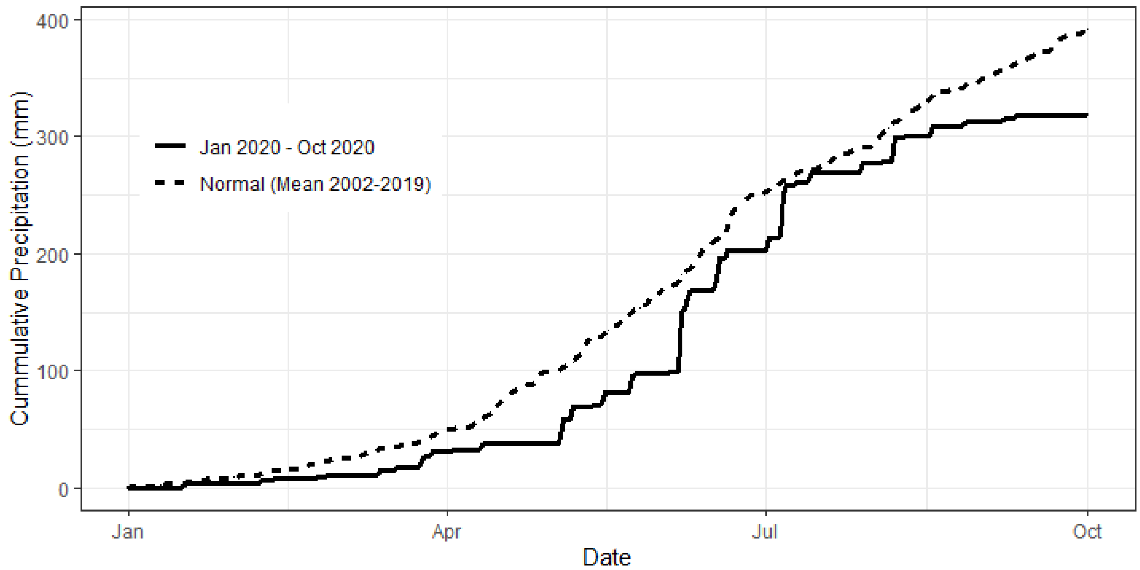

Figure 1.3. Dakota Lakes Research Farm (18 miles east of Pierre, SD) precipitation (January 2020-October 2020). Data source is South Dakota State University Mesonet weather station located at Dakota Lakes Research Farm supplemented by rain gauges.

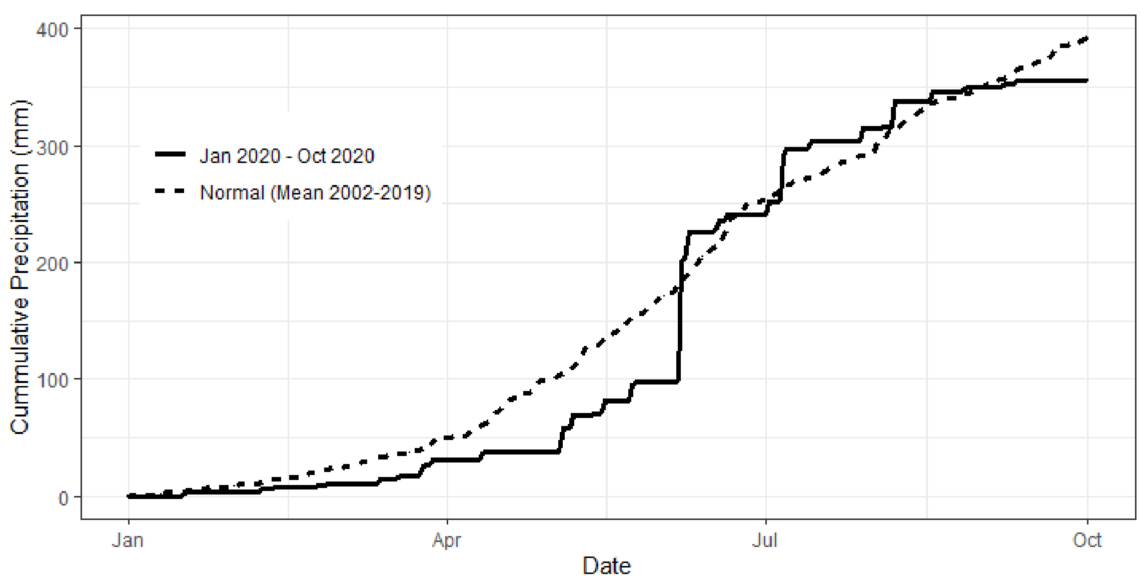

Figure 1.4. Canning (central South Dakota) precipitation (January 2020-October 2020). Data source is South Dakota State University Mesonet weather station located at Dakota Lakes Research Farm supplemented by rain gauges.

Table 1.6. Dakota Lakes Research Farm (18 miles east of Pierre, SD) plant available water (mm) for 0-90 cm soil profile. Web soil survey used to obtain soil water at permanent wilting point (PWP). Gravimetric soil samples used to calculate total soil water. Soil water at PWP subtracted from total soil water to estimate plant available water (mm).

Mixture	Termination	2019-07-26	2019-09-24	2019-11-08	2020-04-08	2020-06-16	2020-10-02
Grass-M1	Term 1	21 (6.5)	100 (11) ***	87 (20) **	60 (17) ***	137 (4.2) NS	97 (9.2) NS
Grass-M1	Term 2	21 (6.5)	100 (11) ***	87 (20) **	68 (29) **	142 (9.8) NS	113 (15) NS
Grass-M1	Term 3	21 (6.5)	100 (11) ***	71 (35) ***	46 (34) ***	139 (2.7) NS	101 (4.0) **
Grass-M1	Term 4	21 (6.5)	100 (11) ***	82 (19) ***	69 (15) ***	138 (8.3) NS	114 (NA) ‡
Brdlf-M2	Term 1	21 (6.5)	87 (12) ***	90 (25) **	56 (17) ***	132 (3.2) **	104 (7.1) NS
Brdlf-M2	Term 2	21 (6.5)	87 (12) ***	58 (21) ***	30 (23) ***	132 (6.9) ***	106 (8.7) NS
Brdlf-M2	Term 3	21 (6.5)	87 (12) ***	87 (11) **	65 (29) **	132 (3.4) ***	101 (11) **
Brdlf-M2	Term 4	21 (6.5)	87 (12) ***	62 (13) ***	40 (15) ***	138 (6.3) NS	91 (0.5) ***
Blend-M3	Term 1	21 (6.5)	91 (3.9) ***	89 (6.3) **	61 (16) **	134 (10) **	104 (5.8) NS
Blend-M3	Term 2	21 (6.5)	91 (3.9) ***	98 (21) *	68 (23) ***	141 (3.0) NS	103 (11) **
Blend-M3	Term 3	21 (6.5)	91 (3.9) ***	67 (19) ***	48 (15) ***	134 (1.7) **	101 (13) **
Blend-M3	Term 4	21 (6.5)	91 (3.9) ***	83 (27) ***	37 (31) ***	134 (5.6) **	87 (NA) ‡
Control		21 (6.5)	139 (7.5)	118 (13)	104 (7.6)	141 (3.1)	119 (15)

†Standard deviation shown in parentheses after treatment mean
NS Treatment mean not significantly different from Control treatment at α= 0.1
* Treatment mean differs from Control treatment at α= 0.1
** Treatment mean differs from Control treatment at α= 0.05
*** Treatment mean differs from Control treatment at α= 0.01
‡ Insufficient replicated data to produce standard deviation

Table 1.6a. Dakota Lakes Research Farm (18 miles east of Pierre, SD) plant available water (mm) for 0-90 cm soil profile statistical analysis.

Factor	2019-07-26	2019-09-24	2019-11-08	2020-04-08	2020-06-16	2020-10-02
			P Value			
Mixture	-----	<0.001	0.128	0.234	0.072	0.438
Termination	-----	-----	0.394	0.860	0.407	0.604
Mixture*Termination	-----	-----	0.170	0.351	0.471	0.612

†Split-plot ANOVA excluding Control treatment

Table 1.7. Canning (central South Dakota) plant available water (mm) for 0-90 cm soil profile. Web soil survey used to obtain soil water at permanent wilting point (PWP). Gravimetric soil samples used to calculate total soil water. Soil water at PWP subtracted from total soil water to estimate plant available water (mm).

Mixture	Termination	2019-08-09 ‡	2019-09-27	2019-11-15	2020-04-17	2020-06-17	2020-10-15
Grass-M1	Term 1	0	51 (14) ***	78 (9.5) NS	76 (8.1) **	88 (6.3) NS	63 (14) NS
Grass-M1	Term 2	0	51 (14) ***	45 (25) ***	67 (16) ***	92 (17) NS	61 (18) NS
Grass-M1	Term 3	0	51 (14) ***	64 (9.2) **	73 (8.0) ***	97 (14) NS	52 (22) **
Grass-M1	Term 4	0	51 (14) ***	61 (22) **	65 (22) ***	90 (9.7) NS	63 (9.0) NS
Brdlf-M2	Term 1	0	50 (22) ***	61 (25) **	81 (15) NS	94 (21) NS	57 (15) NS
Brdlf-M2	Term 2	0	50 (22) ***	52 (15) ***	67 (17) ***	96 (12) NS	57 (7.4) NS
Brdlf-M2	Term 3	0	50 (22) ***	37 (21) ***	65 (12) ***	94 (11) NS	49 (21) **
Brdlf-M2	Term 4	0	50 (22) ***	47 (26) ***	65 (7.5) ***	101 (14) NS	59 (15) NS
Blend-M3	Term 1	0	50 (12) ***	60 (20) **	67 (13) ***	86 (14) NS	61 (7.8) NS
Blend-M3	Term 2	0	50 (12) ***	61 (5.3) **	66 (14) ***	93 (10) NS	57 (8.3) NS
Blend-M3	Term 3	0	50 (12) ***	56 (11) ***	71 (11) ***	95 (4.5) NS	59 (4.7) NS
Blend-M3	Term 4	0	50 (12) ***	59 (7.9) **	70 (12) ***	93 (12) NS	64 (19) NS
Control		0	79 (14)	85 (13)	93 (5.6)	103 (12)	65 (16)

†Standard deviation shown in parentheses after treatment mean.
NS Treatment mean not significantly different from Control treatment at $\alpha = 0.1$
* Treatment mean differs from Control treatment at $\alpha = 0.1$
** Treatment mean differs from Control treatment at $\alpha = 0.05$
*** Treatment mean differs from Control treatment at $\alpha = 0.01$
‡ 2019-08-09 was estimated to have no measurable PAW and was uniform across all treatments.

Table 1.7a. Canning (central South Dakota) plant available water (mm) for 0-90 cm soil profile statistical analysis.

Factor	2019-08-09	2019-09-27	2019-11-15	2020-04-17	2020-06-17	2020-10-15
			P Value			
Mixture	-----	0.958	0.086	0.929	0.195	0.365
Termination	-----	-----	0.071	0.201	0.562	0.146
Mixture*Termination	-----	-----	0.169	0.607	0.656	0.904

†Split-plot ANOVA excluding Control treatment

Table 1.8. Dakota Lakes Research Farm (18 miles east of Pierre, SD) consumptive water use (mm) for 0-90 cm soil profile from 2019-07-26 – 2020-06-16. Consumptive water use is the amount of water used/lost through evapotranspiration.

Mixture	Termination	Consumptive Water Use (mm)
Grass-M1	Term 1	334 (5.4) NS
Grass-M1	Term 2	329 (13) NS
Grass-M1	Term 3	332 (6.2) NS
Grass-M1	Term 4	332 (12) NS
Brdlf-M2	Term 1	342 (1.6) **
Brdlf-M2	Term 2	339 (13) ***
Brdlf-M2	Term 3	339 (7.2) ***
Brdlf-M2	Term 4	333 (7.7) NS
Blend-M3	Term 1	337 (8.9) **
Blend-M3	Term 2	330 (9.2) NS
Blend-M3	Term 3	337 (6.5) **
Blend-M3	Term 4	337 (12) **
Control		330 (6.6)

†Standard deviation shown in parentheses after treatment mean
NS Treatment mean not significantly different from Control treatment at α= 0.1
* Treatment mean differs from Control treatment at α= 0.1
** Treatment mean differs from Control treatment at α= 0.05
*** Treatment mean differs from Control treatment at α= 0.01

Table 1.8a. Dakota Lakes Research Farm (18 miles east of Pierre, SD) consumptive water use for 0-90 cm soil profile from 2019-07-26 – 2020-06-16 statistical analysis.

Factor	P Value
Mixture	0.072
Termination	0.407
Mixture*Termination	0.471

†Split-plot ANOVA excluding Control treatment

Table 1.9. Canning (central South Dakota) consumptive water use (mm) for 0-90 cm soil profile from 2019-08-09 – 2020-06-17. Consumptive water use is the amount of water used/lost through evapotranspiration.

Mixture	Termination	Consumptive Water Use (mm)
Grass-M1	Term 1	293 (6.3) NS
Grass-M1	Term 2	289 (17) NS
Grass-M1	Term 3	284 (14) NS
Grass-M1	Term 4	291 (9.7) NS
Brdlf-M2	Term 1	287 (21) NS
Brdlf-M2	Term 2	285 (12) NS
Brdlf-M2	Term 3	287 (11) NS
Brdlf-M2	Term 4	281 (14) NS
Blend-M3	Term 1	295 (14) *
Blend-M3	Term 2	288 (10) NS
Blend-M3	Term 3	286 (4.5) NS
Blend-M3	Term 4	288 (12) NS
Control		278 (12)

†Standard deviation shown in parentheses after treatment mean
NS Treatment mean not significantly different from Control treatment at α= 0.1
* Treatment mean differs from Control treatment at α= 0.1
** Treatment mean differs from Control treatment at α= 0.05
*** Treatment mean differs from Control treatment at α= 0.01

Table 1.9a. Canning (central South Dakota) consumptive water use for 0-90 cm soil profile from 2019-08-09 – 2020-06-17 statistical analysis.

Factor	P Value
Mixture	0.195
Termination	0.562
Mixture*Termination	0.656

†Split-plot ANOVA excluding Control treatment

Table 1.10. Dakota Lakes Research Farm (18 miles east of Pierre, SD) water use efficiency (WUE) (kg ha^{-1} mm^{-1}) for 0-90 cm soil profile 2019-07-26 – 2020-10-02. Water use efficiency calculated by corn grain yield biomass (kg ha^{-1}) divided by water used/lost through evapotranspiration (mm).

Mixture	Termination	WUE (kg ha^{-1} mm^{-1})
Grass-M1	Term 1	9.7 (1.0) ^{NS}
Grass-M1	Term 2	9.5 (1.6) ^{NS}
Grass-M1	Term 3	8.9 (3.1) ***
Grass-M1	Term 4	10.3 (NA) ^{NS}
Brdlf-M2	Term 1	10.3 (0.9) ^{NS}
Brdlf-M2	Term 2	7.3 (0.9) ***
Brdlf-M2	Term 3	8.8 (0.8) **
Brdlf-M2	Term 4	8.4 (0.9) **
Blend-M3	Term 1	10.6 (1.1) ^{NS}
Blend-M3	Term 2	8.9 (1.4) ***
Blend-M3	Term 3	9.4 (1.7) **
Blend-M3	Term 4	7.0 (NA) **
Control		11.5 (1.1)

†Standard deviation shown in parentheses after treatment mean
^{NS}Treatment mean not significantly different from Control treatment at α= 0.1
* Treatment mean differs from Control treatment at α= 0.1
** Treatment mean differs from Control treatment at α= 0.05
*** Treatment mean differs from Control treatment at α= 0.01

Table 1.10a. Dakota Lakes Research Farm (18 miles east of Pierre, SD) water use efficiency (WUE) for 0-90 cm soil profile 2019-07-26 – 2020-10-02 statistical analysis.

Factor	P Value
Mixture	0.776
Termination	0.077
Mixture*Termination	0.448

†Split-plot ANOVA excluding Control treatment

Table 1.11. Canning (central South Dakota) water use efficiency (WUE) (kg ha^{-1} mm^{-1}) for 0-90 cm soil profile 2019-08-09 – 2020-10-15. Water use efficiency calculated by corn grain yield biomass (kg ha^{-1}) divided by water used/lost through evapotranspiration (mm).

Mixture	Termination	WUE
Grass-M1	Term 1	11.7 (1.7) ^{NS}
Grass-M1	Term 2	11.1 (1.3) **
Grass-M1	Term 3	11.3 (1.0) *
Grass-M1	Term 4	10.7 (1.9) **
Brdlf-M2	Term 1	11.5 (1.7) ^{NS}
Brdlf-M2	Term 2	11.5 (1.7) ^{NS}
Brdlf-M2	Term 3	10.6 (0.5) ***
Brdlf-M2	Term 4	9.8 (1.4) ***
Blend-M3	Term 1	10.7 (1.5) **
Blend-M3	Term 2	11.8 (1.6) ^{NS}
Blend-M3	Term 3	10.3 (1.3) ***
Blend-M3	Term 4	10.3 (1.1) ***
Control		12.3 (1.4)

†Standard deviation shown in parentheses after treatment mean
^{NS}Treatment mean not significantly different from Control treatment at α= 0.1
* Treatment mean differs from Control treatment at α= 0.1
** Treatment mean differs from Control treatment at α= 0.05
*** Treatment mean differs from Control treatment at α= 0.01

Table 1.11a. Canning (central South Dakota) water use efficiency (WUE) for 0-90 cm soil profile 2019-08-09 – 2020-10-15 statistical analysis.

Factor	P Value
Mixture	0.776
Termination	0.017
Mixture*Termination	0.499

†Split-plot ANOVA excluding Control treatment

Table 1.12. Dakota Lakes Research Farm (18 miles east of Pierre, SD) soil nitrogen for 0-90 cm soil profile (kg of N ha^{-1}).

		2019-07-26	2020-04-08		2020-06-16	2020-10-02	
Mixture	Termination	NO_3^--N	NO_3^--N	NH_4^+-N	NO_3^--N	NO_3^--N	NH_4^+-N
Grass-M1	Term 1	23 (2.9)	37 (11) NS	310 (65) NS	66 (6.1) NS	26 (4.2) NS	190 (46) NS
Grass-M1	Term 2	23 (2.9)	34 (0.9) NS	270 (57) NS	100 (52) NS	21 (2.7) NS	150 (63) NS
Grass-M1	Term 3	23 (2.9)	37 (14) NS	290 (86) NS	75 (13) NS	27 (14) NS	190 (33) NS
Grass-M1	Term 4	23 (2.9)	32 (10) *	300 (64) NS	77 (25) NS	20 (2.3) NS	180 (21) NS
Brdlf-M2	Term 1	23 (2.9)	37 (10) NS	340 (34) ***	87 (24) NS	21 (2.0) NS	170 (22) NS
Brdlf-M2	Term 2	23 (2.9)	41 (16) NS	360 (23) NS	73 (27) NS	25 (8.2) NS	210 (5.0) NS
Brdlf-M2	Term 3	23 (2.9)	34 (4.5) *	380 (28) *	110 (41) *	23 (5.1) NS	170 (43) NS
Brdlf-M2	Term 4	23 (2.9)	35 (4.6) NS	320 (73) NS	88 (24) NS	22 (1.1) NS	200 (16) **
Blend-M3	Term 1	23 (2.9)	33 (7.9) *	320 (71) NS	80 (29) NS	23 (0.3) NS	190 (20) NS
Blend-M3	Term 2	23 (2.9)	42 (15) NS	350 (71) NS	77 (27) NS	22 (5.6) NS	150 (50) NS
Blend-M3	Term 3	23 (2.9)	32 (4.5) *	320 (45) NS	73 (13) NS	22 (4.4) NS	170 (25) NS
Blend-M3	Term 4	23 (2.9)	37 (17) NS	320 (71) NS	82 (26) NS	31 (12) NS	190 (49) NS
Control		23 (2.9)	56 (14)	280 (85)	85 (5.8)	25 (4.3)	160 (43)

†Standard deviation shown in parentheses after treatment mean
NS Treatment mean not significantly different from Control treatment at α= 0.1
* Treatment mean differs from Control treatment at α= 0.1
** Treatment mean differs from Control treatment at α= 0.05
*** Treatment mean differs from Control treatment at α= 0.01

Table 1.12a. Dakota Lakes Research Farm (18 miles east of Pierre, SD) soil nitrogen for 0-90 cm soil profile statistical analysis.

	2019-07-26	2020-04-08		2020-06-15	2020-10-02	
Factor	NO_3^--N	NO_3^--N	NH_4^+-N	NO_3^--N	NO_3^--N	NH_4^+-N
			P Value			
Mixture	-------	0.537	0.080	0.571	0.839	0.670
Termination	-------	0.518	0.712	0.884	0.934	0.573
Mixture*Termination	-------	0.494	0.726	0.342	0.234	0.770

†Split-plot ANOVA excluding Control treatment

Table 1.13. Canning (central South Dakota) soil nitrogen for 0-90 cm soil profile (kg of N ha^{-1}).

		2019-08-09	2020-04-15		2020-06-17	2020-10-15	
Mixture	Termination	NO_3^--N	NO_3^--N	NH_4^+-N	NO_3^--N	NO_3^--N	NH_4^+-N
Grass-M1	Term 1	59 (12.3)	46 (5.7) ***	360 (85) ***	44 (16) *	23 (8.5) ^{NS}	140 (22) ^{NS}
Grass-M1	Term 2	59 (12.3)	37 (4.1) ***	350 (33) **	53 (21) ^{NS}	21 (5.4) ^{NS}	130 (7.8) ^{NS}
Grass-M1	Term 3	59 (12.3)	40 (7.8) ***	400 (82) ***	53 (10) ^{NS}	23 (10) ^{NS}	120 (8.8) ^{NS}
Grass-M1	Term 4	59 (12.3)	48 (23) ***	350 (20) ***	44 (16) **	27 (9.5) **	130 (17) ^{NS}
Brdlf-M2	Term 1	59 (12.3)	45 (10) ***	330 (59) ***	51 (10) *	20 (5.7) ^{NS}	130 (14) ^{NS}
Brdlf-M2	Term 2	59 (12.3)	38 (4.0) ***	330 (39) ***	48 (10) *	19 (4.9) ^{NS}	170 (100) **
Brdlf-M2	Term 3	59 (12.3)	40 (5.2) ***	310 (47) **	46 (13) **	22 (3.8) ^{NS}	130 (19) ^{NS}
Brdlf-M2	Term 4	59 (12.3)	29 (7.3) ***	330 (70) ***	45 (9.2) **	20 (3.1) ^{NS}	120 (12) ^{NS}
Blend-M3	Term 1	59 (12.3)	45 (12) ***	320 (46) **	44 (8.8) **	25 (8.5) ^{NS}	140 (14) ^{NS}
Blend-M3	Term 2	59 (12.3)	33 (6.3) ***	340 (46) ***	52 (19) *	18 (7.0) ^{NS}	130 (12) ^{NS}
Blend-M3	Term 3	59 (12.3)	32 (11) ***	280 (39) ^{NS}	42 (9.7) ***	17 (2.8) ^{NS}	130 (10) ^{NS}
Blend-M3	Term 4	59 (12.3)	36 (10) ***	280 (29) ^{NS}	40 (4.2) ***	17 (0.6) ^{NS}	140 (15) ^{NS}
Control		59 (12.3)	77 (17)	240 (19)	68 (11)	19 (4.4)	130 (17)

†Standard deviation shown in parentheses after treatment mean
^{NS} Treatment mean not significantly different from Control treatment at α= 0.1
* Treatment mean differs from Control treatment at α= 0.1
** Treatment mean differs from Control treatment at α= 0.05
*** Treatment mean differs from Control treatment at α= 0.01

Table 1.13a. Canning (central South Dakota) soil nitrogen for 0-90 cm soil profile statistical analysis.

	2020-08-09	2020-04-15		2020-06-17	2020-10-15	
Factor	NO_3^--N	NO_3^--N	NH_4^+-N	NO_3^--N	NO_3^--N	NH_4^+-N
			P Value			
Mixture	-------	0.341	0.070	0.407	0.250	0.929
Termination	-------	0.100	0.859	0.329	0.568	0.550
Mixture*Termination	-------	0.338	0.605	0.331	0.449	0.332

†Split-plot ANOVA excluding Control treatment

Table 1.14. Dakota Lakes Research Farm (18 miles east of Pierre, SD) soil sulfate sulfur (SO_4^{2-}-S) for 0-90 cm soil profile (kg of S ha^{-1}).

Mixture	Termination	2019-07-26	2020-04-08	2020-06-15	2020-10-02
Grass-M1	Term 1	150 (20)	250 (38) NS	220 (50) NS	360 (190) **
Grass-M1	Term 2	150 (20)	270 (110) NS	230 (49) NS	250 (48) NS
Grass-M1	Term 3	150 (20)	260 (77) NS	220 (51) NS	280 (67) NS
Grass-M1	Term 4	150 (20)	260 (64) NS	210 (53) NS	260 (55) NS
Brdlf-M2	Term 1	150 (20)	290 (80) NS	220 (67) NS	270 (110) NS
Brdlf-M2	Term 2	150 (20)	240 (7.6) NS	200 (71) NS	330 (94) NS
Brdlf-M2	Term 3	150 (20)	240 (50) NS	190 (44) NS	250 (63) NS
Brdlf-M2	Term 4	150 (20)	220 (35) NS	190 (27) NS	310 (54) NS
Blend-M3	Term 1	150 (20)	270 (7.9) NS	270 (88) NS	290 (38) NS
Blend-M3	Term 2	150 (20)	290 (67) NS	260 (63) NS	310 (48) NS
Blend-M3	Term 3	150 (20)	220 (26) NS	250 (34) NS	230 (26) NS
Blend-M3	Term 4	150 (20)	250 (49) NS	230 (30) NS	310 (100) NS
Control		150 (20)	270 (110)	240 (47)	230 (36)

†Standard deviation shown in parentheses after treatment mean
NS Treatment mean not significantly different from Control treatment at α= 0.1
* Treatment mean differs from Control treatment at α= 0.1
** Treatment mean differs from Control treatment at α= 0.05
*** Treatment mean differs from Control treatment at α= 0.01

Table 1.14a. Dakota Lakes Research Farm (18 miles east of Pierre, SD) soil sulfate sulfur (SO_4^{2-}-S) for 0-90 cm soil profile statistical analysis.

