SUSTAINABLE AGRICULTURE PRACTICE: QUANTIFYING THE EFFECTS OF COVER CROP PLANTING DATES AND SEEDING RATES ON COVERAGE RATES AND BIOMASS YIELDS IN DELAWARE

By

JASON CHALLANDES

A Thesis

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in
the Natural Resources Graduate
Program of Delaware State University

DOVER, DELAWARE
May 2019

This thesis is approved by the following members of the Final Oral Review Committee:

Dr. Gulnihal Ozbay, Committee Chairperson, Department of Agriculture and Natural Resources, Delaware State University

Dr. Richard Barczewski, Committee Member, Department of Agriculture and Natural Resources, Delaware State University

Dr. Sathyanarayana Elavarthi, Committee Member, Department of Agriculture and Natural Resources, Delaware State University

Dr. Mingxin Guo, Committee Member, Department of Agriculture and Natural Resources, Delaware State University

Dr. Amy Shober, External Committee Member, Department of Plant and Soil Sciences, University of Delaware

DEDICATION

This thesis is dedicated to my wife Lauri, my kids, PJ, Justin and Max, my parents Jim and Kathy, and my siblings, Janet, Joyce, Jill, and Jim. Everyone has helped me in different ways and at different times in my life to reach a fulfilled and happy life. Thanks.

ACKNOWLEDGEMENTS

First, I would like to thank my faculty advisor Dr. Gulnihal Ozbay for encouraging me to move towards a research project that was more compatible with my employment requirements at Delaware State University and for helping me along the way. Next, I would like to thank Dr. Amy Shober for helping me design, coordinate, and interpret this project. I would also like to thank Dr. Richard Barczewski, who has helped me since I first arrived at DSU as an undergrad in 2005. He assisted in finding me a student worker position as an on-farm program assistant, which eventually lead to my current career in sustainable agriculture at DSU Cooperative Extension, which in turn contributed to the scope of this thesis. Additionally, I would like to thank my entire advisory committee, Drs. Amy Shober, Sathya Elavarthi, Mingxin Guo, Richard Barczewski, and Gulnihal Ozbay for offering insight and recommendations during the planning and implementation of this thesis research. I would also like to thank Delaware NRCS conservationists, Sally Kepfer and Jayme Arthurs, and Delaware Conservation Districts Executive Director, Jen Nelson for guidance, technical information, and recommendations. I would especially like to thank Jamie Timson, former Small Farms Program Assistant who spent countless hours, days and weeks in the field helping to mark plots, guide plantings, take photos, and collect biomass and soil samples. She is currently a USDA Farm Service Program Technician in Dover, DE. Additionally, I would like to thank Dwight Meyers, former DSU farm manager for going beyond his normal duties to operate the grain drill in unusually time-consuming conditions.

Finally, I would like to acknowledge funding sources and support from Delaware State University, the University of Delaware, and Delaware NRCS, as well as programming support from Northeast SARE projects NEDSU17-001 and ENE15-141.

Sustainable Agriculture Practice: Quantifying the Effects of Cover Crop Planting Dates and Seeding Rates on Coverage Rates and Biomass Yields in Delaware

By Jason Challandes

Faculty Advisor: Dr. Gulnihal Ozbay

Abstract

Cover crops have been proven to have many potential environmental and financial benefits if they are managed properly. However, proper management is dependent on the unique soil and climatic conditions in the immediate area. Management techniques that are effective in one geographical area may not be sufficient to support cover crops in other nearby conditions. While several cover crop research projects have been conducted locally, Delaware is still lacking important knowledge to provide effective recommendations to farmers growing cover crops. Specifically, the evaluation of planting dates and seeding rates is needed in order to maximize the environmental and agricultural benefits of the most commonly used varieties of cover crops. Currently, the Delaware Natural Resources Conservation Service (NRCS) offers financial subsidies to farmers who grow cover crops according to their regulations through the Environmental Quality Incentives Program (EQIP). It has been brought to their attention by farmers that their planting date deadlines may be earlier and seeding rates higher than necessary to produce sufficient groundcover and biomass. However, without research data in Delaware to legally justify changes to these