Factor	2019-07-26	2020-04-08	2020-06-15	2020-10-02
		P Value		
Mixture	-----	0.597	0.994	0.901
Termination	-----	0.373	0.371	0.439
Mixture*Termination	-----	0.511	0.393	0.769

†Split-plot ANOVA excluding Control treatment

Table 1.15. Canning (central South Dakota) soil sulfate sulfur (SO_4^{2-}-S) for 0-90 cm soil profile (kg of S ha^{-1}).

Mixture	Termination	2019-08-09	2020-04-15	2020-06-17	2020-10-15
Grass-M1	Term 1	25000 (12000)	2550 (880) ^{NS}	1760 (2000) ^{NS}	8390 (11000) **
Grass-M1	Term 2	25000 (12000)	19700 (20000) ^{NS}	12600 (13000) ^{NS}	13800 (13000) ^{NS}
Grass-M1	Term 3	25000 (12000)	10700 (20300) ^{NS}	12700 (21000) ^{NS}	5860 (5100) **
Grass-M1	Term 4	25000 (12000)	22800 (27000) ^{NS}	14700 (17000) ^{NS}	16000 (18000) ^{NS}
Brdlf-M2	Term 1	25000 (12000)	37200 (60000) ^{NS}	20000 (14000) *	27300 (33000) ^{NS}
Brdlf-M2	Term 2	25000 (12000)	7100 (13000) ^{NS}	22900 (22000) ^{NS}	8770 (7700) *
Brdlf-M2	Term 3	25000 (12000)	1640 (1100) ^{NS}	5750 (6870) ^{NS}	12200 (21000) *
Brdlf-M2	Term 4	25000 (12000)	31100 (27000) *	17100 (16000) ^{NS}	24700 (28000) ^{NS}
Blend-M3	Term 1	25000 (12000)	16600 (18000) ^{NS}	5750 (6700) ^{NS}	4190 (7400) **
Blend-M3	Term 2	25000 (12000)	9770 (17000) ^{NS}	7460 (10000) ^{NS}	10700 (17000) ^{NS}
Blend-M3	Term 3	25000 (12000)	12800 (14000) ^{NS}	5940 (7900) ^{NS}	7200 (10000) *
Blend-M3	Term 4	25000 (12000)	8880 (7700) ^{NS}	7180 (9700) ^{NS}	15300 (15000) ^{NS}
Control		25000 (12000)	23000 (20000)	12800 (17300)	26700 (30000)

†Standard deviation shown in parentheses after treatment mean
^{NS} Treatment mean not significantly different from Control treatment at α= 0.1
* Treatment mean differs from Control treatment at α= 0.1
** Treatment mean differs from Control treatment at α= 0.05
*** Treatment mean differs from Control treatment at α= 0.01

Table 1.15a. Canning (central South Dakota) soil sulfate sulfur (SO_4^{2-}-S) for 0-90 cm soil profile statistical analysis.

Factor	2019-08-09	2020-04-15	2020-06-17	2020-10-15
		P Value		
Mixture	-------	0.697	0.175	0.465
Termination	-------	0.495	0.524	0.184
Mixture*Termination	-------	0.326	0.483	0.395

†Split-plot ANOVA excluding Control treatment

Table 1.16. Dakota Lakes Research Farm (18 miles east of Pierre, SD) soil Phospholipid-derived fatty acids (PLFA) sampled on 2019-09-18. Samples obtained prior to any termination treatments being applied, therefore mixture is the only factor considered.

	Grass-M1	Brdlf-M2	Blend-M3	Control	P Value	F Stat
Total Living Microbial Biomass (ng/g)	2710	3650	3240	2110	0.274	1.46
Functional Group Diversity Index	1.44	1.52	1.51	1.51	0.266	1.49
Total Bacteria (ng/g)	1050	1220	1740	1530	0.218	1.71
Total Bacteria as % of Total Biomass	45.7	48.4	47.3	49.8	0.155	2.09
Gram (+) Biomass	815	1086	969	778	0.318	1.31
Gram (+) as % of Total Biomass	31.8	30.9	30.2	37.3	0.114	2.45
Gram (-) Biomass	407	65	559	276	0.161	2.05
Gram (-) as % of Total Biomass	14.0	17.5	17.1	12.5	0.239	1.61
Actinomycetes (ng/g)	31	409	338	271	0.318	1.31
Actinomycetes as % of Total Biomass	12.1	11.5	10.4	12.8	0.107	2.53
Total Fungi (ng/g)	330	498	402	123	0.246	1.58
Total Fungi as % of Total Biomass	9.74	12.8	11.9	5.40	0.178	1.94
Arbuscular Mycorrhizal Fungi (ng/g)	83.0	159	134	50.8	0.151	2.12
Arbuscular Mycorrhizal Fungi as % of Total Biomass	2.42	4.25	4.01	2.18	0.141	2.20
Saprophytes (ng/g)	247	339	268	72.5	0.280	1.44
Saprophytes as % of Total Biomass	7.32	8.52	7.87	3.21	0.183	1.90
Protozoa (ng/g)	54.2	36.9	36.5	2.10	0.459	0.92
Protozoa as % of Total Biomass	1.43	0.81	0.99	0.09	0.379	1.12
Undifferentiated (ng/g)	1110	1370	1270	930	0.367	1.16
Undifferentiated as % of Total Biomass	43.1	38.0	39.8	44.8	0.317	1.31

	Grass-M1	Brdlf-M2	Blend-M3	Control	P Value	F Stat
Fungi:Bacteria Ratio	0.22	0.27	0.25	0.11	0.187	1.88
Gram (+):Gram (-) Ratio	2.64	1.85	1.79	3.69	0.294	1.39
Saturated Fatty Acids:Unsataturated Fatty Acids Ratio	2.94	1.82	1.86	4.23	0.290	1.40
Monosaturated Fatty Acids:Polysaturated Fatty Acids Ratio	15.6	10.0	11.2	35.9	0.039	3.83

† Treatment mean presented

‡ One-way ANOVA conducted including the Control as a cover crop mixture

Table 1.17. Canning (central South Dakota) soil Phospholipid-derived fatty acids (PLFA) sampled 2019-09-17. Samples obtained prior to any termination treatments being applied, therefore mixture is the only factor considered.

	Grass-M1	Brdlf-M2	Blend-M3	Control	P Value	F Stat
Total Living Microbial Biomass (ng/g)	3270	3700	3890	2700	0.104	2.55
Functional Group Diversity Index	1.34	1.49	1.45	1.38	0.186	1.88
Total Bacteria (ng/g)	1600	1840	1990	1430	0.096	2.65
Total Bacteria as % of Total Biomass	49.0	49.9	51.6	52.7	0.234	1.63
Gram (+) Biomass	1040	1170	1230	910	0.065	3.14
Gram (+) as % of Total Biomass	32.6	31.8	32.0	33.9	0.847	0.27
Gram (-) Biomass	554	676	759	511	0.186	1.89
Gram (-) as % of Total Biomass	16.4	18.1	19.5	18.9	0.238	1.61
Actinomycetes (ng/g)	417	503	505	348	0.019	4.89
Actinomycetes as % of Total Biomass	12.9	13.9	13.0	13.0	0.750	0.41
Total Fungi (ng/g)	204	372	364	178	0.104	2.55
Total Fungi as % of Total Biomass	5.83	9.82	9.06	6.67	0.167	2.01
Arbuscular Mycorrhizal Fungi (ng/g)	56.8	124	124	67.7	0.122	2.36
Arbuscular Mycorrhizal Fungi as % of Total Biomass	1.56	3.26	3.12	2.52	0.133	2.27
Saprophytes (ng/g)	148	248	241	110	0.105	2.55
Saprophytes as % of Total Biomass	4.28	6.56	5.95	4.15	0.192	1.85
Protozoa (ng/g)	5.56	11.8	9.10	0.53	0.090	2.73
Protozoa as % of Total Biomass	0.15	0.340	0.212	0.023	0.083	2.84

	Grass-M1	Brdlf-M2	Blend-M3	Control	P Value	F Stat
Undifferentiated (ng/g)	1470	1470	1520	1100	0.158	2.07
Undifferentiated as % of Total Biomass	45.1	40.0	39.2	40.6	0.065	3.14
Fungi:Bacteria Ratio	0.12	0.198	0.178	0.127	0.203	1.79
Gram (+):Gram (-) Ratio	2.12	1.77	1.65	1.82	0.593	0.66
Saturated Fatty Acids:Unsataturated Fatty Acids Ratio	2.76	1.85	1.86	2.14	0.141	2.20
Monosaturated Fatty Acids:Polysaturated Fatty Acids Ratio	39.5	20.3	29.7	51.2	0.081	2.86

† Treatment mean presented

‡ One-way ANOVA conducted including the Control as a cover crop mixture

Table 1.18. Dakota Lakes Research Farm (18 miles east of Pierre, SD) cover crop biomass (kg ha^{-1}), biomass carbon content (kg ha^{-1}), biomass nitrogen content (kg ha^{-1}), and biomass C:N ratio.

Date	Mixture	Biomass	Carbon	Nitrogen	C:N Ratio
		-----------------kg ha^{-1}-----------------			
2019-09-27	Grass-M1	3100 (780)	1320 (360)	47.2 (9.7)	27.6 (2.7)
2019-09-27	Brdlf-M2	1940 (390)	839 (160)	58.8 (11)	14.3 (0.4)
2019-09-27	Blend-M3	2850 (500)	1220 (190)	65.2 (5.9)	18.7 (2.0)
2019-10-07	Grass-M1	4500 (330)	1920 (140)	77.7 (18)	25.9 (6.9)
2019-10-07	Brdlf-M2	4020 (560)	1770 (250)	158 (40)	11.5 (1.7)
2019-10-07	Blend-M3	4410 (1200)	1910 (510)	101 (28)	19.4 (3.8)
2019-11-02	Grass-M1	4920 (1200)	2160 (550)	96.9 (51)	24.5 (6.8)
2019-11-02	Brdlf-M2	6110 (960)	3190 (930)	210 (55)	15.2 (1.8)
2019-11-02	Blend-M3	5620 (1200)	2500 (550)	144 (53)	18.2 (3.5)

†Standard deviation shown in parentheses after treatment mean

Table 1.18a. Dakota Lakes Research Farm (18 miles east of Pierre, SD) cover crop biomass, biomass carbon content, biomass nitrogen content, and biomass C:N ratio content statistical analysis.

Factor	Biomass	Carbon	Nitrogen	C:N Ratio
		P Value		
Date	<0.001	<0.001	<0.001	0.709
Mixture	0.633	0.785	<0.001	<0.001
Date*Mixture	0.146	0.036	0.076	0.610

†Two-way ANOVA excluding Termination timing factor

‡Control not included in dataset (negligible growing biomass in the fall of 2019)

Table 1.19. Canning (central South Dakota) cover crop biomass (kg ha^{-1}), biomass carbon content (kg ha^{-1}), biomass nitrogen content (kg ha^{-1}), and biomass C:N ratio.

Date	Mixture	Biomass	Carbon	Nitrogen	C:N Ratio
		-----------------kg ha^{-1}-----------------			
2019-09-27	Grass-M1	2420 (350)	1050 (150)	56.9 (15)	19.1 (3.7)
2019-09-27	Brdlf-M2	1900 (290)	821 (130)	54.7 (8.1)	15.0 (1.1)
2019-09-27	Blend-M3	2210 (150)	962 (74)	57.3 (6.5)	16.9 (1.7)
2019-10-07	Grass-M1	4430 (410)	1930 (160)	104 (18)	18.8 (2.2)
2019-10-07	Brdlf-M2	3860 (280)	1660 (98)	130 (20)	13.0 (1.4)
2019-10-07	Blend-M3	4980 (440)	1830 (160)	127 (24)	14.6 (1.8)
2019-11-02	Grass-M1	6610 (400)	2930 (170)	161 (32)	18.5 (2.2)
2019-11-02	Brdlf-M2	5220 (1000)	2280 (440)	137 (23)	16.7 (1.7)
2019-11-02	Blend-M3	4980 (620)	2210 (240)	119 (8.2)	18.6 (2.1)

†Standard deviation shown in parentheses after treatment mean

Table 1.19a. Canning (central South Dakota) cover crop biomass, biomass carbon content, biomass nitrogen content, and biomass C:N ratio statistical analysis.

Factor	Biomass	Carbon	Nitrogen	C:N Ratio
		P Value		
Date	<0.001	<0.001	<0.001	0.025
Mixture	<0.001	<0.001	0.656	<0.001
Date*Mixture	0.062	0.031	0.025	0.310

†Two-way ANOVA excluding Termination timing factor

‡Control not included in dataset (negligible growing biomass in the fall of 2019)

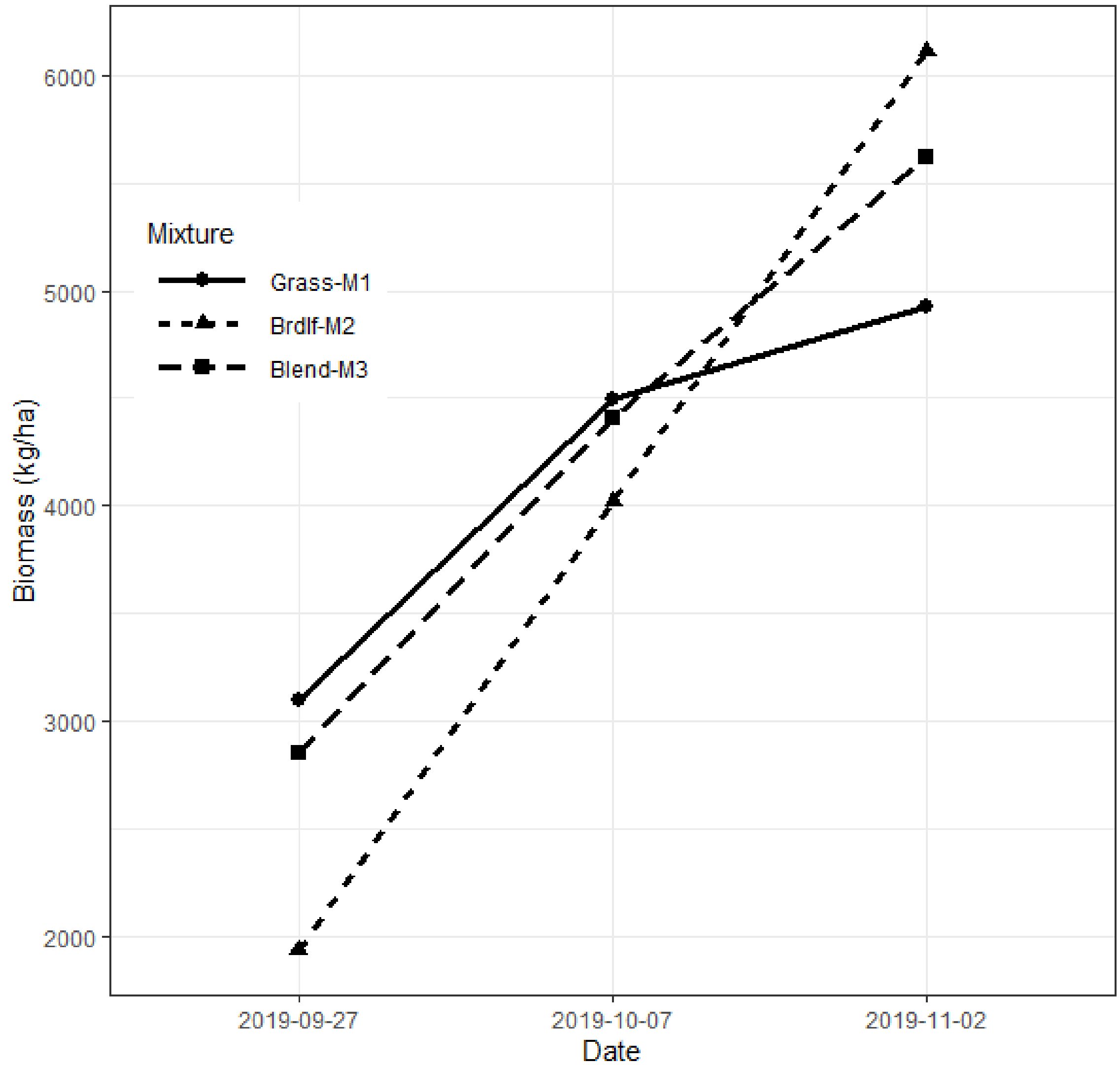

Figure 1.5. Dakota Lakes Research Farm (18 miles east of Pierre, SD) fall cover crop biomass (kg ha^{-1}). Biomass calculated using 0.25 m^2 samples harvested from each plot on three dates (2019-09-27, 2019-10-07, 2019-11-02).

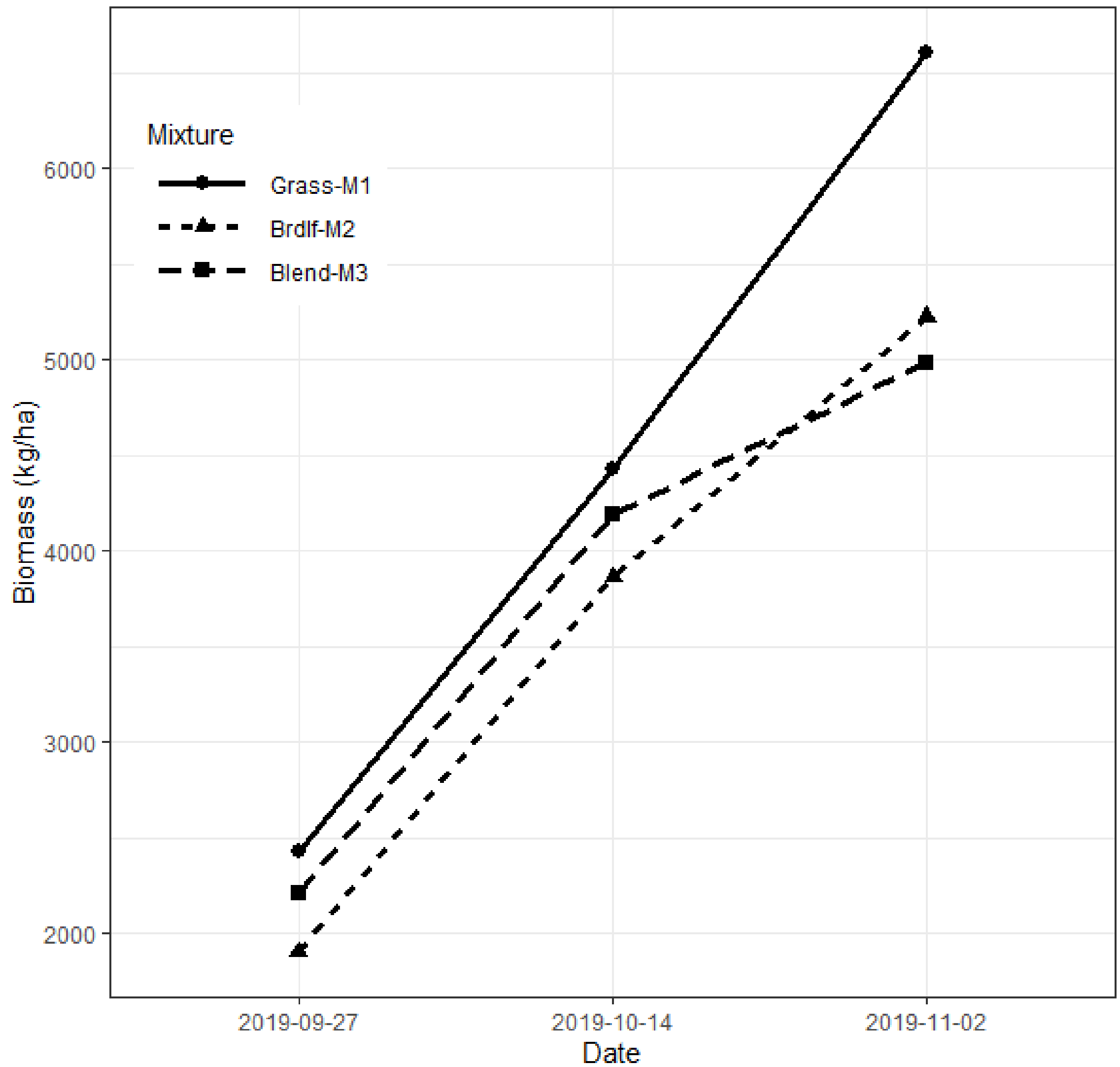

Figure 1.6. Canning (central South Dakota) fall cover crop biomass (kg ha^{-1}). Cover crop biomass calculated using 0.25 m^2 biomass samples harvested from each plot on three dates (2019-09-27, 2019-10-07, 2019-11-02).

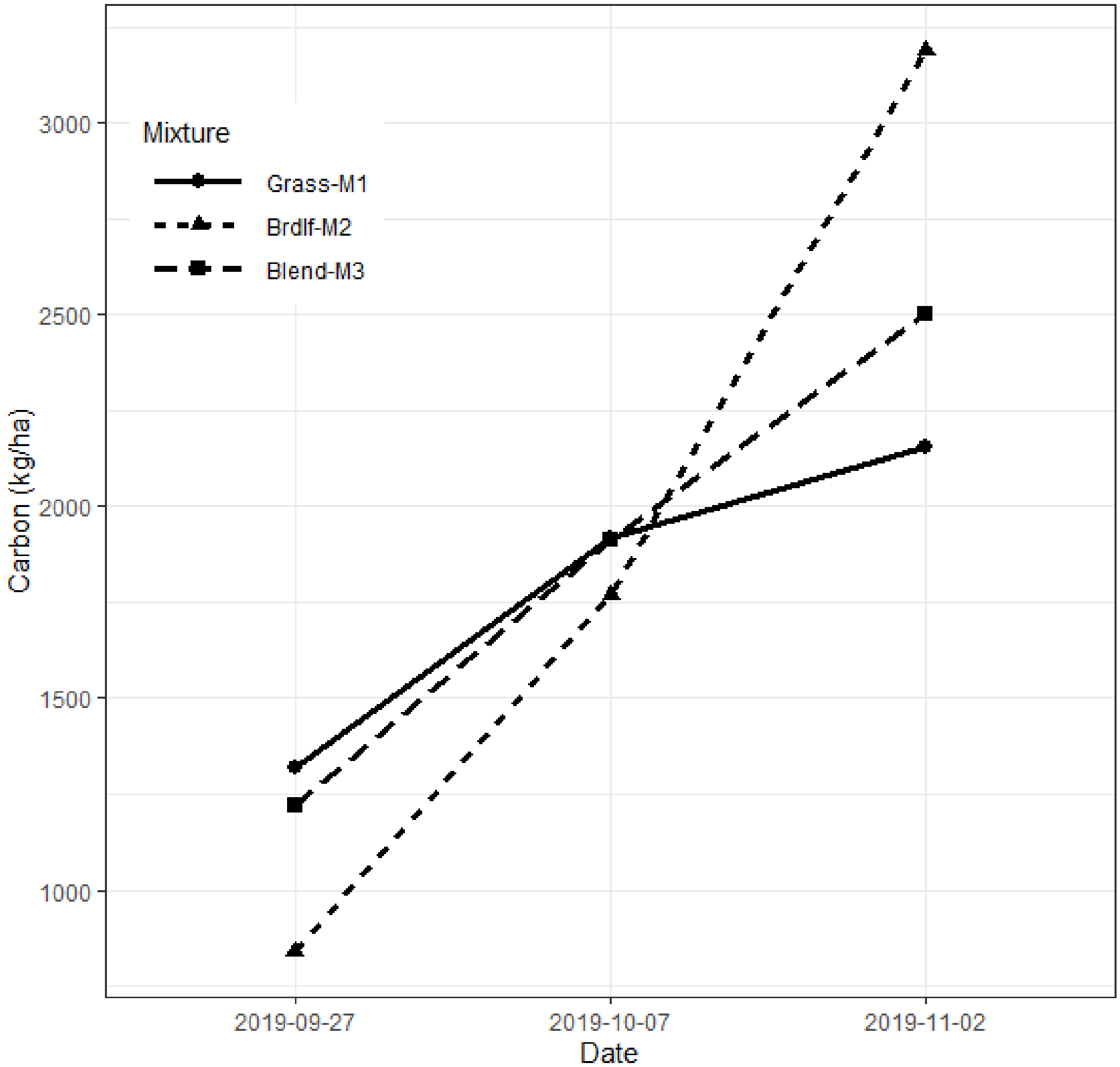

Figure 1.7. Dakota Lakes Research Farm (18 miles east of Pierre, SD) cover crop biomass carbon content (kg ha^{-1}). Cover crop biomass carbon content (kg ha^{-1}) was calculated using 0.25 m^2 biomass samples harvested from each plot on three dates (2019-09-27, 2019-10-07, 2019-11-02) and their respective carbon percentage.

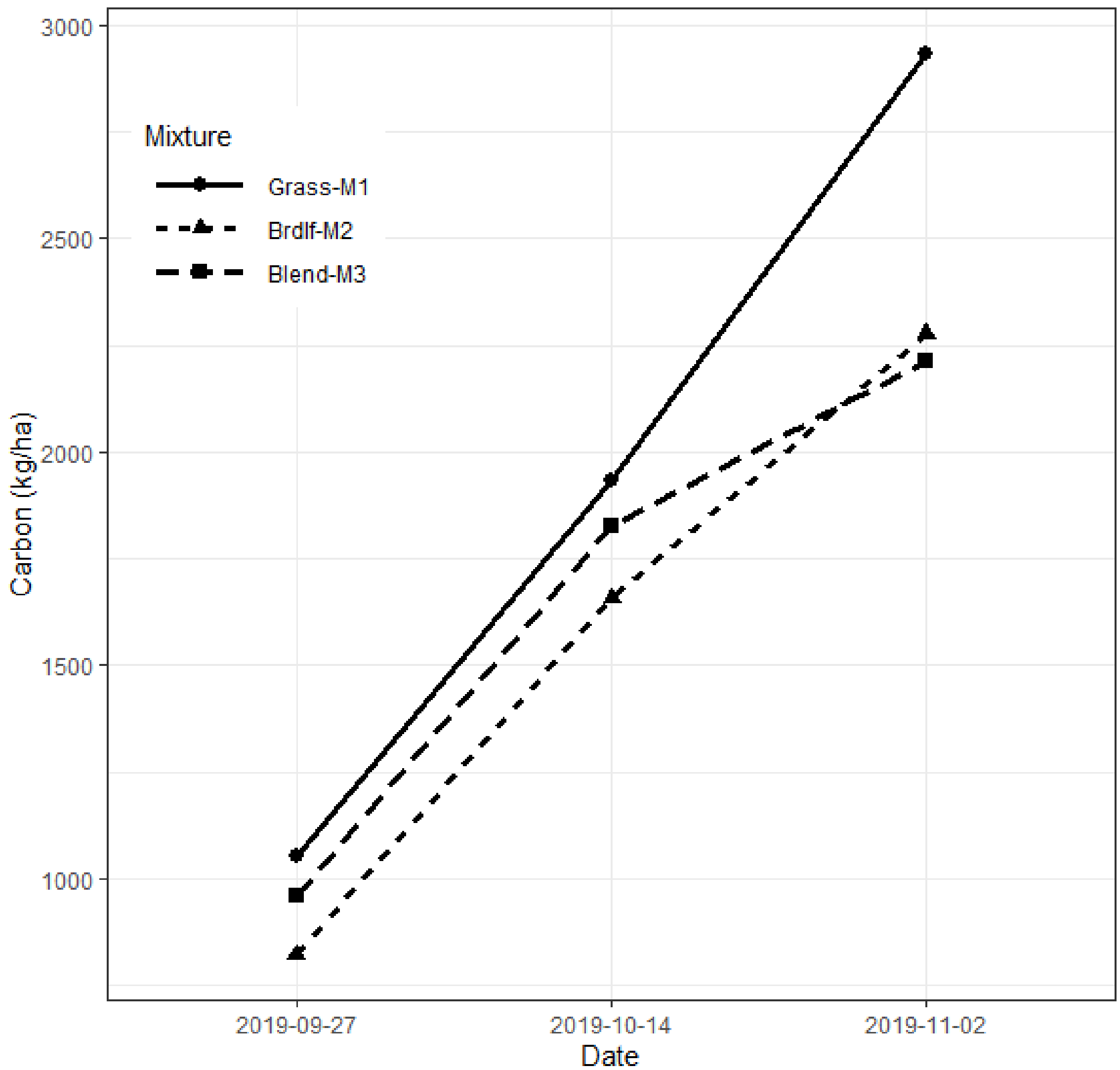

Figure 1.8. Canning (central South Dakota) cover crop biomass carbon content (kg ha^{-1}). Cover crop biomass carbon content (kg ha^{-1}) was calculated using 0.25 m^2 biomass samples harvested from each plot on three dates (2019-09-27, 2019-10-07, 2019-11-02) and their respective carbon percentage.

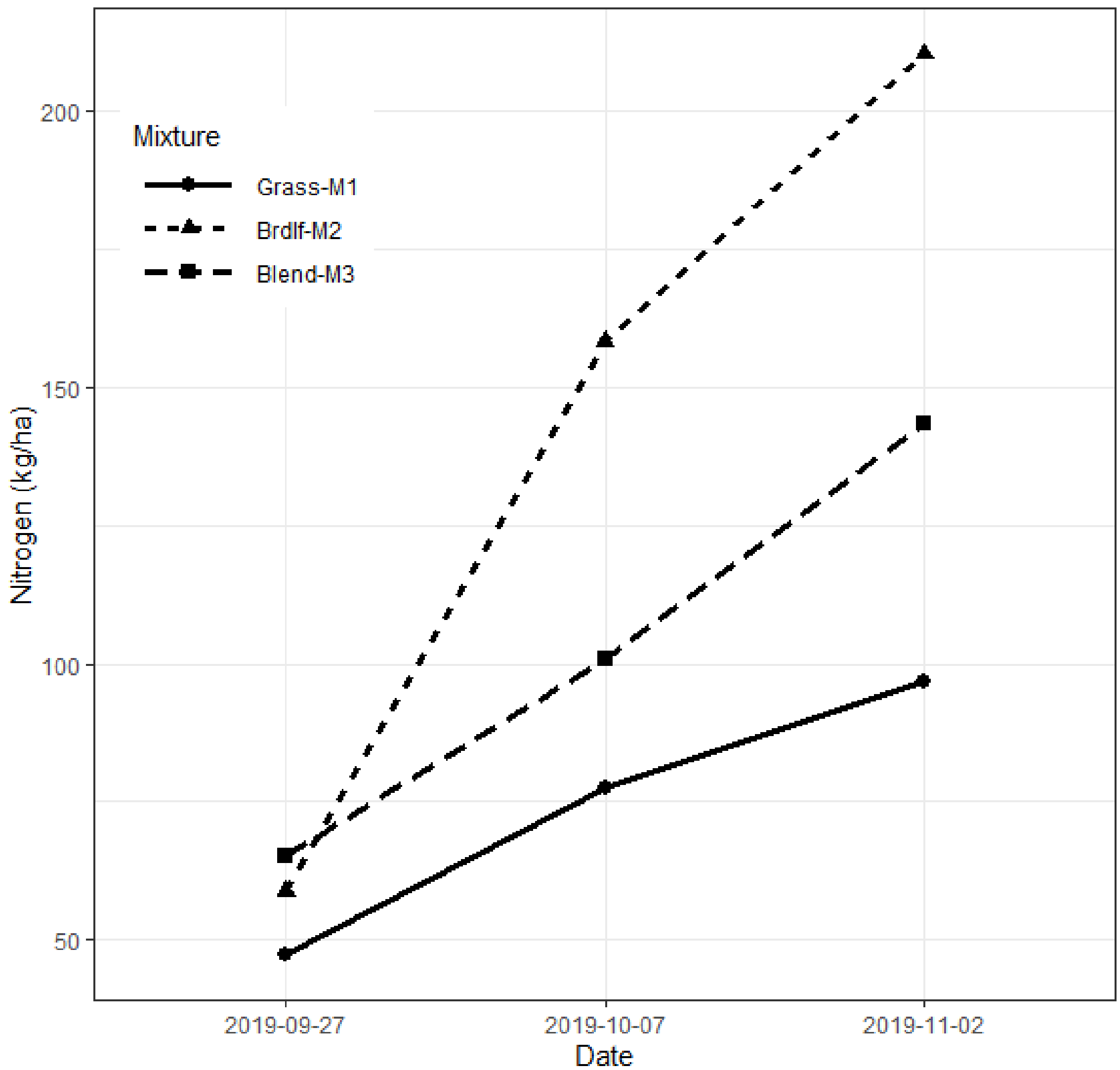

Figure 1.9. Dakota Lakes Research Farm (18 miles east of Pierre, SD) cover crop biomass nitrogen content (kg ha^{-1}). Cover crop biomass carbon content (kg ha^{-1}) was calculated using 0.25 m^2 biomass samples harvested from each plot on three dates (2019-09-27, 2019-10-07, 2019-11-02) and their respective nitrogen percentage.

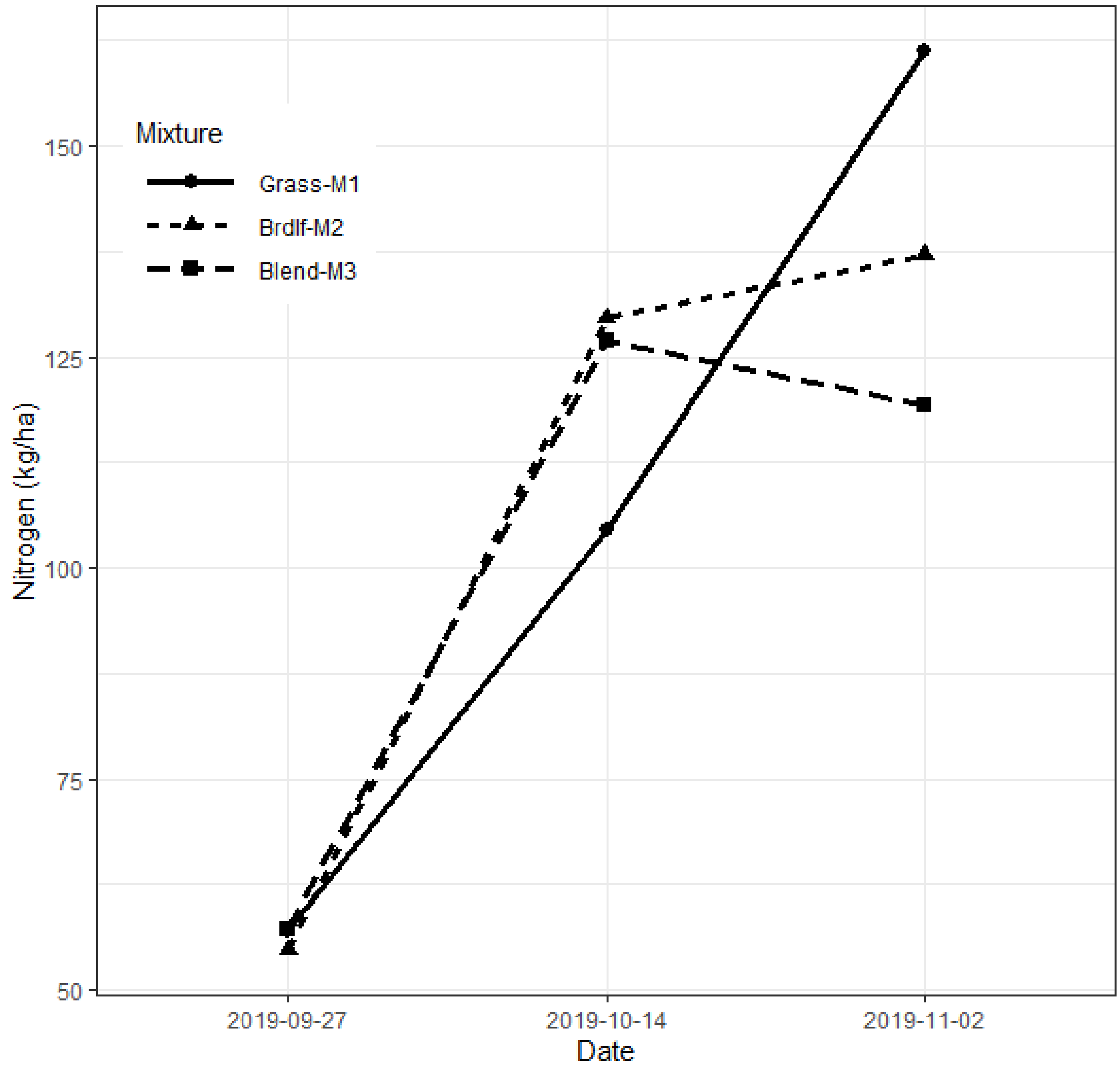

Figure 1.10. Canning (central South Dakota) cover crop biomass nitrogen content (kg ha^{-1}). Cover crop biomass carbon content (kg ha^{-1}) was calculated using 0.25 m^2 biomass samples harvested from each plot on three dates (2019-09-27, 2019-10-07, 2019-11-02) and their respective nitrogen percentage.

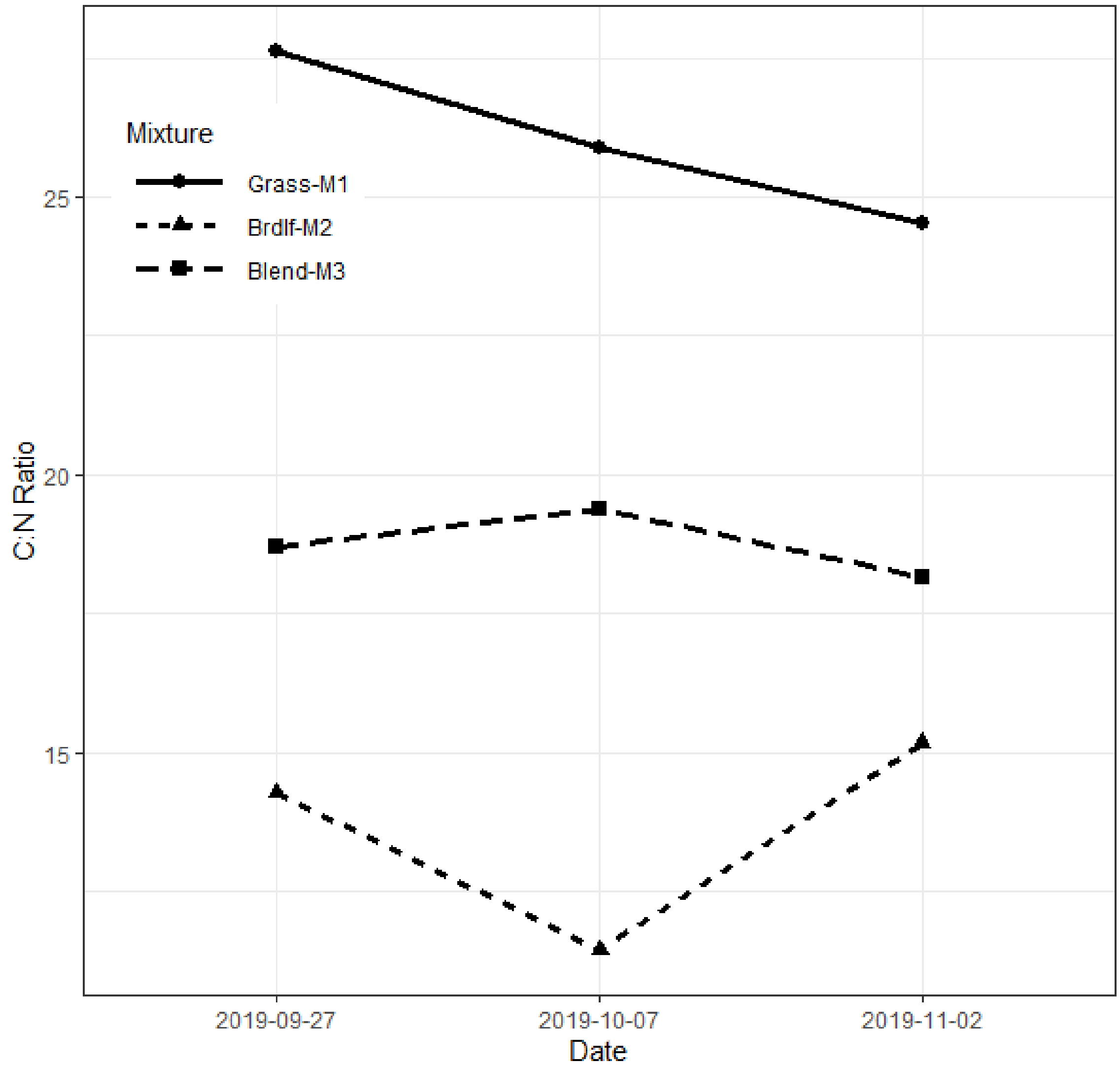

Figure 1.11. Dakota Lakes Research Farm (18 miles east of Pierre, SD) cover crop biomass C:N ratio. Cover crop biomass carbon content (kg ha^{-1}) was calculated using 0.25 m^2 biomass samples harvested from each plot on three dates (2019-09-27, 2019-10-07, 2019-11-02) and their respective carbon and nitrogen percentages.

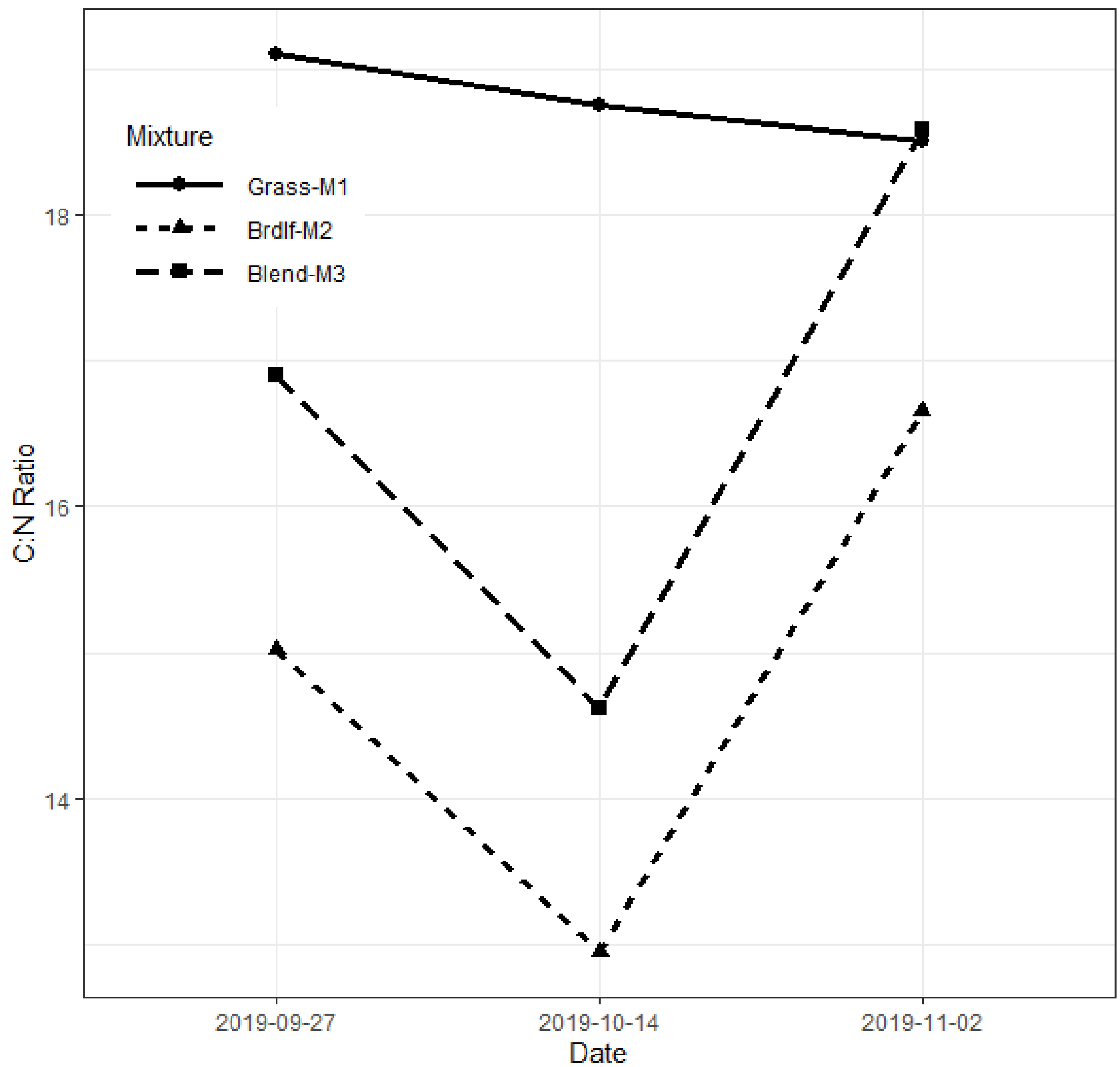

Figure 1.12. Canning (central South Dakota) cover crop biomass C:N ratio. Cover crop biomass carbon content (kg ha^{-1}) was calculated using 0.25 m^{2} biomass samples harvested from each plot on three dates (2019-09-27, 2019-10-07, 2019-11-02) and their respective carbon and nitrogen percentages.

Table 1.20. Dakota Lakes Research Farm (18 miles east of Pierre, SD) spring surface residue biomass (kg ha^{-1}) measured 2020-04-30.

Mixture	Termination	Surface Residue Biomass (kg ha^{-1})
Grass-M1	Term 1	4150 (650) ^{NS}
Grass-M1	Term 2	5080 (851) ^{NS}
Grass-M1	Term 3	5090 (574) ^{NS}
Grass-M1	Term 4	4490 (1420) ^{NS}
Brdlf-M2	Term 1	4790 (1090) ^{NS}
Brdlf-M2	Term 2	4420 (1490) ^{NS}
Brdlf-M2	Term 3	4830 (467) ^{NS}
Brdlf-M2	Term 4	4440 (1210) ^{NS}
Blend-M3	Term 1	4410 (1150) ^{NS}
Blend-M3	Term 2	5120 (1230) ^{NS}
Blend-M3	Term 3	5370 (1520) *
Blend-M3	Term 4	4350 (1210) ^{NS}
Control		4250 (464)

†Standard deviation shown in parentheses after treatment mean
^{NS} Treatment mean not significantly different from Control treatment at α= 0.1
* Treatment mean differs from Control treatment at α= 0.1
** Treatment mean differs from Control treatment at α= 0.05
*** Treatment mean differs from Control treatment at α= 0.01

Table 1.20a. Dakota Lakes spring surface residue measured 2020-04-30 statistical analysis.

Factor	P Value
Mixture	0.774
Termination	0.458
Mixture*Termination	0.937

†Split-plot ANOVA excluding Control treatment

Table 1.21. Canning (central South Dakota) spring surface residue biomass (kg ha^{-1}) measured 2020-04-30.

Mixture	Termination	Biomass (kg ha^{-1})
Grass-M1	Term 1	3980 (890) *
Grass-M1	Term 2	3400 (760) ^{NS}
Grass-M1	Term 3	4650 (420) ***
Grass-M1	Term 4	4120 (650) **
Brdlf-M2	Term 1	3250 (400) ^{NS}
Brdlf-M2	Term 2	3400 (650) ^{NS}
Brdlf-M2	Term 3	3900 (740) *
Brdlf-M2	Term 4	3170 (630) ^{NS}
Blend-M3	Term 1	3330 (360) ^{NS}
Blend-M3	Term 2	3890 (1300) *
Blend-M3	Term 3	4220 (800) ***
Blend-M3	Term 4	3210 (790) ^{NS}
Control		3190 (250)

†Standard deviation shown in parentheses after treatment mean
^{NS} Treatment mean not significantly different from Control treatment at α= 0.1
* Treatment mean differs from Control treatment at α= 0.1
** Treatment mean differs from Control treatment at α= 0.05
*** Treatment mean differs from Control treatment at α= 0.01

Table 1.21a. Canning (central South Dakota) spring surface residue biomass measured 2020-04-30 statistical analysis.

Factor	P Value
Mixture	0.119
Termination	0.066
Mixture*Termination	0.687

†Split-plot ANOVA excluding Control treatment

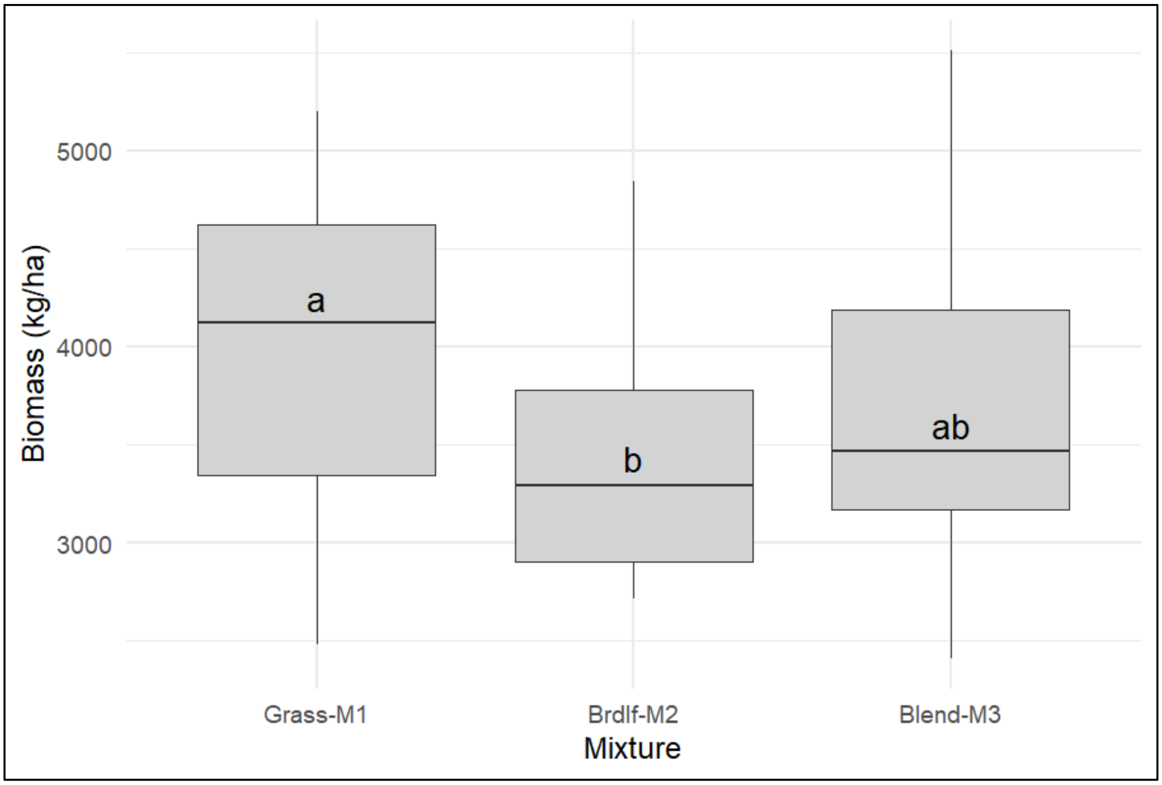

Figure 1.13. Canning surface residue measured 2020-04-30. Fishers LSD mean separation test at α=0.05 conducted on mixture means.

Table 1.22. Dakota Lakes Research Farm (18 miles east of Pierre, SD) corn stand count (live plants). Area counted was 3m by 2 rows (51cm spacing).

Mixture	Termination	2020-05-26	2020-06-01	2020-06-08
Grass-M1	Term 1	6 (3.2) NS	17 (1.0) NS	18 (0.8) NS
Grass-M1	Term 2	7 (2.2) NS	16 (2.8) NS	18 (1.7) NS
Grass-M1	Term 3	4 (1.7) **	16 (1.0) NS	18 (1.3) NS
Grass-M1	Term 4	7 (5.4) NS	17 (1.5) NS	18 (0.8) NS
Brdlf-M2	Term 1	5 (5.1) **	18 (1.3) NS	19 (0.6) NS
Brdlf-M2	Term 2	8 (5.1) NS	18 (0.5) NS	18 (0.8) NS
Brdlf-M2	Term 3	4 (1.3) **	16 (1.8) NS	17 (1.7) NS
Brdlf-M2	Term 4	7 (3.1) NS	17 (0.8) NS	18 (1.5) NS
Blend-M3	Term 1	6 (2.4) NS	16 (1.7) NS	18 (0.6) NS
Blend-M3	Term 2	7 (3.4) NS	17 (0.5) NS	18 (0.5) NS
Blend-M3	Term 3	7 (4.7) NS	16 (1.4) NS	17 (1.3) NS
Blend-M3	Term 4	7 (3.2) NS	16 (2.4) NS	17 (2.4) NS
Control		10 (2.1)	17 (1.3)	18 (1.8)

†Standard deviation shown in parentheses after treatment mean
NS Treatment mean not significantly different from Control treatment at α= 0.1
* Treatment mean differs from Control treatment at α= 0.1
** Treatment mean differs from Control treatment at α= 0.05
*** Treatment mean differs from Control treatment at α= 0.01

Table 1.22a. Dakota Lakes Research Farm (18 miles east of Pierre, SD) corn stand count statistical analysis.

Factor	2020-05-26	2020-06-01	2020-06-08
		P Value	
Mixture	0.741	0.064	0.701
Termination	0.413	0.594	0.329
Mixture*Termination	0.942	0.612	0.702

†Split-plot ANOVA excluding Control treatment

Table 1.23. Canning (central South Dakota) corn stand count (live plants). Area counted was 3m by 2 rows (76cm spacing).

Mixture	Termination	2020-05-27	2020-06-02	2020-06-15‡
Grass-M1	Term 1	18 (3.2) **	25 (1.2) ^{NS}	23 (1.9) ^{NS}
Grass-M1	Term 2	18 (5.1) **	24 (1.4) **	22 (2.2) ^{NS}
Grass-M1	Term 3	16 (8.8) ***	23 (3.1) ***	22 (2.9) ^{NS}
Grass-M1	Term 4	12 (2.2) ***	21 (3.2) ***	22 (1.3) ^{NS}
Brdlf-M2	Term 1	18 (2.9) **	25 (1.0) ^{NS}	24 (2.9) ^{NS}
Brdlf-M2	Term 2	21 (2.6) ^{NS}	24 (3.3) *	24 (3.3) ^{NS}
Brdlf-M2	Term 3	18 (1.7) **	24 (1.3) **	24 (2.6) ^{NS}
Brdlf-M2	Term 4	21 (2.6) ^{NS}	24 (2.9) **	22 (2.2) ^{NS}
Blend-M3	Term 1	19 (3.1) **	25 (3.1) *	22 (0.5) ^{NS}
Blend-M3	Term 2	18 (2.2) **	23 (0.5) **	22 (2.1) ^{NS}
Blend-M3	Term 3	16 (2.6) ***	23 (1.5) ***	22 (2.4) ^{NS}
Blend-M3	Term 4	18 (3.2) **	25 (2.1) ^{NS}	23 (2.5) ^{NS}
Control		25 (2.6)	27 (1.5)	24 (3.1)

† Standard deviation shown in parentheses after treatment mean
^{NS} Treatment mean not significantly different from Control treatment at α= 0.1
* Treatment mean differs from Control treatment at α= 0.1
** Treatment mean differs from Control treatment at α= 0.05
*** Treatment mean differs from Control treatment at α= 0.01

‡ 2020-06-15 sampling date occurred after damaging hail/wind event

Table 1.23a. Canning (central South Dakota) corn stand count statistical analysis.

Factor	2020-05-27	2020-06-02	2020-06-15
		P Value	
Mixture	0.200	0.341	0.400
Termination	0.223	0.446	0.083
Mixture*Termination	0.517	0.320	0.648

†Split-plot ANOVA excluding Control treatment

Table 1.24. Dakota Lakes Research Farm (18 miles east of Pierre, SD) stomatal conductance (mmol m^{-2} s^{-1}) of corn crop measured 2020-07-23. Corn at VT (tasseling) stage.

Mixture	Termination	Conductance (mmol m^{-2} s^{-1})
Grass-M1	Term 1	116 (40) ^{NS}
Grass-M1	Term 2	118 (57) ^{NS}
Grass-M1	Term 3	127 (61) ^{NS}
Grass-M1	Term 4	99 (60) ^{NS}
Brdlf-M2	Term 1	162 (140) **
Brdlf-M2	Term 2	164 (120) **
Brdlf-M2	Term 3	123 (22) ^{NS}
Brdlf-M2	Term 4	96 (41) ^{NS}
Blend-M3	Term 1	82 (46) ^{NS}
Blend-M3	Term 2	102 (63) ^{NS}
Blend-M3	Term 3	105 (42) ^{NS}
Blend-M3	Term 4	101 (52) ^{NS}
Control		92.5 (65)

†Standard deviation shown in parentheses after treatment mean
^{NS} Treatment mean not significantly different from Control treatment at α= 0.1
* Treatment mean differs from Control treatment at α= 0.1
** Treatment mean differs from Control treatment at α= 0.05
*** Treatment mean differs from Control treatment at α= 0.01

Table 1.24a. Dakota Lakes Research Farm (18 miles east of Pierre, SD) stomatal conductance measured 2020-07-23 statistical analysis.

Factor	P Value
Mixture	0.512
Termination	0.528
Mixture*Termination	0.714

†Split-plot ANOVA excluding Control treatment

Table 1.25. Canning (central South Dakota) stomatal conductance (mmol m^{-2} s^{-1}) of corn crop measured 2020-07-24. Corn at V12 stage.

Mixture	Termination	Conductance (mmol m^{-2} s^{-1})
Grass-M1	Term 1	245 (246) NS
Grass-M1	Term 2	262 (128) NS
Grass-M1	Term 3	271 (124) NS
Grass-M1	Term 4	263 (131) NS
Brdlf-M2	Term 1	197 (149) NS
Brdlf-M2	Term 2	252 (97) NS
Brdlf-M2	Term 3	311 (194) NS
Brdlf-M2	Term 4	230 (145) NS
Blend-M3	Term 1	351 (171) *
Blend-M3	Term 2	196 (104) NS
Blend-M3	Term 3	274 (227) NS
Blend-M3	Term 4	255 (105) NS
Control		290 (111)

†Standard deviation shown in parentheses after treatment mean
NS Treatment mean not significantly different from Control treatment at α= 0.1
* Treatment mean differs from Control treatment at α= 0.1
** Treatment mean differs from Control treatment at α= 0.05
*** Treatment mean differs from Control treatment at α= 0.01

Table 1.25a. Canning (central South Dakota) stomatal conductance of corn crop measured 2020-07-24 statistical analysis.

Factor	P Value
Mixture	0.929
Termination	0.162
Mixture*Termination	0.860

†Split-plot ANOVA excluding Control treatment

Table 1.26. Dakota Lakes Research Farm (18 miles east of Pierre, SD) normalized difference vegetation index (NDVI) during corn growing season. UAV used to capture imagery which was used in NDVI calculations.

Mixture	Termination	2020-06-11	2020-06-19	2020-07-01	2020-07-13	2020-08-03
Grass-M1	Term 1	0.366 (0.009) ^{NS}	0.486 (0.019) ^{NS}	0.788 (0.021) ^{NS}	0.894 (0.007) ^{NS}	0.885 (0.008) ^{NS}
Grass-M1	Term 2	0.366 (0.007) ^{NS}	0.479 (0.018) ^{NS}	0.783 (0.008) ^{NS}	0.892 (0.009) ^{NS}	0.878 (0.004) ***
Grass-M1	Term 3	0.370 (0.011) **	0.478 (0.010) ^{NS}	0.770 (0.030) **	0.890 (0.018) ^{NS}	0.878 (0.025) ***
Grass-M1	Term 4	0.369 (0.011) **	0.497 (0.019) ^{NS}	0.785 (0.026) ^{NS}	0.894 (0.011) ^{NS}	0.880 (0.013) ***
Brdlf-M2	Term 1	0.364 (0.009) ^{NS}	0.495 (0.011) ^{NS}	0.795 (0.012) ^{NS}	0.901 (0.009) ^{NS}	0.885 (0.010) ^{NS}
Brdlf-M2	Term 2	0.369 (0.017) **	0.487 (0.005) ^{NS}	0.788 (0.016) ^{NS}	0.899 (0.012) ^{NS}	0.886 (0.010) ^{NS}
Brdlf-M2	Term 3	0.375 (0.006) ***	0.496 (0.022) ^{NS}	0.770 (0.028) **	0.885 (0.017) **	0.884 (0.016) *
Brdlf-M2	Term 4	0.373 (0.013) ***	0.501 (0.027) ^{NS}	0.794 (0.014) ^{NS}	0.902 (0.009) ^{NS}	0.883 (0.005) **
Blend-M3	Term 1	0.368 (0.009) **	0.488 (0.013) ^{NS}	0.774 (0.014) ^{NS}	0.884 (0.009) **	0.885 (0.003) *
Blend-M3	Term 2	0.373 (0.014) ***	0.502 (0.024) *	0.792 (0.013) ^{NS}	0.893 (0.011) ^{NS}	0.881 (0.010) **
Blend-M3	Term 3	0.377 (0.009) ***	0.492 (0.030) ^{NS}	0.772 (0.017) *	0.884 (0.016) **	0.886 (0.010) ^{NS}
Blend-M3	Term 4	0.383 (0.007) ***	0.492 (0.013) ^{NS}	0.775 (0.016) ^{NS}	0.894 (0.011) ^{NS}	0.889 (0.005) ^{NS}
Control		0.356 (0.008)	0.484 (0.025)	0.790 (0.027)	0.900 (0.010)	0.893 (0.008)

†Standard deviation shown in parentheses after treatment mean
^{NS} Treatment mean not significantly different from Control treatment at $\alpha = 0.1$
* Treatment mean differs from Control treatment at $\alpha = 0.1$
** Treatment mean differs from Control treatment at $\alpha = 0.05$
*** Treatment mean differs from Control treatment at $\alpha = 0.01$

Table 1.26a. Dakota Lakes Research Farm (18 miles east of Pierre, SD) normalized difference vegetation index (NDVI) during corn growing season statistical analysis.

Factor	2020-06-11	2020-06-19	2020-07-01	2020-07-13	2020-08-03
			P Value		
Mixture	0.573	0.251	0.452	0.236	0.217
Termination	0.033	0.505	0.190	0.283	0.867
Mixture*Termination	0.666	0.296	0.906	0.759	0.804

†Split-plot ANOVA excluding Control treatment

Table 1.27. Canning (central South Dakota) normalized difference vegetation index (NDVI) during corn growing season. UAV used to capture imagery which was used in NDVI calculations.

Mixture	Termination	2020-06-23	2020-07-07	2020-07-24	2020-08-03
Grass-M1	Term 1	0.418 (0.007) ^{NS}	0.733 (0.023) *	0.878 (0.008) ^{NS}	0.847 (0.008) *
Grass-M1	Term 2	0.399 (0.010) **	0.707 (0.025) ***	0.874 (0.003) ^{NS}	0.852 (0.007) *
Grass-M1	Term 3	0.398 (0.012) **	0.711 (0.023) ***	0.876 (0.009) ^{NS}	0.852 (0.013) ^{NS}
Grass-M1	Term 4	0.404 (0.019) *	0.708 (0.030) ***	0.871 (0.012) ^{NS}	0.843 (0.010) **
Brdlf-M2	Term 1	0.405 (0.022) *	0.721 (0.034) **	0.871 (0.005) ^{NS}	0.862 (0.017) ^{NS}
Brdlf-M2	Term 2	0.399 (0.023) **	0.711 (0.031) ***	0.868 (0.012) ^{NS}	0.843 (0.012) **
Brdlf-M2	Term 3	0.394 (0.013) ***	0.706 (0.032) ***	0.868 (0.007) ^{NS}	0.846 (0.006) *
Brdlf-M2	Term 4	0.390 (0.018) ***	0.675 (0.032) ***	0.859 (0.015) ***	0.837 (0.011) ***
Blend-M3	Term 1	0.406 (0.018) ^{NS}	0.721 (0.016) **	0.870 (0.006) ^{NS}	0.846 (0.011) *
Blend-M3	Term 2	0.403 (0.008) **	0.710 (0.018) ***	0.873 (0.005) ^{NS}	0.855 (0.012) ^{NS}
Blend-M3	Term 3	0.397 (0.009) **	0.704 (0.002) ***	0.871 (0.006) ^{NS}	0.845 (0.003) **
Blend-M3	Term 4	0.406 (0.008) ^{NS}	0.714 (0.007) ***	0.864 (0.008) *	0.833 (0.008) ***
Control		0.419 (0.017)	0.761 (0.025)	0.875 (0.006)	0.858 (0.010)

†Standard deviation shown in parentheses after treatment mean
^{NS} Treatment mean not significantly different from Control treatment at α= 0.1
* Treatment mean differs from Control treatment at α= 0.1
** Treatment mean differs from Control treatment at α= 0.05
*** Treatment mean differs from Control treatment at α= 0.01

Table 1.27a. Canning (central South Dakota) normalized difference vegetation index (NDVI) during corn growing season statistical analysis.

Factor	2020-06-23	2020-07-07	2020-07-24	2020-08-03
		P Value		
Mixture	0.214	0.749	0.240	0.946
Termination	0.063	0.022	0.084	0.019
Mixture*Termination	0.736	0.682	0.887	0.061

†Split-plot ANOVA excluding Control treatment

Table 1.28. Dakota Lakes Research Farm (18miles east of Pierre, SD) corn tissue nutrients (% nitrogen and % sulfur) at V5/V6 and R1 growth stages.

		% Nitrogen		% Sulfur	
Mixture	Termination	V5/V6	R1	V5/V6	R1
Grass-M1	Term 1	4.31 (0.14) ^{NS}	2.64 (0.34) ^{NS}	0.263 (0.008) ^{NS}	0.205 (0.022) ^{NS}
Grass-M1	Term 2	4.05 (0.21) **	2.59 (0.19) *	0.240 (0.010) ^{NS}	0.206 (0.015) ^{NS}
Grass-M1	Term 3	4.06 (0.27) **	2.79 (0.51) ^{NS}	0.246 (0.026) ^{NS}	0.207 (0.026) ^{NS}
Grass-M1	Term 4	4.13 (0.42) ^{NS}	2.50 (0.42) **	0.243 (0.027) ^{NS}	0.199 (0.030) ^{NS}
Brdlf-M2	Term 1	4.19 (0.24) ^{NS}	2.77 (0.30) ^{NS}	0.248 (0.022) ^{NS}	0.202 (0.025) ^{NS}
Brdlf-M2	Term 2	4.15 (0.37) ^{NS}	2.95 (0.22) ^{NS}	0.239 (0.012) ^{NS}	0.212 (0.016) ^{NS}
Brdlf-M2	Term 3	4.06 (0.30) **	2.76 (0.23) ^{NS}	0.235 (0.023) *	0.216 (0.014) ^{NS}
Brdlf-M2	Term 4	4.16 (0.20) ^{NS}	2.81 (0.32) ^{NS}	0.237 (0.016) *	0.215 (0.015) ^{NS}
Blend-M3	Term 1	4.09 (0.41) *	2.74 (0.25) ^{NS}	0.250 (0.030) ^{NS}	0.204 (0.013) ^{NS}
Blend-M3	Term 2	4.01 (0.42) **	2.68 (0.23) ^{NS}	0.245 (0.030) ^{NS}	0.201 (0.038) ^{NS}
Blend-M3	Term 3	4.07 (0.35) **	2.73 (0.15) ^{NS}	0.243 (0.019) ^{NS}	0.206 (0.017) ^{NS}
Blend-M3	Term 4	4.07 (0.56) **	2.77 (0.33) ^{NS}	0.237 (0.023) *	0.205 (0.011) ^{NS}
Control		4.31 (0.20)	2.79 (0.20)	0.258 (0.004)	0.211 (0.014)

†Standard deviation shown in parentheses after treatment mean
^{NS} Treatment mean not significantly different from Control treatment at $\alpha = 0.1$
* Treatment mean differs from Control treatment at $\alpha = 0.1$
** Treatment mean differs from Control treatment at $\alpha = 0.05$

Table 1.28a. Dakota Lakes Research Farm (18 miles east of Pierre, SD) corn tissue nutrients (% nitrogen and % sulfur) at V5/V6 and R1 growth stages statistical analysis.

	% Nitrogen		% Sulfur	
Factor	V5/V6	R1	V5/V6	R1
	P Value			
Mixture	0.636	0.186	0.589	0.734
Termination	0.145	0.880	0.049	0.770
Mixture*Termination	0.516	0.397	0.869	0.877

†Split-plot ANOVA excluding Control treatment

Table 1.29. Canning (central South Dakota) corn tissue nutrients (% nitrogen and % sulfur) at V5/V6 and R1 growth stages.

		% Nitrogen		% Sulfur	
Mixture	Termination	V5/V6	R1	V5/V6	R1
Grass-M1	Term 1	3.04 (0.40) ^{NS}	2.57 (0.12) ***	0.226 (0.033) ^{NS}	0.195 (0.012) ***
Grass-M1	Term 2	3.27 (0.33) ^{NS}	2.52 (0.11) ***	0.225 (0.026) ^{NS}	0.199 (0.014) ***
Grass-M1	Term 3	3.30 (0.30) *	2.54 (0.27) ***	0.230 (0.028) ^{NS}	0.193 (0.016) ***
Grass-M1	Term 4	3.08 (0.32) ^{NS}	2.50 (0.09) ***	0.228 (0.013) ^{NS}	0.189 (0.012) ***
Brdlf-M2	Term 1	3.38 (0.14) **	2.77 (0.19) *	0.254 (0.027) **	0.227 (0.027) ^{NS}
Brdlf-M2	Term 2	3.28 (0.29) ^{NS}	2.72 (0.19) **	0.253 (0.051) **	0.210 (0.015) *
Brdlf-M2	Term 3	3.16 (0.16) ^{NS}	2.62 (0.20) ***	0.229 (0.048) ^{NS}	0.205 (0.022) **
Brdlf-M2	Term 4	3.39 (0.06) **	2.59 (0.33) ***	0.240 (0.023) ^{NS}	0.202 (0.021) ***
Blend-M3	Term 1	3.13 (0.20) ^{NS}	2.66 (0.20) ***	0.230 (0.033) ^{NS}	0.191 (0.011) ***
Blend-M3	Term 2	3.27 (0.20) ^{NS}	2.52 (0.10) ***	0.217 (0.030) ^{NS}	0.193 (0.013) ***
Blend-M3	Term 3	3.29 (0.07) *	2.55 (0.09) ***	0.237 (0.026) ^{NS}	0.194 (0.012) ***
Blend-M3	Term 4	3.14 (0.36) ^{NS}	2.59 (0.08) ***	0.229 (0.037) ^{NS}	0.193 (0.006) ***
Control		2.99 (0.41)	2.96 (0.07)	0.226 (0.027)	0.235 (0.028) ***

†Standard deviation shown in parentheses after treatment mean
^{NS} Treatment mean not significantly different from Control treatment at $\alpha = 0.1$
* Treatment mean differs from Control treatment at $\alpha = 0.1$
** Treatment mean differs from Control treatment at $\alpha = 0.05$
*** Treatment mean differs from Control treatment at $\alpha = 0.01$

Table 1.29a. Canning (central South Dakota) corn tissue nutrients (% nitrogen and % sulfur) at V5/V6 and R1 growth stages statistical analysis.

	% Nitrogen		% Sulfur	
Factor	V5/V6	R1	V5/V6	R1
	P Value			
Mixture	0.665	0.340	0.244	0.096
Termination	0.570	0.176	0.904	0.200
Mixture*Termination	0.085	0.931	0.340	0.285

†Split-plot ANOVA excluding Control treatment

Table 1.30. Dakota Lakes Research Farm (18 miles east of Pierre, SD) corn grain yield (Mg ha^{-1}), corn grain test weight (kg m^{-3}), and corn grain crude protein (%). Corn harvested on 2020-10-01.

Mixture	Termination	Grain Yield (Mg ha^{-1})	Grain Test Weight (kg m^{-3})	Grain Crude Protein (%)
Grass-M1	Term 1	6.39 (0.5) ***	777 (4.9) ^{NS}	9.2 (0.8) ^{NS}
Grass-M1	Term 2	6.03 (0.8) ***	772 (12) ^{NS}	8.2 (1.1) *
Grass-M1	Term 3	6.05 (2.1) ***	766 (15) ^{NS}	9.3 (0.8) ^{NS}
Grass-M1	Term 4	6.37 (1.2) ***	758 (9.1) **	8.6 (0.7) ^{NS}
Brdlf-M2	Term 1	7.10 (0.5) *	774 (7.1) ^{NS}	9.0 (0.8) ^{NS}
Brdlf-M2	Term 2	5.47 (0.8) ***	775 (6.8) ^{NS}	9.1 (0.5) ^{NS}
Brdlf-M2	Term 3	5.99 (0.5) ***	773 (7.9) ^{NS}	9.0 (1.2) ^{NS}
Brdlf-M2	Term 4	5.55 (0.6) ***	771 (11) ^{NS}	9.3 (0.6) ^{NS}
Blend-M3	Term 1	7.39 (0.6) ^{NS}	771 (5.9) ^{NS}	8.4 (0.5) ^{NS}
Blend-M3	Term 2	6.06 (0.9) ***	773 (14) ^{NS}	8.7 (1.0) ^{NS}
Blend-M3	Term 3	6.36 (1.2) ***	770 (7.4) ^{NS}	8.7 (1.0) ^{NS}
Blend-M3	Term 4	5.72 (1.0) ***	763 (15) ^{NS}	9.4 (1.1) ^{NS}
Control		7.99 (0.8)	771 (6.5)	9.4 (0.6)

†Standard deviation shown in parentheses after treatment mean
^{NS} Treatment mean not significantly different from Control treatment at α= 0.1
* Treatment mean differs from Control treatment at α= 0.1
** Treatment mean differs from Control treatment at α= 0.05
*** Treatment mean differs from Control treatment at α= 0.01

Table 1.30a. Dakota Lakes corn grain yield, corn grain test weight, and corn grain crude protein statistical analysis.

Factor	Grain Yield	Test Weight	Grain Crude Protein
		P Value	
Mixture	0.608	0.530	0.156
Termination	0.052	0.108	0.778
Mixture*Termination	0.745	0.789	0.598

†Split-plot ANOVA excluding Control treatment

Table 1.31. Canning (central South Dakota) corn grain yield (Mg ha^{-1}), corn grain test weight (kg m^{-3}), and corn grain crude protein (%). Corn harvested on 2020-10-09.

Mixture	Termination	Grain Yield (Mg ha^{-1})	Grain Test Weight (kg m^{-3})	Grain Crude Protein (%)
Grass-M1	Term 1	8.17 (1.3) ^{NS}	769 (0.2) *	8.1 (0.2) ***
Grass-M1	Term 2	7.71 (1.0) **	764 (0.4) ^{NS}	8.0 (0.3) ***
Grass-M1	Term 3	7.77 (0.8) **	764 (0.5) ^{NS}	8.1 (0.5) ***
Grass-M1	Term 4	7.52 (1.3) **	763 (0.4) ^{NS}	8.0 (0.4) ***
Brdlf-M2	Term 1	7.99 (1.3) ^{NS}	764 (0.5) ^{NS}	8.3 (0.5) ***
Brdlf-M2	Term 2	8.00 (1.2) ^{NS}	769 (0.3) *	8.3 (0.3) ***
Brdlf-M2	Term 3	7.28 (0.4) **	767 (0.3) ^{NS}	7.9 (0.3) ***
Brdlf-M2	Term 4	6.79 (1.0) **	764 (0.2) ^{NS}	8.1 (0.5) ***
Blend-M3	Term 1	7.48 (1.1) ***	767 (0.4) ^{NS}	8.0 (0.3) ***
Blend-M3	Term 2	8.19 (1.1) ^{NS}	762 (0.2) ^{NS}	7.7 (0.3) ***
Blend-M3	Term 3	7.11 (0.9) ***	765 (0.4) ^{NS}	7.8 (0.2) ***
Blend-M3	Term 4	7.29 (0.9) ***	763 (0.5) ^{NS}	7.7 (0.1) ***
Control		8.67 (1.1)	764 (0.5)	8.6 (0.4)

†Standard deviation shown in parentheses after treatment mean
^{NS} Treatment mean not significantly different from Control treatment at α= 0.1
* Treatment mean differs from Control treatment at α= 0.1
** Treatment mean differs from Control treatment at α= 0.05
*** Treatment mean differs from Control treatment at α= 0.01

Table 1.31a. Canning (central South Dakota) corn grain yield, corn grain test weight, and corn grain crude protein statistical analysis.

Factor	Grain Yield	Grain Test Weight	Grain Crude Protein
		P Value	
Mixture	0.751	0.618	0.221
Termination	0.011	0.556	0.059
Mixture*Termination	0.454	0.230	0.241

†Split-plot ANOVA excluding Control treatment

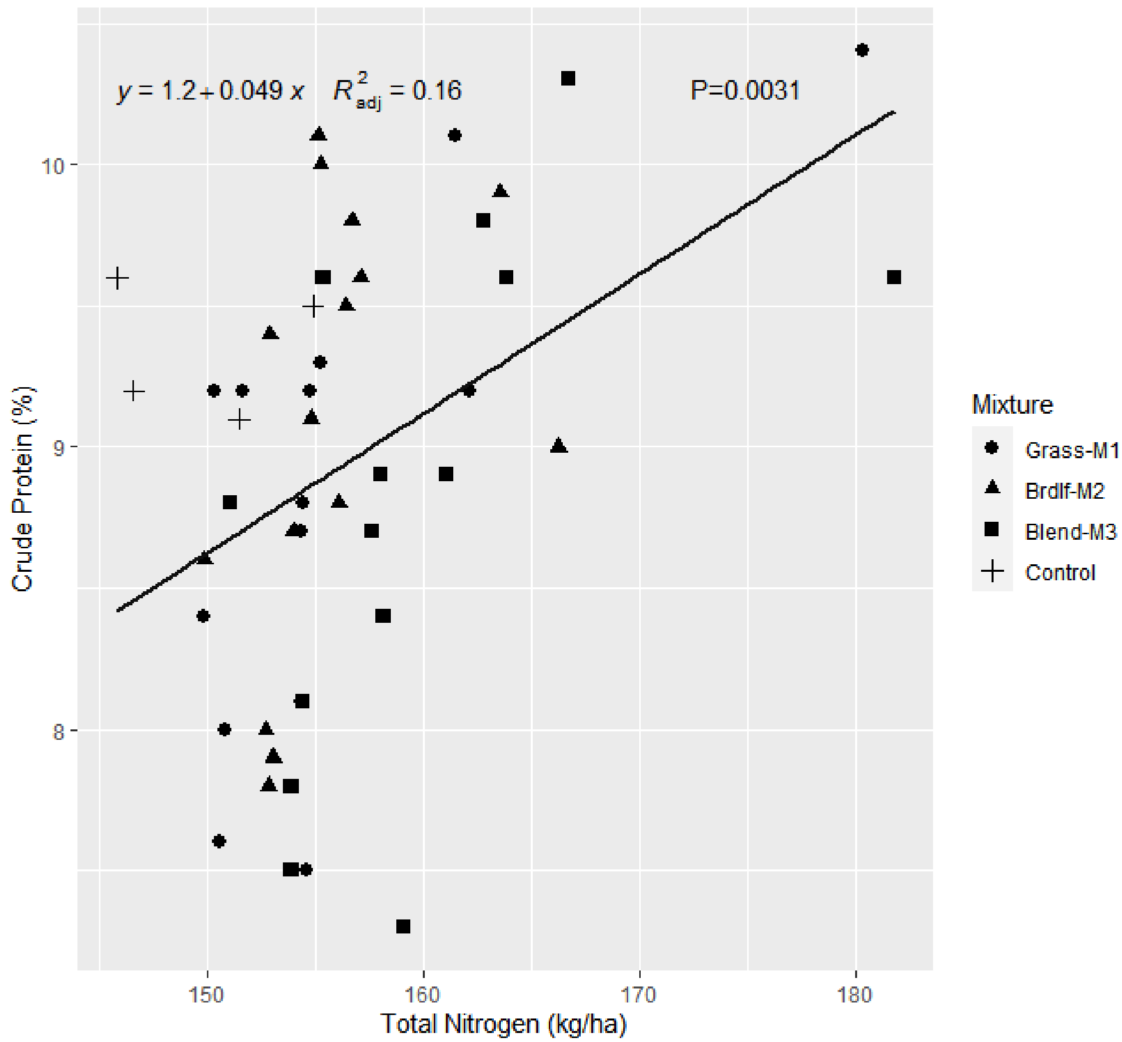

Figure 1.14. Dakota Lakes Research Farm (18 miles east of Pierre, SD) total nitrogen (spring soil nitrate-nitrogen plus nitrogen fertilizer applied) (kg ha^{-1}) versus corn grain crude protein (%). P value < 0.05 indicates the slope of the line is different from 0 at α= 0.05.

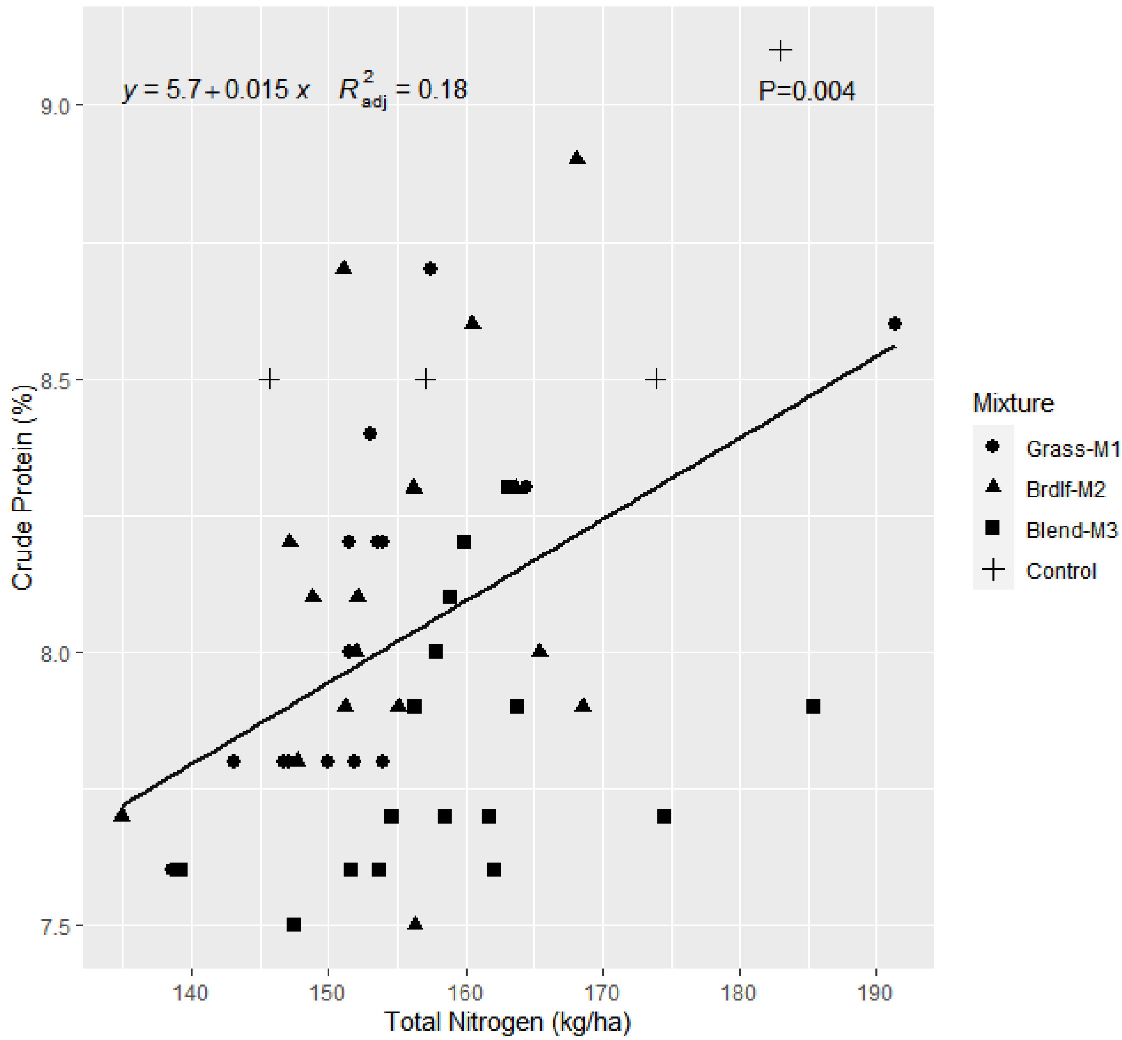

Figure 1.15. Canning (central South Dakota) total nitrogen (spring soil nitrate-nitrogen plus nitrogen fertilizer applied) (kg ha^{-1}) versus corn grain crude protein (%). P value < 0.05 indicates the slope of the line is different from 0 at α= 0.05.

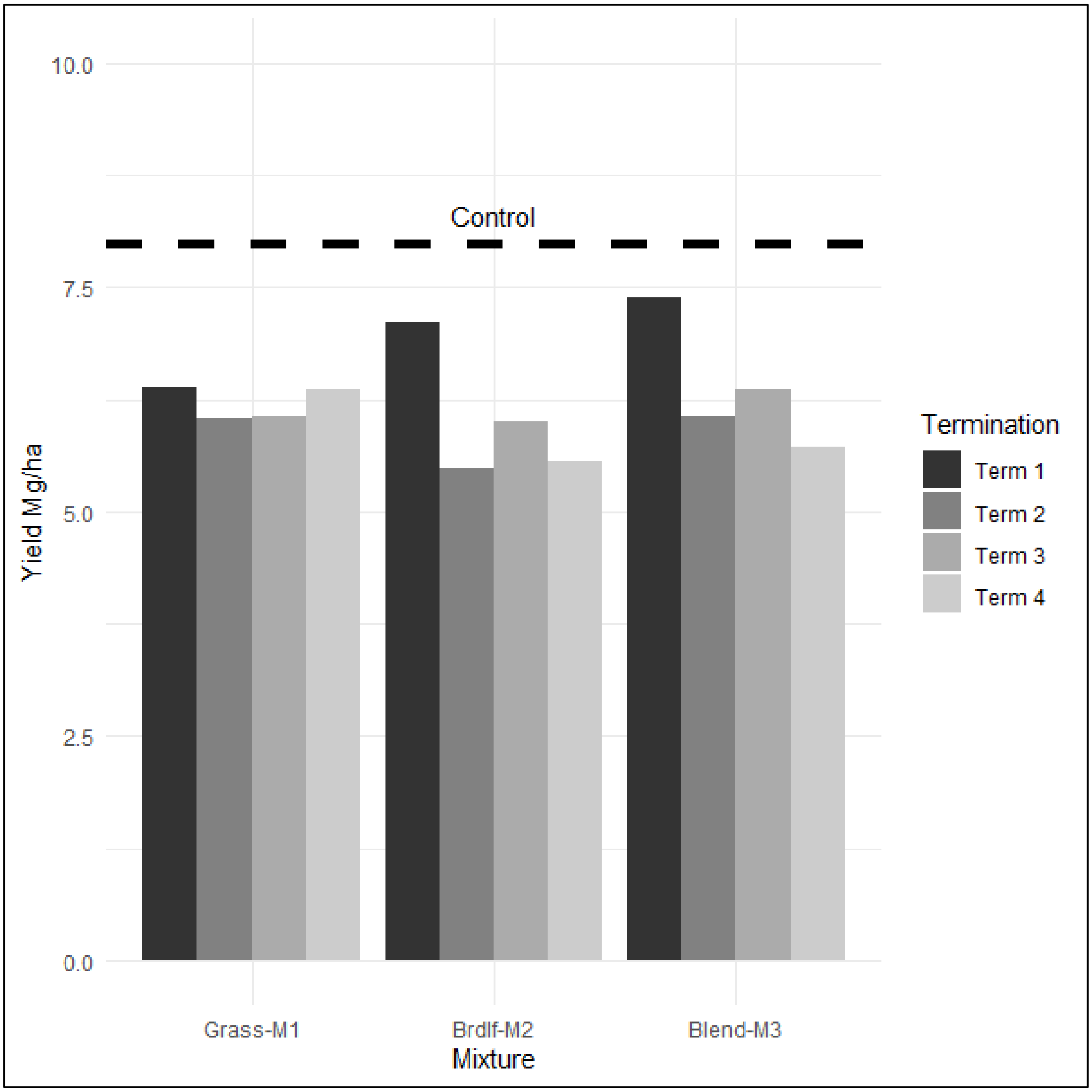

Figure 1.16. Dakota Lakes Research Farm (18 miles east of Pierre, SD) corn grain yield (Mg ha^{-1}). Corn harvested on 2020-10-01.

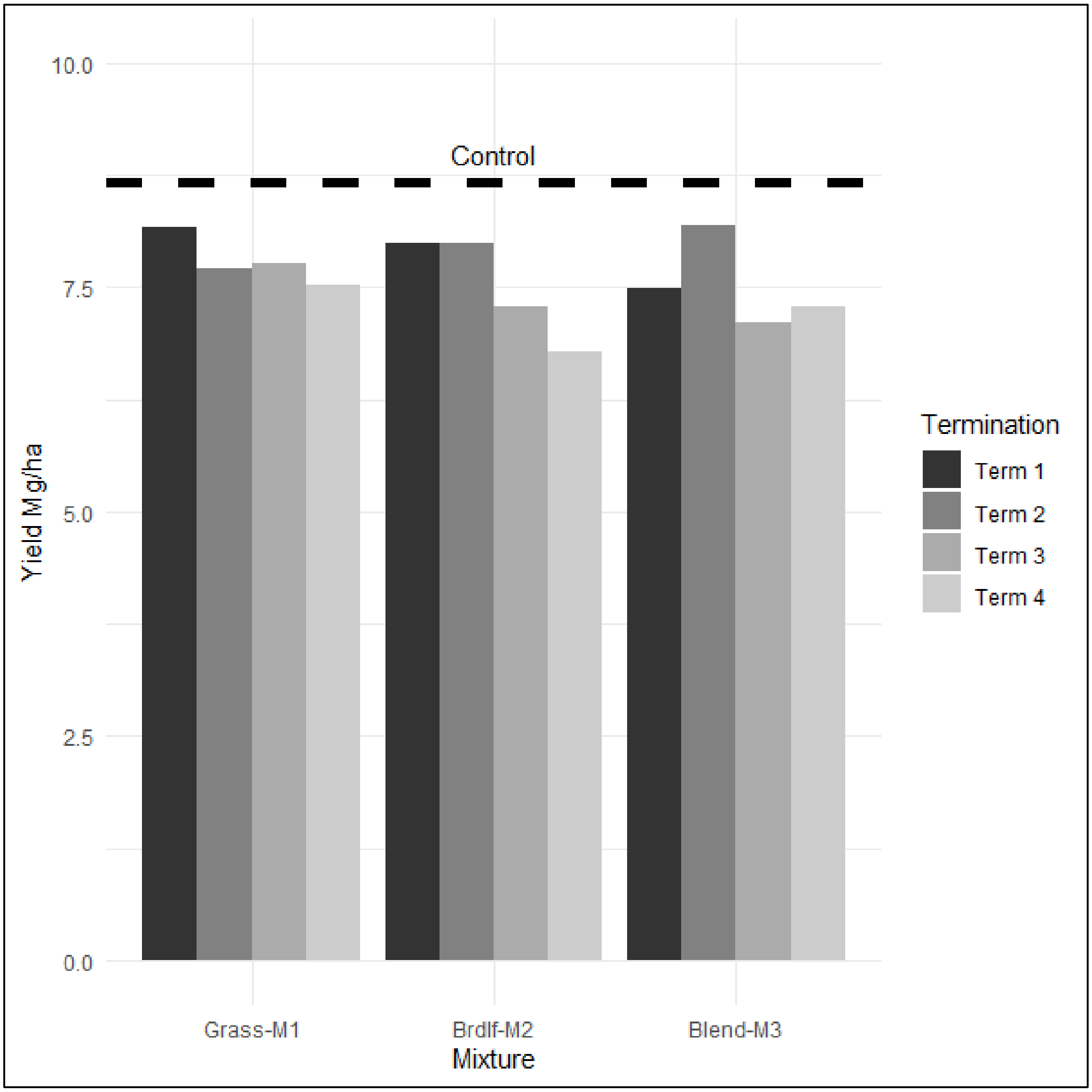

Figure 1.17. Canning (central South Dakota) corn grain yield (Mg ha^{-1}). Corn harvested on 2020-10-09.

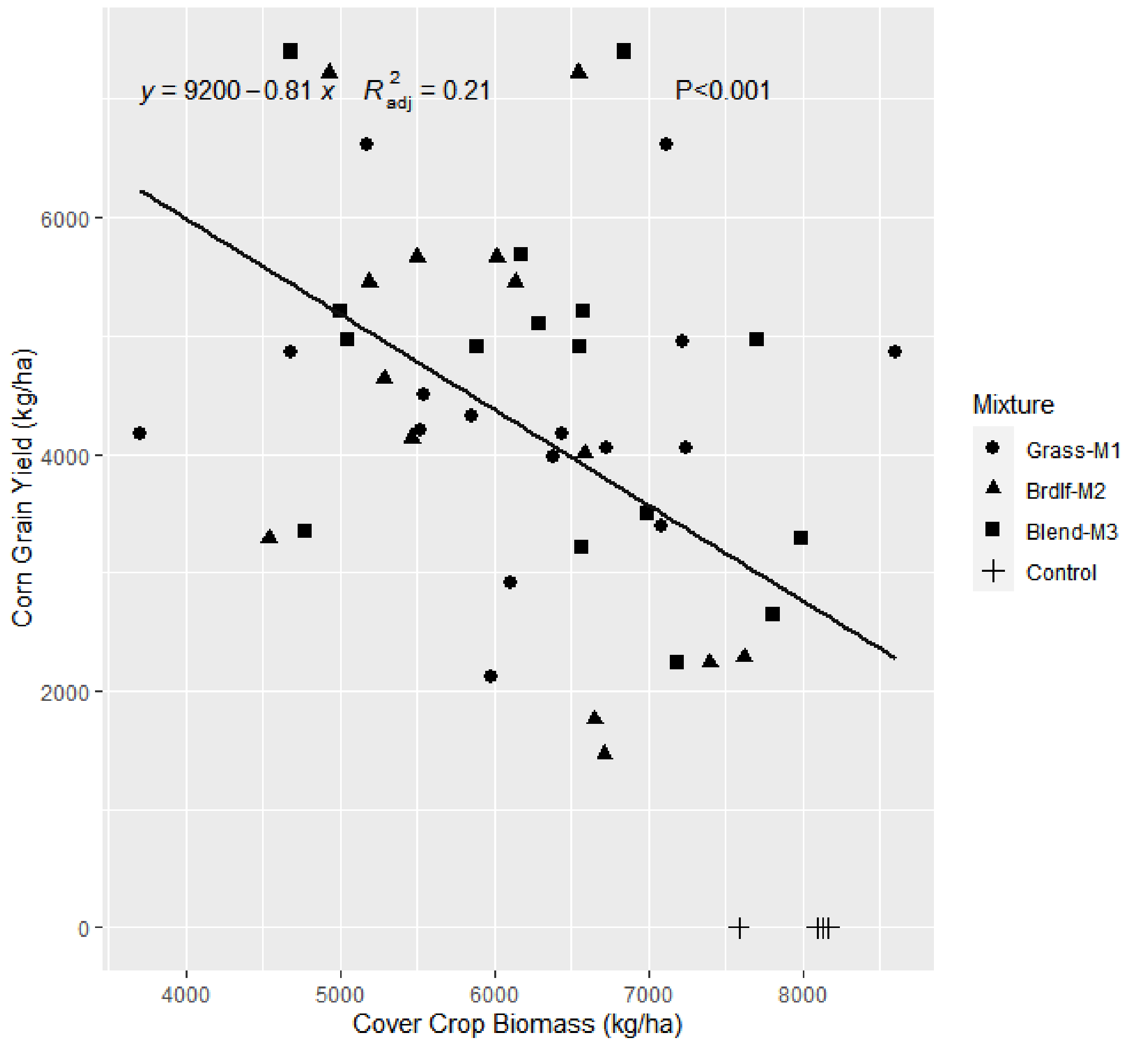

Figure 1.18. Dakota Lakes Research Farm (18 miles east of Pierre, SD) cover crop biomass (kg ha^{-1}) versus corn grain yield (kg ha^{-1}). P value < 0.05 indicates the slope of the line is different from 0 at α= 0.05.

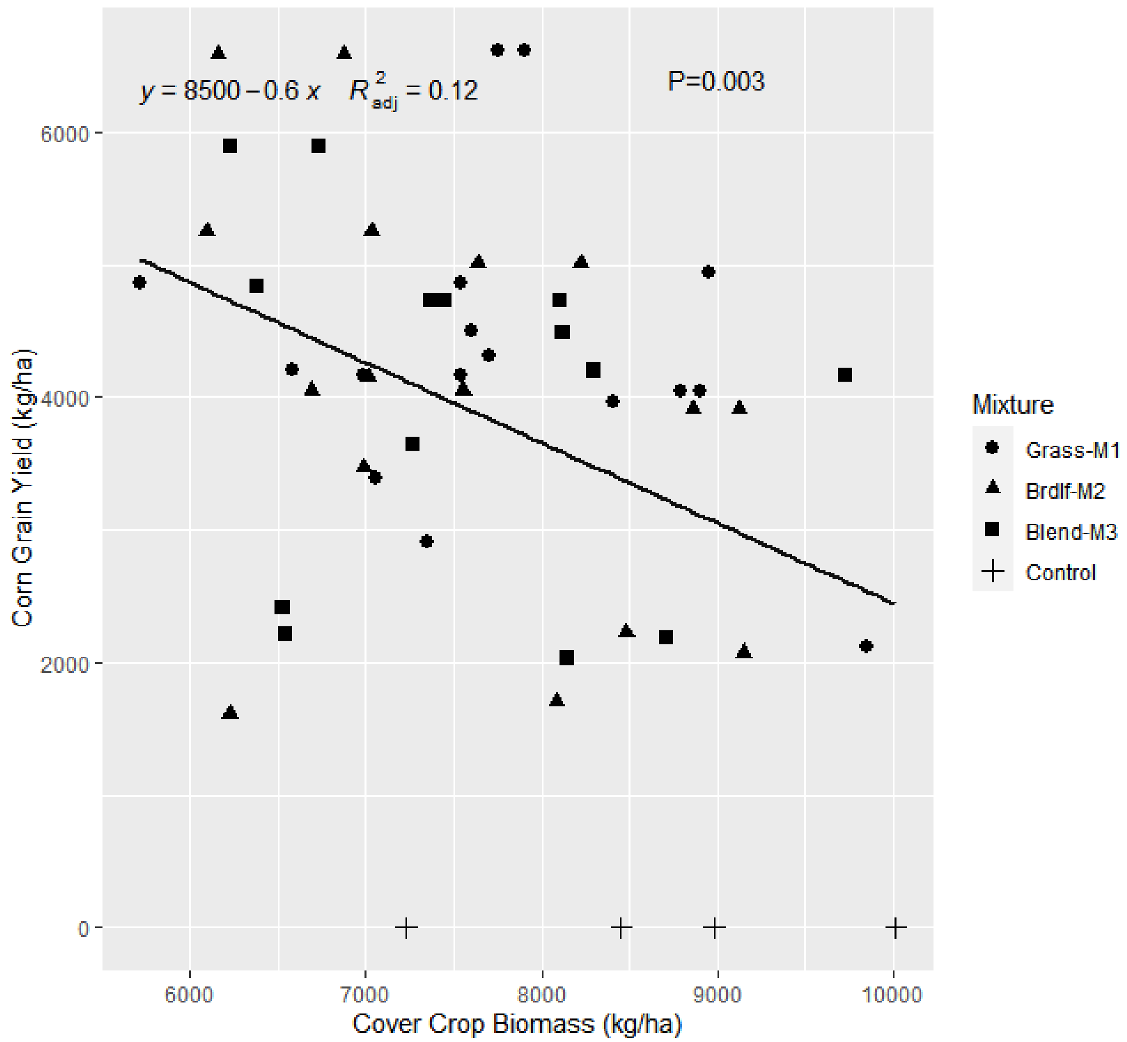

Figure 1.19. Canning (central South Dakota) cover crop biomass (kg ha^{-1}) versus corn grain yield (kg ha^{-1}). P value < 0.05 indicates the slope of the line is different from 0 at α= 0.05.

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CHAPTER 2. COVER CROP TERMINATION DECISION MODEL FOR SOIL MOISTURE RECHARGE

ABSTRACT

In South Dakota, the fallow period between wheat harvest (July) and corn planting (following April/May) presents an opportunity for cover crops. The State's limited growing season restricts late fall and winter plant growth, which narrows this cover crop window. To address this climatic constraint, the cover crop should be seeded as soon as the wheat crop has been harvested. Biomass production will typically decrease as more time passes between wheat harvest and cover crops being planted. If a producer decides to wait for additional moisture to arrive before planting, they may be too late. A cover crop failure due to insufficient soil moisture incurs the cost of seeding and moisture used by the cover crop. To address the obstacle that cover crops create by depleting a soil moisture profile, a model was developed to estimate water use and ultimately determine when the cover crop should be terminated to conserve soil moisture. To assess the accuracy of the model field experiments were conducted in 2019 through 2020 at the Dakota Lakes Research Farm (Pierre, SD) and on a producer's field near Canning, SD. Three different cover crop mixes (Grass-M1 (grass dominated blend), Brdlf-M2 (broadleaf dominated blend), and Blend-M3 (equally weighted by rate of grass and broadleaves)) were planted following winter wheat. A chemical fallow treatment was implemented as a control. Cover crops were terminated with herbicides at different times in the fall of 2019.

Crop coefficients are variables used in evapotranspiration calculations. Cover crops are sometimes grown in polycultures, which complicates the crop coefficient value.

In this study, crop coefficients were developed for three cover crop mixes. This model utilizes the difference between evapotranspiration and precipitation to calculate a precipitation deficit. The total water storage capacity of a soil is used to determine how much soil moisture is required for a soil profile to be full. Lastly, historical precipitation data is used to determine the likelihood of receiving the amount of precipitation necessary to have a full soil profile when it is needed. In this experiment, historical precipitation data showed that if normal precipitation was received, every treatment would have been refilled on or before 2020-05-16.

The calculated total soil water values produced by the model were plotted against the measured total soil water values to develop a regression. Accuracy of the model was determined by testing if the slope of the regression was different from one. Different soil profile depths and time frames were considered at the two locations. At the Dakota Lakes site, the model accurately predicted total soil moisture. At the Canning site, the model displayed flaws for the time frame (2019-09-27) – (2020-06-17). The 0-60 cm soil profile ($p>0.001$) and 0-90 cm soil profile ($p>0.001$) slopes were significantly different from one. The 0-90 cm soil profile for the time frame (2019-09-27) – (2019-11-15) resulted in a slope different from one ($p=0.090$).

INTRODUCTION

In central South Dakota, cover crops are used to replace part of the fallow period that ensues after wheat harvest (mid-summer) and lasts until corn planting (mid-spring) (Clay et al., 2016; Sexton, 2012). A function of cover crops is to use excess water. In some cases, cover crops have been found to short-change the following cash crop soil moisture (Kahimba et al., 2008; Nielsen & Vigil, 2005; Lu et al., 2000). If limited soil moisture becomes a concern during the cover crop's lifespan, one option to conserve this soil moisture is to use herbicides to terminate the growing cover crop (Legleiter et al., 2012; Nielsen & Vigil, 2005). To adjust to variable weather conditions, a model was developed with the goal of fine-tuning cover crop management decisions.

One of the primary purposes for building this model is to give producers an estimate of when to terminate cover crops to conserve soil moisture. The goal is to conserve enough soil moisture such that precipitation will recharge the soil profile prior to the next cash crop needing that soil moisture. Historical precipitation records can provide an estimate of how much precipitation to expect for a given time frame. A precipitation/evapotranspiration deficit is an input to the model that will be approached with what is referred to as the "checkbook method". The "checkbook" method is a commonly used irrigation scheduling calculation (Melvin & Yonts., 2009). This procedure utilizes three variables: a soil's water holding capacity, precipitation (or irrigation water), and evapotranspiration. Precipitation is the input, evapotranspiration is the output, and the water holding capacity of the soil profile provides the floor (permanent wilting point) and ceiling (field capacity) as to how much soil water will be held in the soil. Another goal of the model is to present the number of years, out of the 16 years of historical precipitation data, that each treatment would recharge their soil profile by the time the next cash crop was seriously using soil moisture.

Precipitation in semiarid regions ranges from 20-50% of the potential evaporation (Hatfield, 1990). In these climates, soil water is a limited resource and must be treated as such. Furthermore, farming practices must attempt to maximize their water use efficiency. The water cycle encompasses but is not limited to the following processes: precipitation, evaporation, transpiration by plants, groundwater recharge and surface runoff (Brady & Weil, 1999). Agricultural land management impacts each of these processes (Vorosmarty & Sahagian, 2000). Consideration can be directed to the relationship between precipitation, evaporation, and transpiration by plants, as these processes can be viewed simply as inputs and outputs to a system (Melvin & Yonts, 2009).

Driven by solar radiation, evapotranspiration is the sum of all water leaving the earth's surface as water vapor (Peixoto & Kettani, 1973). In terrestrial ecosystems, the main components involved in this process are soil evaporation and plant transpiration. Transpiration of water through a plant can make money for a farmer, while evaporation from the soil cannot (Kite, 2000). To optimize the water use efficiency of a system, an effort must be made to reduce evaporation and increase transpiration. Reduced tillage, returned crop residues, and wind breaks have shown to be effective methods towards reducing soil evaporation (Klocke et al., 2009; Rosenberg et al., 1983). Reducing the amount of soil water lost to evaporation increases the amount available for plant transpiration.

Reference evapotranspiration is the rate of evapotranspiration from a hypothetical reference crop (typically grass or alfalfa) (Irmak & Haman, 2003). Accurate calculation of reference evapotranspiration requires a parameter referred to as a crop coefficient (KC). A crop coefficient is the ratio of actual crop evapotranspiration to reference crop evapotranspiration (Kang et al., 2003). There has been a significant amount of work done in developing crop coefficients for monoculture crops grown in agriculture using lysimeters (Jensen, 1968). Mixed plant species have received much less attention from the scientific community in-regards-to developing crop coefficients (Corbari et al., 2017). Remotely sensed vegetation indices have been used in estimating crop coefficients in natural ecosystems (mixed species) on a field-by-field reflectance basis (Glenn et al., 2011). This method presents an opportunity to develop crop coefficients for a mixed plant species cover crop. The objective of developing a crop coefficient is for use in the evapotranspiration equation (Equation 2.1). Evapotranspiration will then be used in a model that will assist in making cover crop termination decisions.

$$ETc = Kc * ETo \qquad \textbf{Eq. 2.1}$$

MATERIALS AND METHODS

Site Descriptions/ Experimental Design/ Statistical Analysis

Site descriptions and the experimental design were described in "Chapter 1. Impact of Cover Crops and Termination Timing to Following Cash Crop (Corn)." Surface residue and K_C for dead vegetation were statistically analyzed in the same manner as was performed in Chapter 1. This includes two analyses: 1) a split-plot ANOVA with the Control being removed, and 2) a one-way ANOVA on transformed data to compare the cover cropped treatments to the Control.

The developed model was analyzed for accuracy using a two-sided linear slope test. This procedure was carried out by creating a linear regression of the measured total soil water versus the modeled total soil water. Slope of the regression was analyzed to determine if it was significantly different from one at $\alpha = 0.10$. Statistical analysis was performed in R programming language using the "car" package to conduct analysis of variance.

Precipitation/Evapotranspiration Measurements

The South Dakota State University Mesonet weather station located at Dakota Lakes Research Farm was used as the primary weather record. ClearVu 12.7 cm (5 in) rain gauges (Taylor USA) were utilized at both sites for periods of 2019 and 2020. Rain gauge precipitation data supplemented the precipitation data recorded by the South Dakota State University Mesonet weather station (Mesonet at SDSTATE, 2020) at Dakota Lakes. This weather station also records the appropriate data to calculate ET_R (reference evapotranspiration). Two reference evapotranspiration datasets were analyzed to assess the accuracy of the model. The dataset presented in the results of the model estimated less evapotranspiration than the dataset that is not presented. The model utilized this precipitation and evapotranspiration data for 2019 and 2020. Historical precipitation is considered in the decision-making portion of the model to evaluate the likelihood of soil moisture recharge. South Dakota State University Mesonet (Mesonet at SDSTATE, 2020) provided precipitation data for the Dakota Lakes weather station for the years 2002-2019.

Remote Sensing/Image Processing/Surface Residue

Details of the specifications for the remote sensing equipment and the procedure to process imagery can be found in the Materials and Methods section of "Chapter 1. Impact of Cover Crops and Termination Timing to Following Cash Crop (Corn)."

On 2020-05-29, a remote-sensing flight was conducted to estimate percent cover of the remaining residue. The corn crop had emerged but did not have significant canopy as it was at the VE/V1 stage. Furthermore, the surface residue was responsible for nearly all light wave reflectance. The blue band width was analyzed at this time to estimate residue cover. Obade et al. (2011) found the blue band width to have a high correlation with surface residue cover. The blue band width is useful for distinguishing soil from vegetation (Obade et al. 2011). These values were used to estimate the percent ground cover. According to FAO Chapter 11, K_C for surface covered with dead vegetation can be set equal to K_C initial while reducing the value 5% for each 10% of soil surface cover present. A linear regression equation was developed for the Dakota Lakes and Canning sites to relate blue light bandwidth value to percent ground cover of surface residue. The procedure to develop this regression was developed by using eight calibration values located near the edge of the plots at each location. Eight control points were developed by manually manipulating surface residue cover to known visually determined surface cover percentages. Methodology for this was subject to human error, as estimates were made in the field by a single observer (observing point approximately 2 m above soil surface) based on the amount of bare soil exposed. These control points were correlated to the blue light band width obtained from the RGB camera carried by the drone during the remote-sensing flight.

Crop Coefficient Development

Crop coefficients were developed for each treatment at their respective site location. The crop coefficient curves developed for each mixture and termination timing are shown in Figures 2.3, 2.4, and 2.5 for Dakota Lakes and Figures 2.6, 2.7, and 2.8 for Canning. The equations for the crop coefficient curves are presented in Table 2.1 for Dakota Lakes and Table 2.2 for Canning. The time frame and number of days for each stage were determined from FAO Chapter 6-ET_C-Single crop coefficient (K_C) (Allen et al., 1998). K_C initial was determined from FAO Chapter 6-ET_C-Single crop coefficient (K_C) (Allen et al., 1998). Soil texture, time between wetting events, and average ET_R (reference) were used to develop the K_C initial value. K_C mid-season was calculated from NDVI values. Remote-sensing flights were conducted during the cover crop's growing season. These images were used to extract NDVI values that were converted into K_C values. Crop development K_C is a linear regression between K_C initial and K_C mid-season. K_C late season is a linear regression between K_C mid-season and K_C end. K_C end is interpolated for each mixture based on FAO (Chapter 6-ET_C-Single crop coefficient (K_C) Table 12) (Allen et al., 1998). K_C for surface covered with dead vegetation was utilized in the model as the K_C value post cover crop termination. This value was determined from FAO Chapter 11-ET_C during non-growing periods (Allen et al., 1998). Each treatment K_C for surface covered with dead vegetation is presented in Table 2.3 for Dakota Lakes and Table 2.4 for Canning.

Checkbook Approach to Determine Precipitation Deficit

Web Soil Survey was used to obtain the volumetric moisture content of the respective soils at permanent wilting point and field capacity (Table 2.5) (Web Soil Survey, 2020). At Dakota Lakes, the Dorna silt loam soil has a permanent wilting point of 10.9% when considering the 0-60 cm soil profile, and 15.6% when considering the 0-90 cm soil profile. The field capacity is 26.6% when considering the 0-60 cm soil profile, and 28.5% for the 0-90 cm soil profile. At Canning, the Hurley silt loam has a permanent wilting point of 33.9% when considering the 0-60 cm soil profile, and 34.5% when considering the 0-90 cm soil profile. The field capacity is 40.7% when considering the 0-60 cm soil profile, and 41.1% for the 0-90 cm soil profile. The drastic difference in permanent wilting points between the Dorna silt loam and Hurley silt loam can be explained by the clay content. The Dorna silt loam consists of 32% clay, while the Hurley silt loam consists of 63%. In general, higher clay content soils hold more water, while their permanent wilting point is also higher (less plant available water).

Measured total soil water prior to planting cover crops was used as the starting point. Details of measured soil water (calculated from gravimetric soil samples) can be found in the Materials and Methods section of "Chapter 1. Impact of Cover Crops and Termination Timing to Following Cash Crop (Corn)." Precipitation was added and evapotranspiration was subtracted. The field capacity values from Web Soil Survey were utilized to estimate how much precipitation was needed to fill the soil profile and to track at what date this occurred.

No signs of runoff from running water were observed at Dakota Lakes. Infiltration tests on soils near the Dakota Lakes site with similar characteristics and management practices suggest that none of the precipitation events would result in runoff or at the very least would be minimal. 100% infiltration was assumed for every precipitation event at Dakota Lakes. One extreme precipitation event (102 mm) at Canning (2020-06-07) resulted in noticeable runoff. The amount of runoff was estimated to be 34.8 mm. This estimate was calculated by first finding the difference in soil moisture from soil samples measured before and after the precipitation event. Next the precipitation/evapotranspiration difference between the two sampling events (2020-04-17 and 2020-06-17) was calculated to determine how much water would have been added to the soil profile assuming no runoff. The difference in soil moisture from soil samples was then subtracted from the precipitation/evapotranspiration difference to find the amount of unaccounted for water (34.8 mm). This runoff accounted for 34.1% of the precipitation event, which was very atypical for this soil.

RESULTS AND DISCUSSION

The model was developed and calibrated using the same data that was used to test its accuracy. Clearly this is an imperfect approach, however the concepts used to create the model remain legitimate. Additional replicated data would benefit the weight of confidence behind this model.

Soil Profile Moisture Recharge Confidence

A goal of the model was to determine the probability of recharging a soil profile with soil moisture based on the date of termination and historical data. In this experiment, the model showed all treatments had refilled for every year considering the 17 years of weather data.

For corn, soil moisture is being used significantly at the V5/V6 stage (Trooien et al., 2009). This growth stage was reached at Dakota Lakes on 2020-06-15 and at Canning on 2020-06-30. Based on the 17 years of precipitation data, every treatment at both sites was recharged prior to the V5/V6 growth stage in corn being reached. This is partially due to a wetter than normal fall (2019). Plant available water (PAW) estimates in April show many of the cover cropped treatments soil profiles had not yet recharged (Table 1.6). These measurements contradicted the model's predictions.

Problems with the model arose when considering field capacity (-1/3 bar). Gravimetric soil samples indicated higher field capacity values than Web Soil Survey. Explanations for this disagreement could be due to the management practices of both sites. Both sites have been subject to long-term no-till and high levels of returned crop residues. No-till is an agricultural practice capable of sequestering atmospheric CO_2 and increasing SOM levels (Reicosky et al., 2007). As the soil organic matter in a soil decreases, so too does the soil's water storage capacity. No-tillage or low soil disturbance systems make more efficient use of precipitation than do high soil disturbance tillage systems (Nielsen et al., 2005). When soil vertical hydraulic conductivity is low, and a soil reaches saturation, perched water tables can occur. This situation occurs as soil water reaches an impermeable layer and begins to move laterally (Walker et al. 2020). On the Dorna silt loam soil at Dakota Lakes and Hurley silt loam at Canning, conditions are present for this phenomenon to take place. This is due to the management (long-term no-till resulting in large macropores and extensive drainage) and a slowly permeable underlying clay layer.

Measured Versus Modeled Soil Water

Measured total soil water was plotted against modeled total soil water to develop a linear regression (Table 2.6). A perfect model regression would have a slope of 1 and an adjusted R^2 value of 1. A two-sided linear slope test was conducted on the linear regression developed by plotting the total soil moisture predicted by the model versus total soil moisture measured and calculated with gravimetric soil samples (Figures 2.9, 2.10, 2.11, 2.12, 2.13, 2.14, 2.15, and 2.16). These figures are differentiated from one another by their respective site location (Dakota Lakes or Canning), dates considered (September 2019-November 2019 or September 2019-June 2020) and soil profile depth considered (0-60 cm or 0-90 cm).

At Dakota Lakes, the model proved to be quite accurate (Figures 2.9, 2.10, 2.11, 2.12). For the shallow soil profile depth (0-60 cm) and time frame (2019-09-24) - (2020-06-16) the slope of the model was not different from one (p=0.191). The shallow soil profile depth and time frame (2019-09-24) - (2019-11-08) again did not differ significantly from one (p=0.498). The deep soil profile depth (0-90 cm) combined with the (2019-09-24) - (2020-06-16) time frame was not significantly different from one (p=0.181). Considering the 0-90 cm soil profile depth and the (2019-09-24) - (2019-11-08) time frame, the model produced a slope close to one (m=1.2) and was again not significantly different from one (p=0.430).

At Canning, the model did not perform as well as it did at Dakota Lakes. For the shallow soil profile depth (0-60 cm) and time frame (2019-09-27) - (2020-06-17) the slope was significantly different from one (p<0.001). The shallow soil profile depth combined with the time frame (2019-09-27) - (2019-11-15) resulted in a slope not significantly different from one (p=0.396). The deep soil profile depth (0-90 cm) and time frame (2019-09-27) - (2020-06-17) resulted in a regression slope different from one (p<0.001). The other deep soil profile analyzed the time frame (2019-09-27) - (2019-11-15) and produced a slope significantly different from one (p=0.090).

At Dakota Lakes, the time frame (2019-09-24) - (2019-11-08) produced slopes closer to one than did the time frame (2019-09-24) - (2020-06-16). At Canning, a similar trend occurred as the time frame (2019-09-27) - (2019-11-15) produced linear slopes closer to one than the time frame (2019-09-27) - (2019-11-15). The SDSU Mesonet weather station was used to collect precipitation data for most of this time frame including the entirety of the winter months. The weather station does not estimate snowmelt accurately. This could explain inaccuracies with the model in the spring. Soil profile depth, 0-60 cm versus 0-90 cm, did not produce a trend to indicate a major change to the model. The model overestimated total soil water at the Canning site. Reason for this leaning could have been an inaccurate estimate of runoff during the 2020-06-07 extreme precipitation event. As forementioned two reference evapotranspiration datasets were analyzed to assess the model. The dataset that is presented estimated less evapotranspiration than the dataset that is not presented. Using the other dataset swayed the model to underestimate total soil water at Dakota Lakes and Canning.

Suggestions for Improvement/Future Work

Numerous inputs were utilized in the model (crop coefficients, surface residue cover, soil water holding characteristics, precipitation data, runoff estimates). Combining each of these components resulted in a model of complexity that may not be practical for use by producers. Simplifying some of these constituents to reduce input information could be of benefit to the end user. This could be accomplished by making estimates of crop coefficients based upon geographical location, growing degree days, and planting mixture. Surface residue is another input that could be estimated visually rather than using blue light reflectance.

The model was developed based on data from two sites and therefore is limited. Different cover crop mixes, soil types, and geographical location will likely produce different results. The perched water table was not considered in the model. An estimate of the water that is plant available at the perched water table would be a valuable addition to the model.

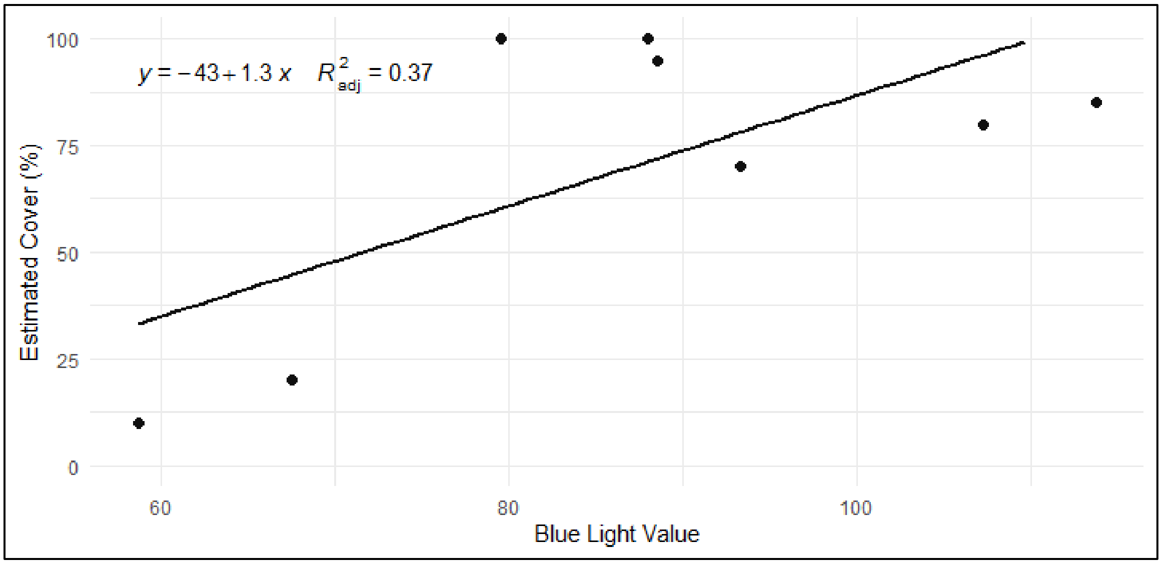

Figure 2.1. Dakota Lakes Research Farm (18 miles east of Pierre, SD) blue light value (bandwidth) versus estimated surface cover (%) linear regression.

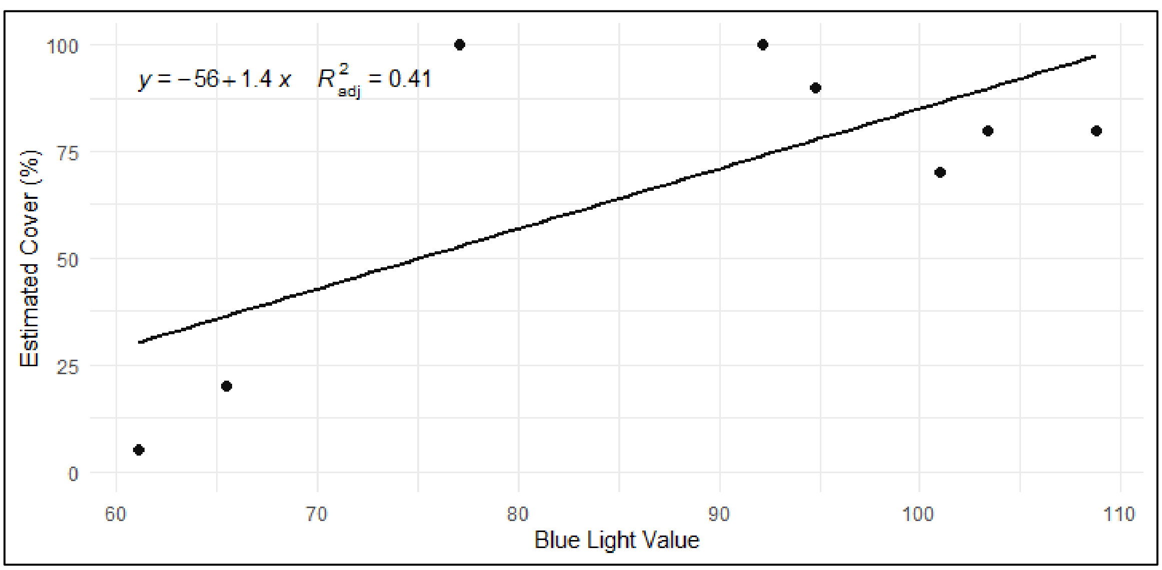

Figure 2.2 Canning (central South Dakota) blue light value (bandwidth) versus estimated surface cover (%) linear regression.

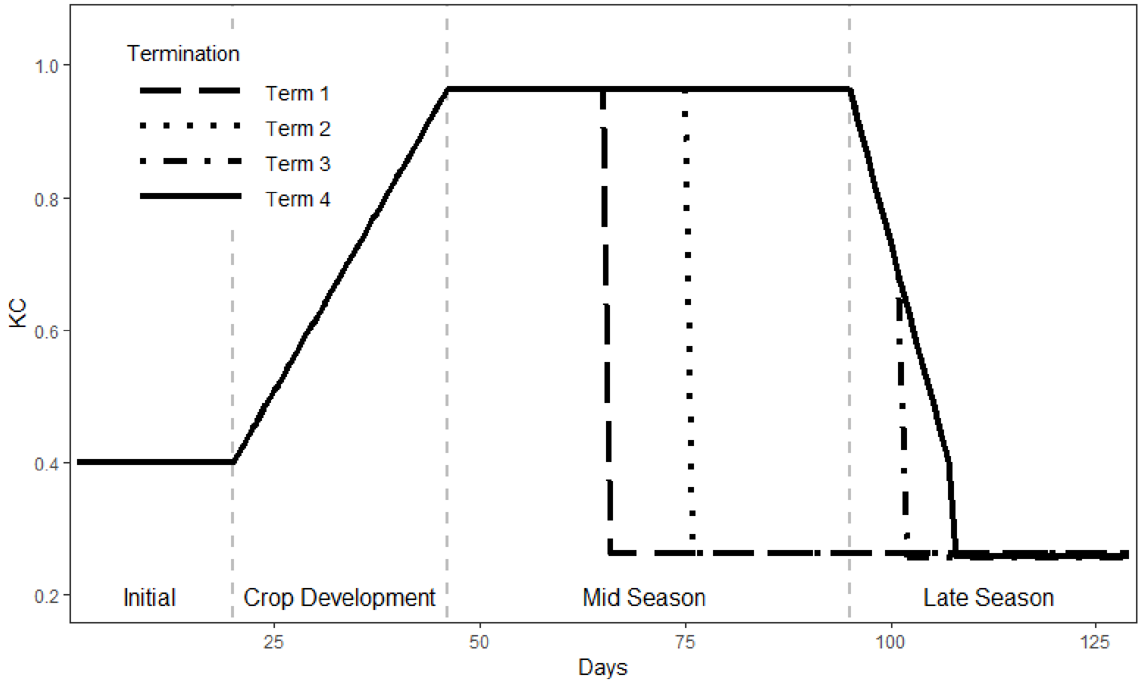

Figure 2.3. Dakota Lakes Research Farm (18 miles east of Pierre, SD) Grass-M1 cover crop blend crop coefficient. Crop coefficient developed during the fall of 2019.

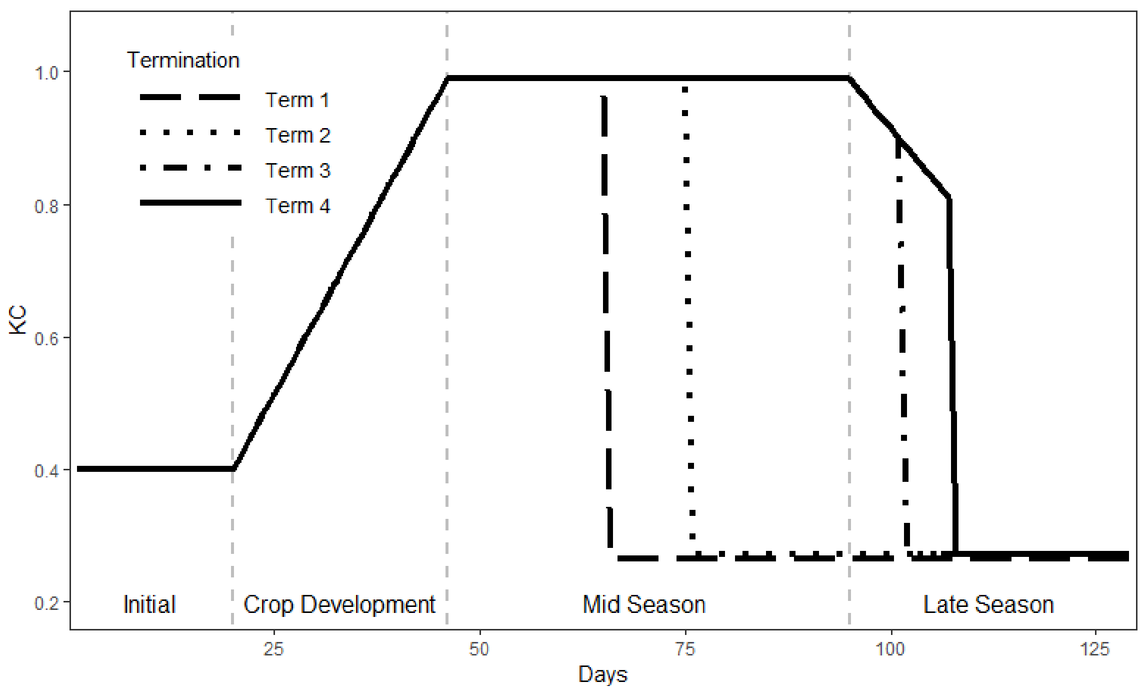

Figure 2.4. Dakota Lakes Research Farm (18 miles east of Pierre, SD) Brdlf-M2 cover crop blend crop coefficient. Crop coefficient developed during the fall of 2019.

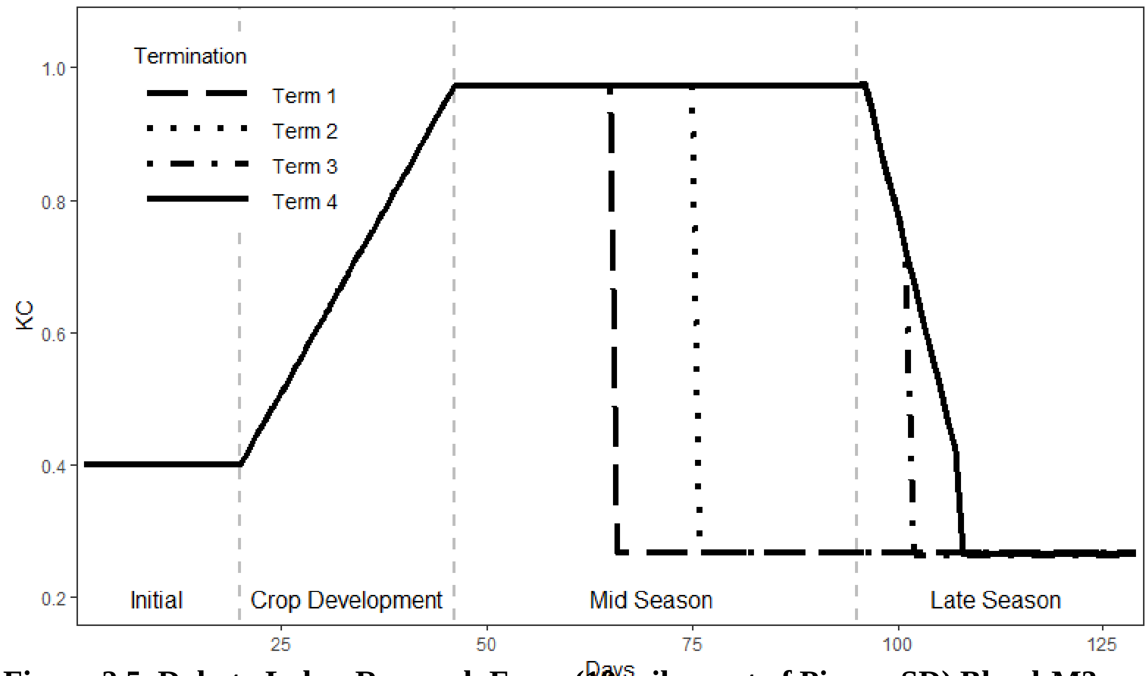

Figure 2.5. Dakota Lakes Research Farm (18 miles east of Pierre, SD) Blend-M3 cover crop blend crop coefficient. Crop coefficient developed during the fall of 2019.

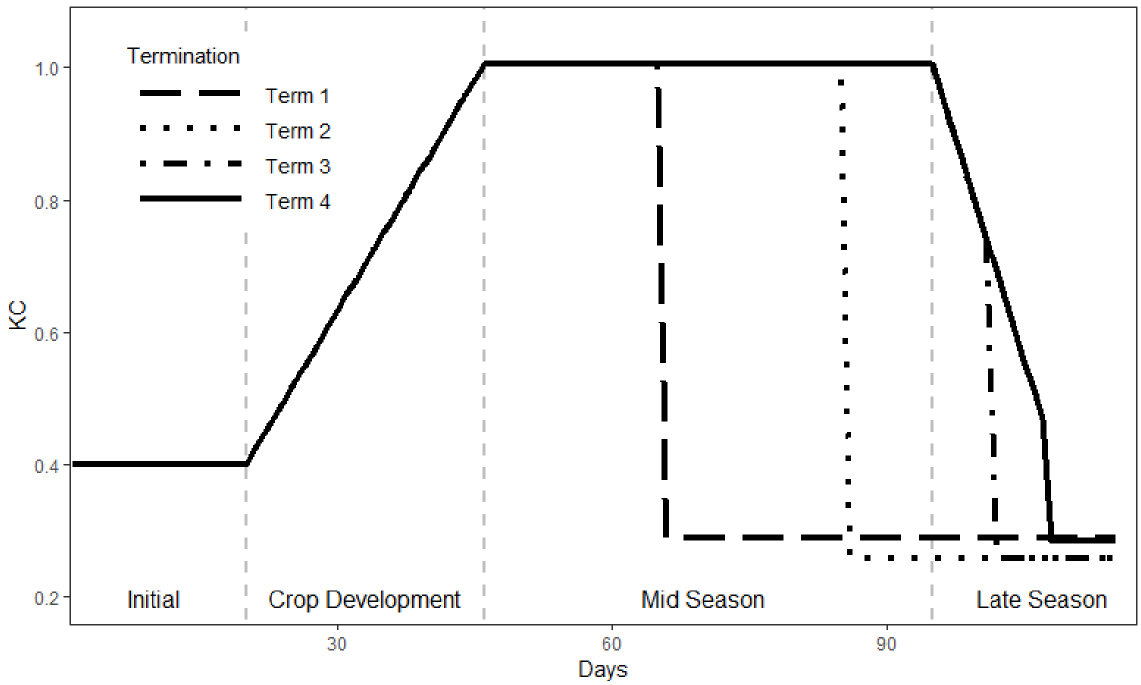

Figure 2.6. Canning (central South Dakota) Grass-M1 cover crop blend crop coefficient. Crop coefficient developed during the fall of 2019.

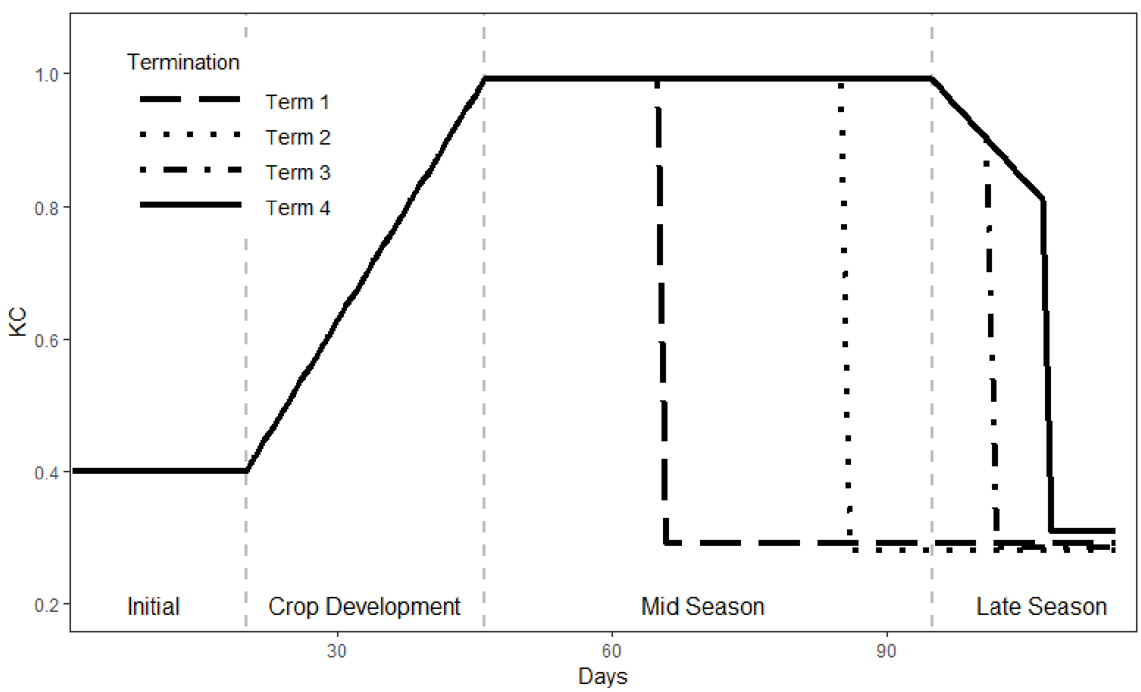

Figure 2.7. Canning (central South Dakota) Brdlf-M2 cover crop blend crop coefficient. Crop coefficient developed during the fall of 2019.

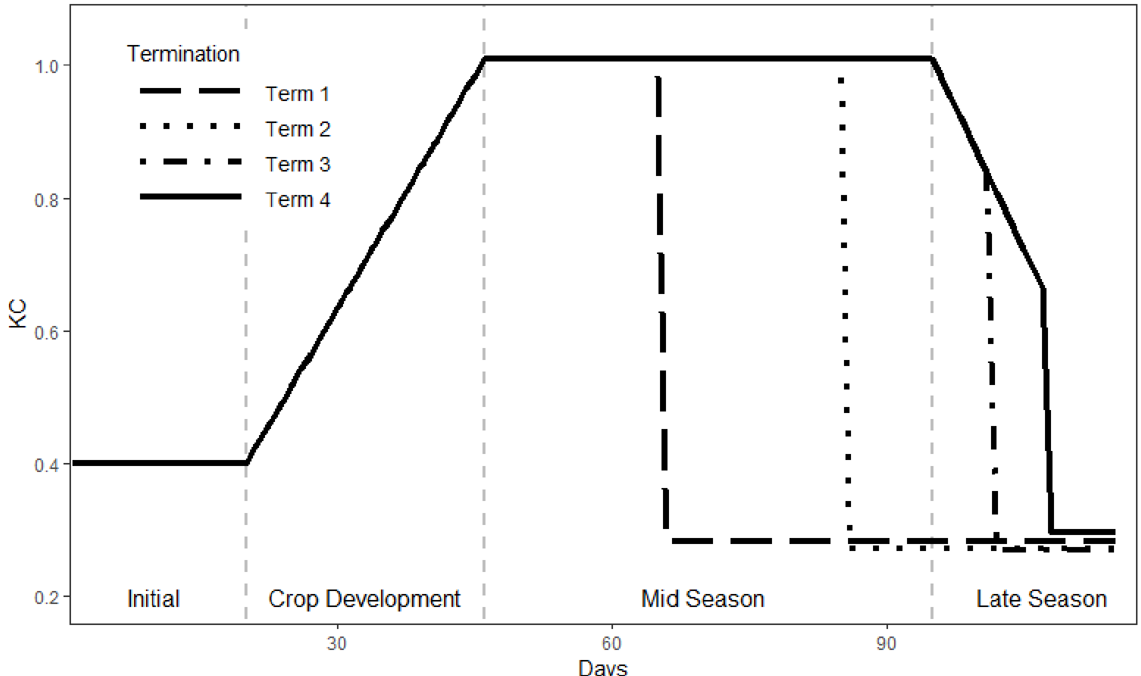

Figure 2.8. Canning (central South Dakota) Blend-M3 cover crop blend crop coefficient. Crop coefficient developed during the fall of 2019.

Table 2.1. Dakota Lakes Research Farm (18 miles east of Pierre, SD) crop coefficient equations developed for cover crop mixes in the fall of 2019.

Time Frame	# of Days	Stage	Grass-M1	Brdlf-M2	Blend-M3
(2019-07-25 – 2019-08-13)	20	Initial	0.4	0.4	0.4
(2019-08-14 – 2019-09-07)	25	Crop Development	0.022x-4.472	0.023x-0.054	0.022x-0.041
(2019-09-08 – 2019-10-27)	50	Mid-season	0.963	0.989	0.972
(2019-10-28 – 2019-11-08)	12	Late season	-0.047x+5.407	-0.015x+2.409	-0.051x+5.825

† x = time of season (days)

Table 2.2. Canning (central South Dakota) crop coefficient equations developed for cover crop mixtures in the fall of 2019.

Time Frame	# of Days	Stage	Grass-M1	Brdlf-M2	Blend-M3
(2019-08-08 – 2019-08-27)	20	Initial	0.4	0.4	0.4
(2019-08-28 – 2019-09-21)	25	Crop Development	0.023x-0.066	0.023x-0.055	0.023x-0.069
(2019-09-22 – 2019-11-08)	48	Mid-season	1.006	0.991	1.010

† x = time of season (days)

*Killing frost occurred on 2019-11-09, therefore late season K_C was not considered.

Table 2.3. Dakota Lakes Research Farm (18 miles east of Pierre, SD) surface cover (%) and K_C for surface covered with dead vegetation. Blue light bandwidth values from 2020-05-29 remote sensing flight used to estimate surface cover (%) and K_C for surface covered with dead vegetation.

Mixture	Termination	Surface Cover (%)	K_C for Surface Covered with Dead Vegetation
Grass-M1	Term 1	83.9 (3.5) ^{NS}	0.261 (0.008) ^{NS}
Grass-M1	Term 2	83.8 (4.9) ^{NS}	0.261 (0.011) ^{NS}
Grass-M1	Term 3	86.3 (3.5) ^{NS}	0.256 (0.008) ^{NS}
Grass-M1	Term 4	85.5 (6.9) ^{NS}	0.258 (0.016) ^{NS}
Brdlf-M2	Term 1	82.2 (8.0) ^{NS}	0.265 (0.018) ^{NS}
Brdlf-M2	Term 2	80.0 (3.4) ^{NS}	0.270 (0.008) ^{NS}
Brdlf-M2	Term 3	79.3 (3.7) ^{NS}	0.271 (0.008) ^{NS}
Brdlf-M2	Term 4	79.6 (2.7) ^{NS}	0.271 (0.006) ^{NS}
Blend-M3	Term 1	81.8 (5.9) ^{NS}	0.266 (0.013) ^{NS}
Blend-M3	Term 2	81.5 (7.8) ^{NS}	0.267 (0.018) ^{NS}
Blend-M3	Term 3	83.8 (6.1) ^{NS}	0.261 (0.014) ^{NS}
Blend-M3	Term 4	82.2 (4.8) ^{NS}	0.265 (0.011) ^{NS}
Control		84.1 (6.8)	0.261 (0.015)

†Standard deviation shown in parentheses after treatment mean
^{NS} Treatment mean not significantly different from Control treatment at α= 0.1
* Treatment mean differs from Control treatment at α= 0.1
** Treatment mean differs from Control treatment at α= 0.05
*** Treatment mean differs from Control treatment at α= 0.01

Table 2.3a. Dakota Lakes Research Farm (18 miles east of Pierre, SD) surface cover and K_C for surface covered with dead vegetation statistical analysis.

Factor	Surface Cover (%) & K_C for Surface Covered w/ Dead Vegetation
	P-Value
Mixture	0.024
Termination	0.947
Mixture*Termination	0.967

†Split-plot ANOVA excluding Control treatment

‡ K_C for surface covered w/ dead vegetation directly correlated with % surface cover

Table 2.3b. Dakota Lakes Research Farm (18 miles east of Pierre, SD) surface cover and K_C for surface covered with dead vegetation separated by mixture means.

Mixture	Surface Cover (%)	K_C for Surface Covered w/ Dead Vegetation
Grass-M1	84.9 (4.5)	0.259 (0.01)
Brdlf-M2	80.3 (4.5)	0.269 (0.01)
Blend-M3	82.3 (5.7)	0.265 (0.01)
Control	84.1 (6.8)	0.261 (0.02)

†Standard deviation shown in parentheses after treatment mean

Table 2.4. Canning (central South Dakota) surface cover (%) and K_C for surface covered with dead vegetation. Blue light bandwidth values from 2020-05-29 remote sensing flight used to estimate surface cover (%) and K_C for surface covered with dead vegetation.

Mixture	Termination	Surface Cover (%)	K_C for Surface Covered w/ Dead Vegetation
Grass-M1	Term 1	71.7 (4.0) ^{NS}	0.289 (0.009) ^{NS}
Grass-M1	Term 2	85.8 (5.0) ***	0.257 (0.011) ***
Grass-M1	Term 3	85.3 (3.0) ***	0.258 (0.007) ***
Grass-M1	Term 4	73.5 (2.9) ^{NS}	0.285 (0.007) ^{NS}
Brdlf-M2	Term 1	70.5 (5.0) **	0.291 (0.011) **
Brdlf-M2	Term 2	76.0 (3.6) ^{NS}	0.279 (0.008) ^{NS}
Brdlf-M2	Term 3	73.8 (2.8) ^{NS}	0.284 (0.006) ^{NS}
Brdlf-M2	Term 4	63.0 (5.7) ***	0.308 (0.013) ***
Blend-M3	Term 1	74.5 (2.9) ^{NS}	0.282 (0.006) ^{NS}
Blend-M3	Term 2	79.2 (1.8) ^{NS}	0.272 (0.004) ^{NS}
Blend-M3	Term 3	81.0 (3.7) **	0.268 (0.008) **
Blend-M3	Term 4	68.5 (8.2) ***	0.296 (0.019) ***
Control		75.5 (5.1)	0.280 (0.011)

†Standard deviation shown in parentheses after treatment mean
^{NS} Treatment mean not significantly different from Control treatment at $\alpha = 0.1$
* Treatment mean differs from Control treatment at $\alpha = 0.1$
** Treatment mean differs from Control treatment at $\alpha = 0.05$
*** Treatment mean differs from Control treatment at $\alpha = 0.01$

Table 2.4a. Canning (central South Dakota) surface cover (%) and K_C for surface covered with dead vegetation statistical analysis.

Factor	Surface Cover (%) & K_C for Surface Covered w/ Dead Vegetation
	P Value
Mixture	0.004
Termination	<0.001
Mixture*Termination	0.259

†Split-plot ANOVA excluding Control treatment

‡ K_C for surface covered w/ dead vegetation directly correlated with % surface cover

Table 2.4b. Canning (central South Dakota) surface cover and K_C for surface covered with dead vegetation separated by mixture means and termination means.

Factor	% Surface Cover	K_C for Surface Covered w/ Dead Vegetation
Grass-M1	79.1 (7.6)	0.272 (0.02)
Brdlf-M2	70.8 (6.5)	0.291 (0.01)
Blend-M3	75.8 (6.6)	0.279 (0.01)
Term 1	72.2 (4.1)	0.287 (0.01)
Term 2	80.3 (5.4)	0.269 (0.01)
Term 3	80.0 (5.8)	0.270 (0.01)
Term 4	68.3 (7.1)	0.296 (0.02)
Control	75.5 (5.1)	0.280 (0.01)

†Standard deviation shown in parentheses after treatment mean

Table 2.5. Soil profile water holding characteristics (source: Web Soil Survey) for Dakota Lakes Research Farm (18 miles east of Pierre, SD) and Canning (central South Dakota). Plant available water is the difference in total soil water at field capacity (-1/3 bars) and permanent wilting point (-15 bars).

	Dakota Lakes	Canning
0-60 cm Soil Profile	Dorna silt loam	Hurley silt loam
Permanent Wilting Point (-15 bars)	10.9 %	33.9 %
Field Capacity (-1/3 bars)	26.6 %	40.7 %
Plant Available Water (mm)	94.2	40.8
0-90 cm Soil Profile		
Permanent Wilting Point (-15 bars)	15.6 %	34.5 %
Field Capacity (-1/3 bars)	28.5 %	41.1%
Plant Available Water (mm)	116	59.0

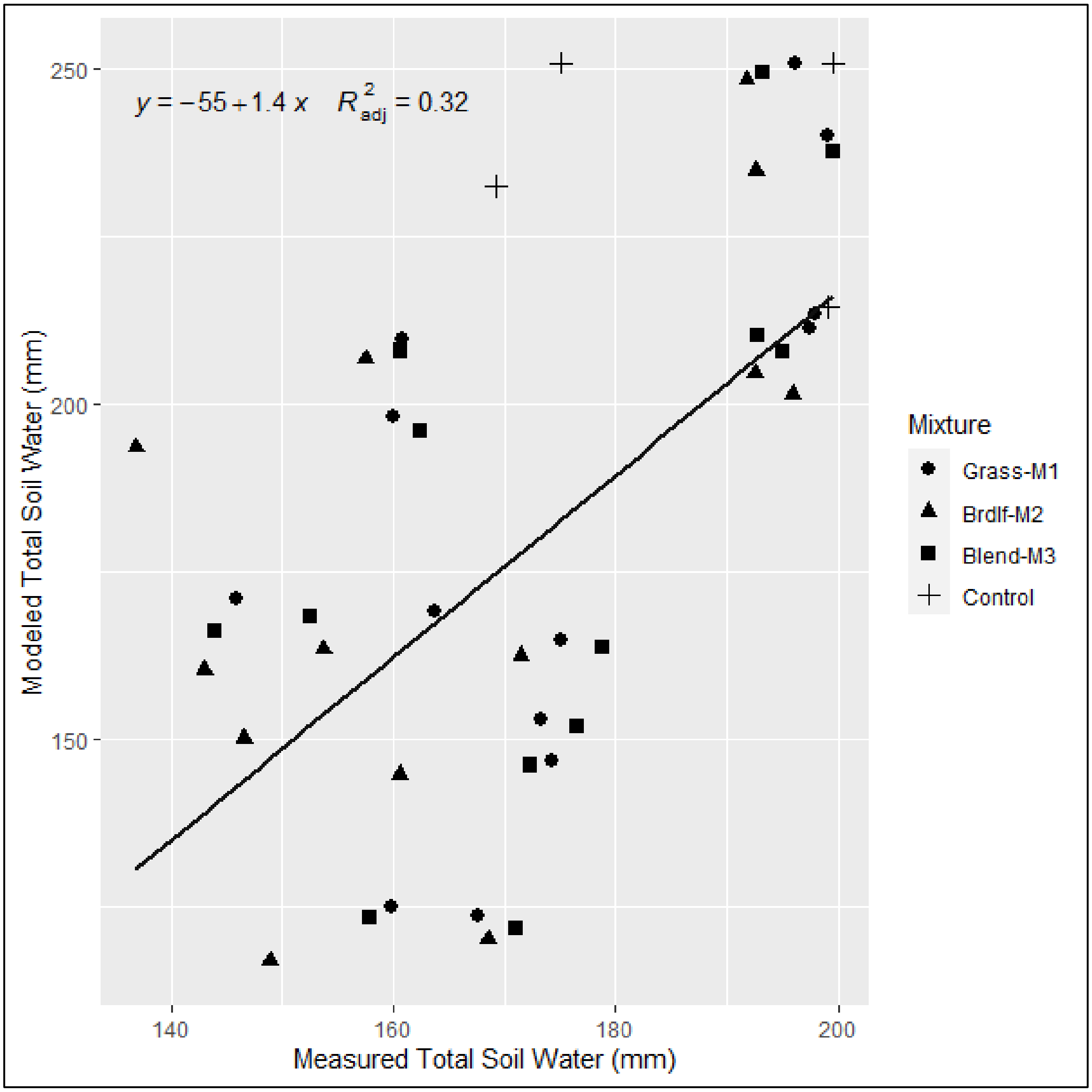

Figure 2.9. Dakota Lakes Research Farm (18 miles east of Pierre, SD) measured total soil water (mm) versus modeled total soil water (mm) for the 0-60 cm soil profile. The time frame considered was 2019-09-24 to 2020-06-16.

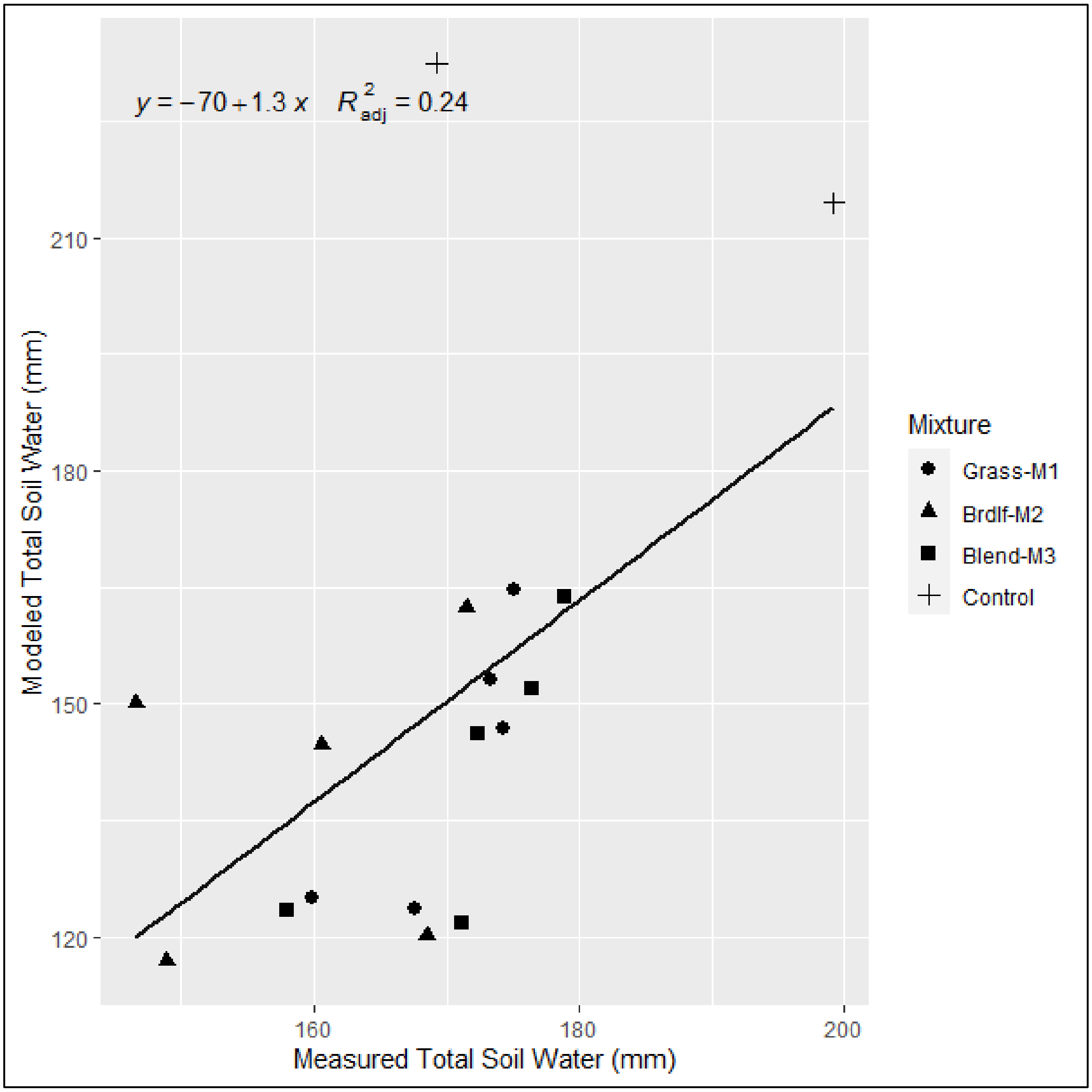

Figure 2.10. Dakota Lakes Research Farm (18 miles east of Pierre, SD) measured total soil water (mm) versus modeled total soil water (mm) for the 0-60 cm soil profile. The time frame considered was 2019-09-24 to 2019-11-08.

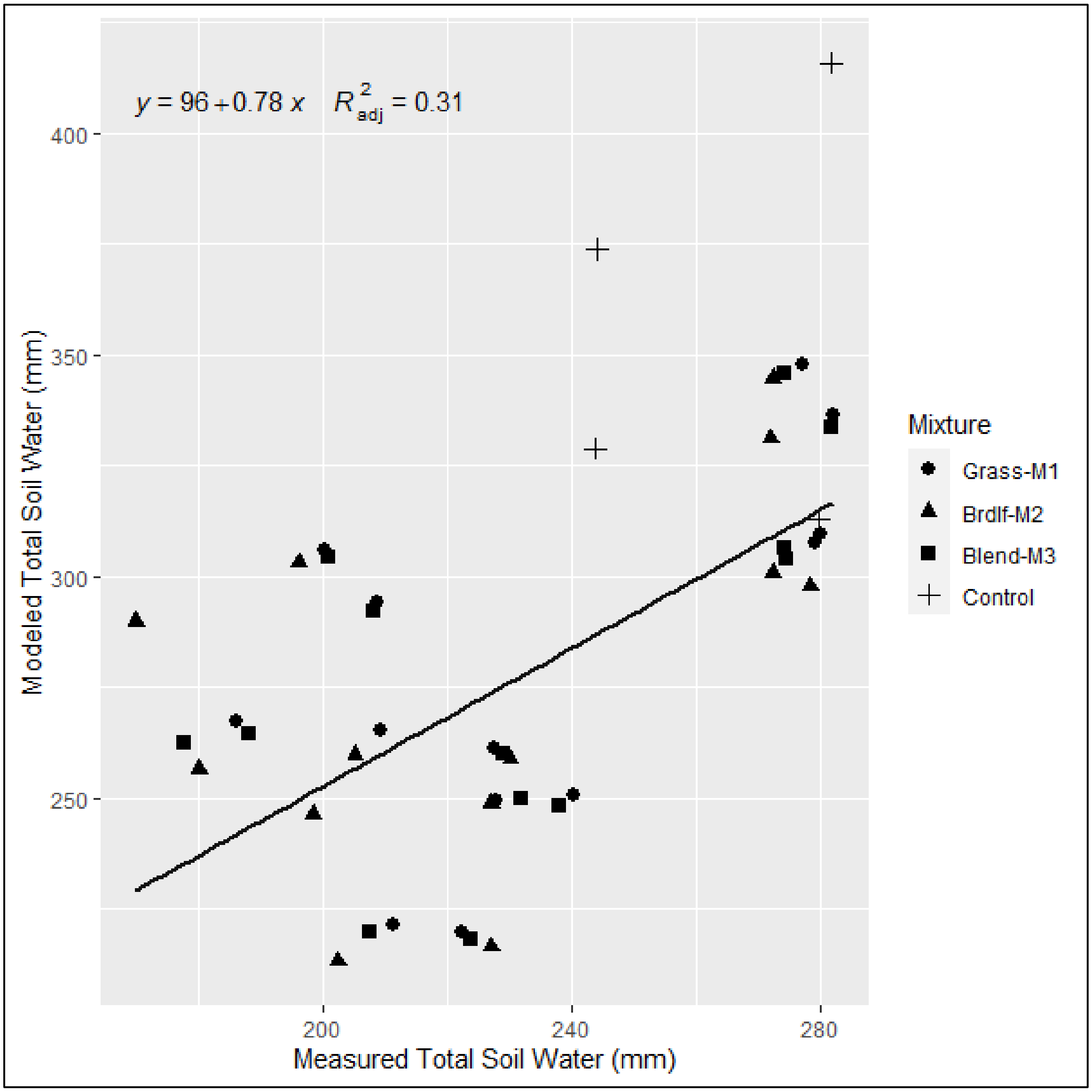

Figure 2.11. Dakota Lakes Research Farm (18 miles east of Pierre, SD) measured total soil water (mm) versus modeled total soil water (mm) for the 0-90 cm soil profile. The time frame considered was 2019-09-24 to 2020-06-16.

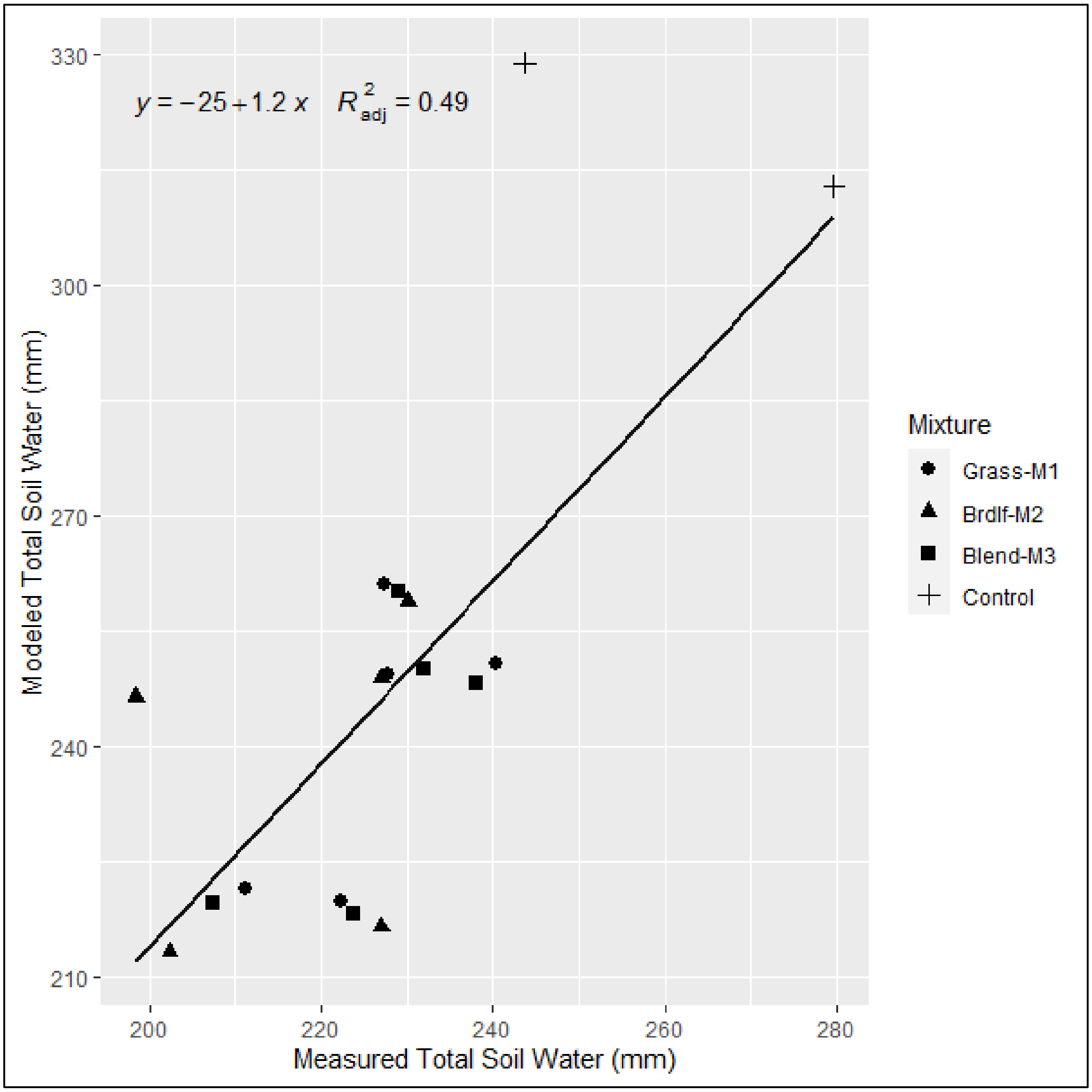

Figure 2.12. Dakota Lakes Research Farm (18 miles east of Pierre, SD) measured total soil water (mm) versus modeled total soil water (mm) for the 0-90 cm soil profile. The time frame considered was 2019-09-24 to 2019-11-08.

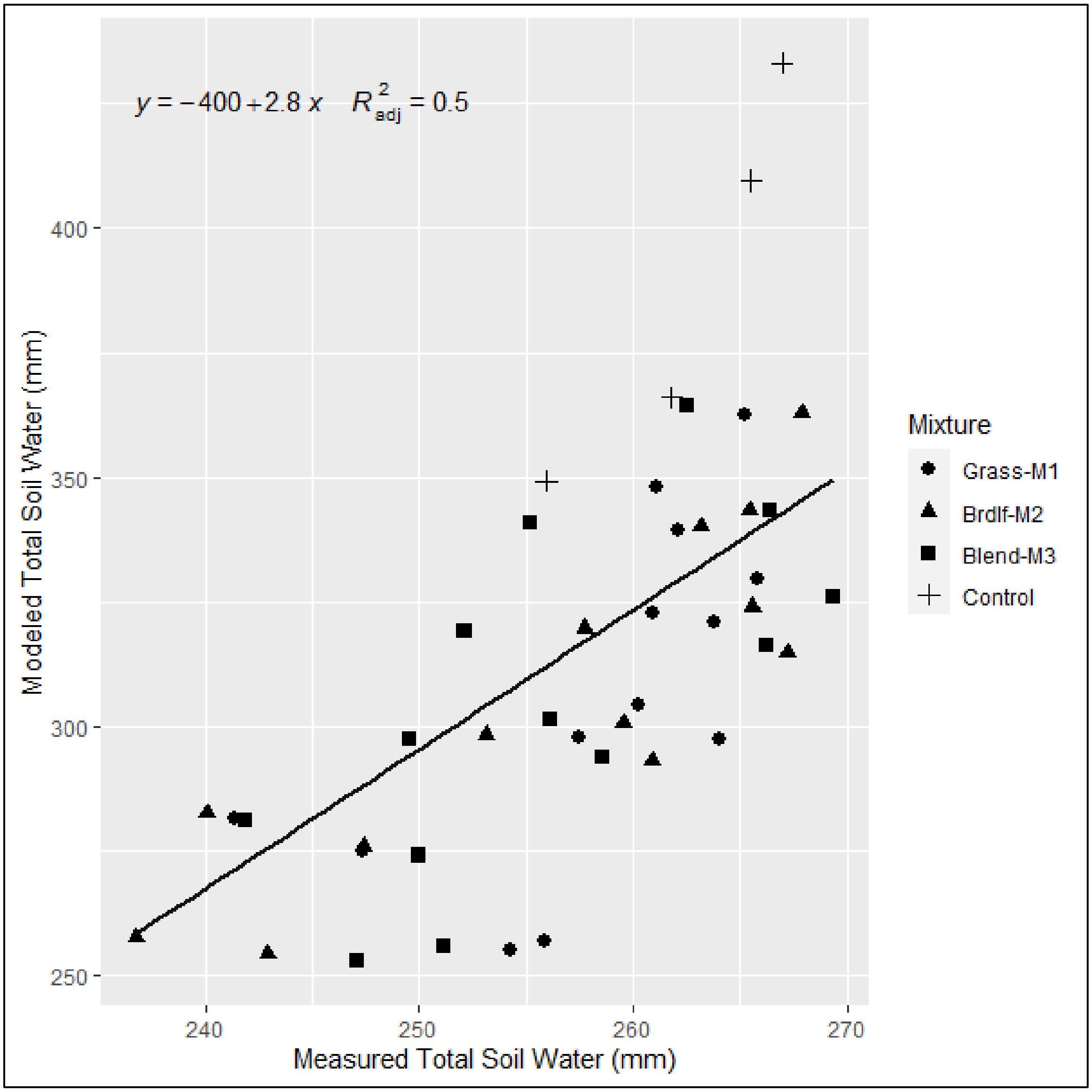

Figure 2.13. Canning (central South Dakota) measured total soil water (mm) versus modeled total soil water (mm) for the 0-60 cm soil profile. The time frame considered was 2019-09-27 to 2020-06-17.

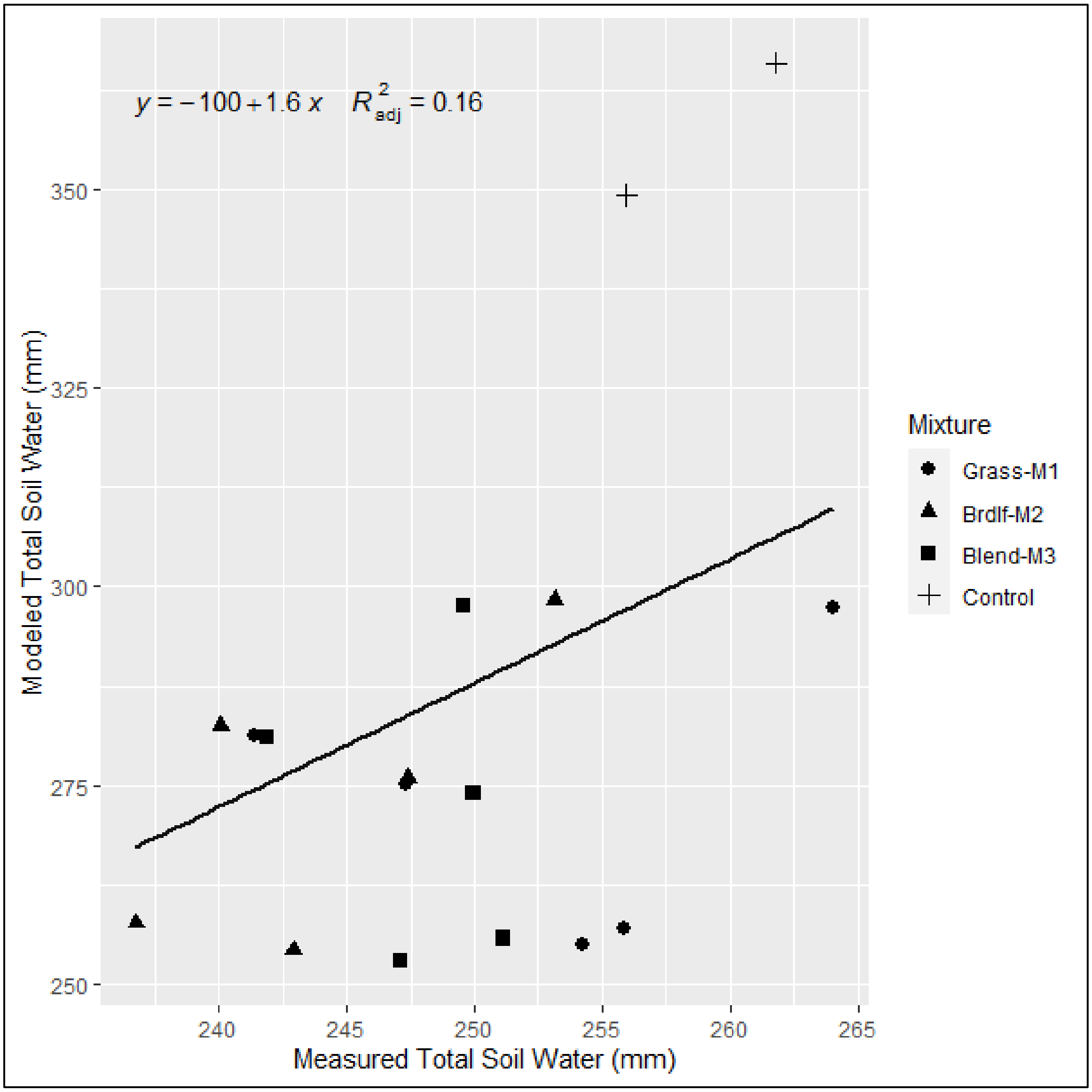

Figure 2.14. Canning (central South Dakota) measured total soil water (mm) versus modeled total soil water (mm) for the 0-60 cm soil profile. The time frame considered was 2019-09-27 to 2019-11-15.

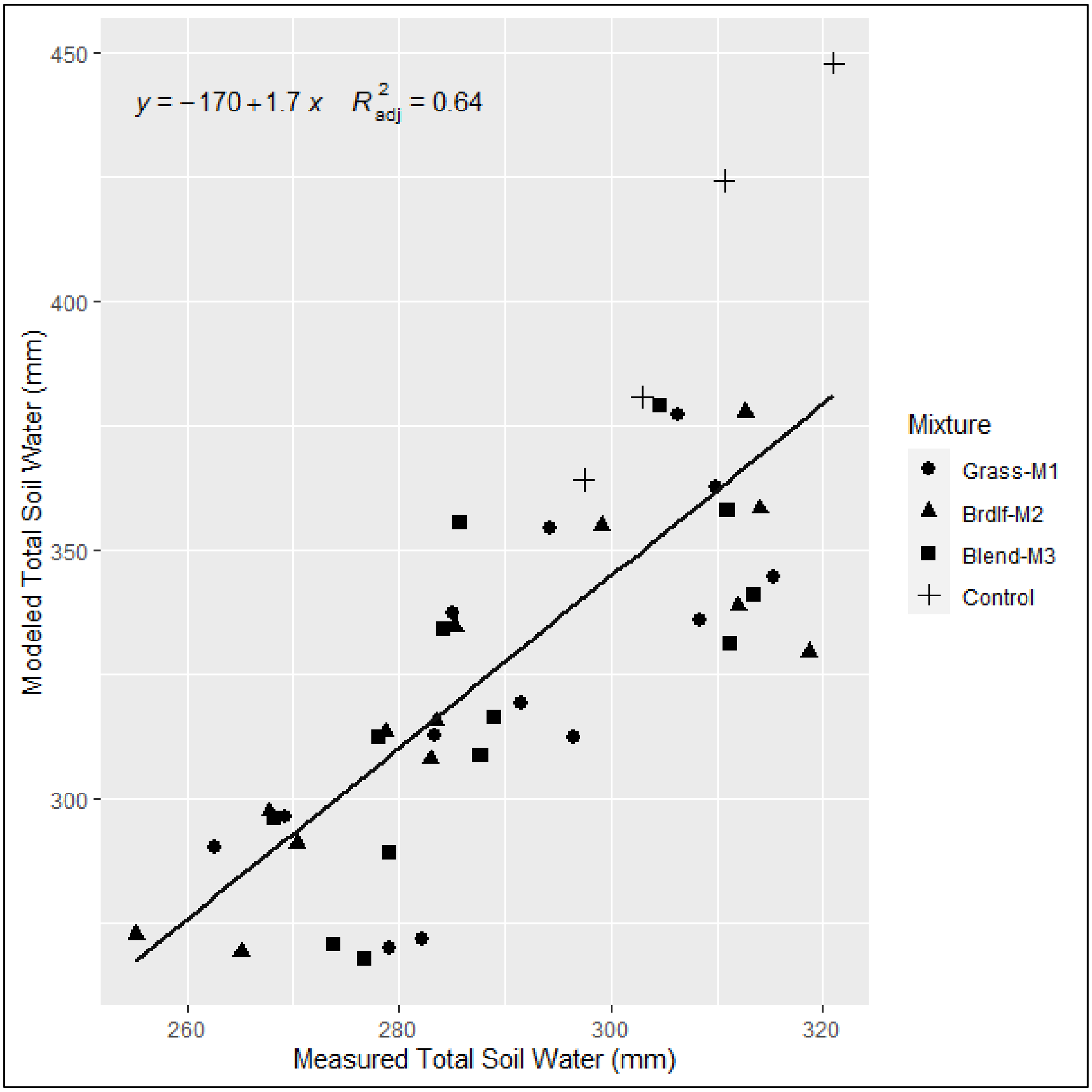

Figure 2.15. Canning (central South Dakota) measured total soil water (mm) versus modeled total soil water (mm) for the 0-90 cm soil profile. The time frame considered was 2019-09-27 to 2020-06-17.

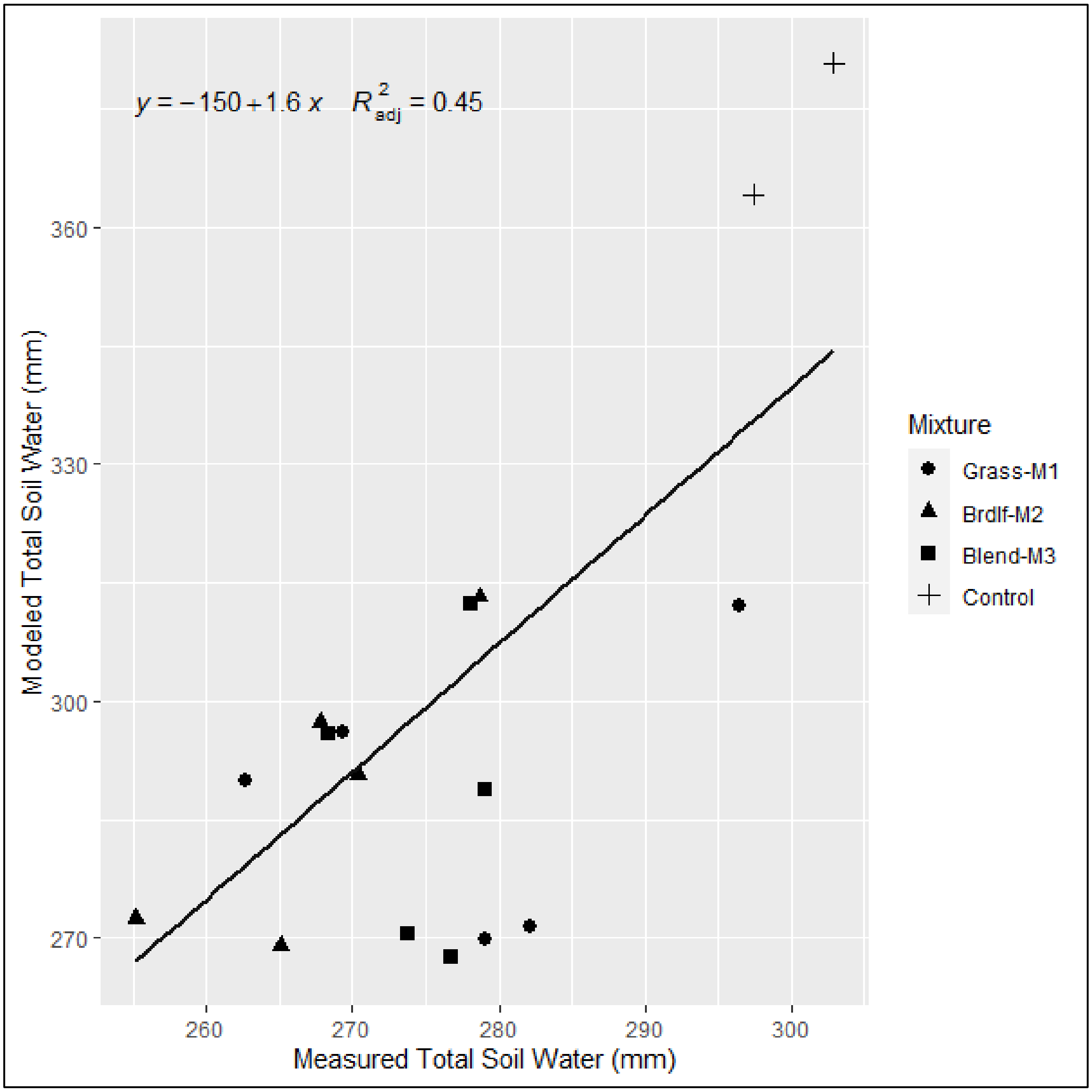

Figure 2.16. Canning (central South Dakota) measured total soil water (mm) versus modeled total soil water (mm) for the 0-90 cm soil profile. The time frame considered was 2019-09-27 to 2019-11-15.

Table 2.6. Accuracy of modeled linear regression of measured total soil water (mm) versus modeled total soil water (mm).

Location	Soil Profile Depth	Time Frame	Slope	Adjusted R^2	P Value	F Statistic
Dakota Lakes	0-60 cm	(2019-09-24) – (2020-06-16)	1.4	0.32	0.191 ^{NS}	1.76
Dakota Lakes	0-60 cm	(2019-09-24) – (2019-11-08)	1.3	0.24	0.498 ^{NS}	0.47
Dakota Lakes	0-90 cm	(2019-09-24) – (2020-06-16)	0.78	0.31	0.181 ^{NS}	1.81
Dakota Lakes	0-90 cm	(2019-09-24) – (2019-11-08)	1.2	0.49	0.430 ^{NS}	0.65
Canning	0-60 cm	(2019-09-27) – (2020-06-17)	2.8	0.50	<0.001***	21.4
Canning	0-60 cm	(2019-09-27) – (2019-11-15)	1.6	0.16	0.396 ^{NS}	0.75
Canning	0-90 cm	(2019-09-27) – (2020-06-17)	1.7	0.64	<0.001***	16.2
Canning	0-90 cm	(2019-09-27) – (2019-11-15)	1.6	0.45	0.090*	3.11

†Two-sided linear slope test performed with H_0: Slope= 1
^{NS} Model slope not significantly different from 1 at α= 0.1
* Model slope not significantly different from 1 at α= 0.1
** Model slope not significantly different from 1 at α= 0.05
*** Model slope not significantly different from 1 at α= 0.01

Table 2.7. Modeled soil profile recharge date for Dakota Lakes and Canning (0-90 cm profile). Soil profile recharge threshold determined using web soil survey estimated field capacity (-1/3 bar).

Mixture	Termination	Dakota Lakes	Canning
Grass-M1	Term 1	2019-11-29	2019-10-05
Grass-M1	Term 2	2019-12-27	2019-11-29
Grass-M1	Term 3	2020-05-04	2019-12-27
Grass-M1	Term 4	2020-05-07	2019-12-27
Brdlf-M2	Term 1	2019-11-29	2019-10-05
Brdlf-M2	Term 2	2019-12-27	2019-11-29
Brdlf-M2	Term 3	2020-05-13	2019-12-27
Brdlf-M2	Term 4	2020-05-16	2019-12-28
Blend-M3	Term 1	2019-11-29	2019-10-05
Blend-M3	Term 2	2019-12-27	2019-11-29
Blend-M3	Term 3	2020-05-07	2019-12-27
Blend-M3	Term 4	2020-05-07	2019-12-28
Control		2019-09-09	2019-08-31

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APPENDIX

Table A.1. Total nitrogen applied (kg of N ha^{-1}) to 2020 corn crop at Dakota Lakes Research Farm (18 miles east of Pierre, SD) and Canning (central South Dakota).

Location	Previous Cover Crop Mixture	N Application (kg of N ha^{-1})
Dakota Lakes	Grass-M1	132
Dakota Lakes	Brdlf-M2	133
Dakota Lakes	Blend-M3	135
Dakota Lakes	Control	105
Canning	Grass-M1	110
Canning	Brdlf-M2	117
Canning	Blend-M3	123
Canning	Control	88

Table A.2. Corn growth stages throughout 2020 growing season at Dakota Lakes Research Farm (18 miles east of Pierre, SD) and Canning (central South Dakota).

Dakota Lakes		Canning	
Date	Stage	Date	Stage
2020-05-26	VE (Emergence)	2020-05-20	VE (Emergence)
2020-06-01	V2	2020-05-27	V1
2020-06-08	V4	2020-06-02	V2
2020-06-15	V5	2020-06-15	V3
2020-06-23	V6	2020-06-23	V4
2020-06-30	V7	2020-06-30	V5
2020-07-07	V8	2020-07-07	V6/V7
2020-07-13	V10	2020-07-13	V9/V10
2020-07-20	V12/VT (Tasseling)	2020-07-20	V12/VT (Tasseling)
2020-07-27	R1	2020-07-27	R1
2020-08-03	R2	2020-08-03	R2
2020-08-10	R3	2020-08-10	R3
2020-08-27	R5	2020-08-27	R5
2020-10-01	Harvested	2020-10-09	Harvested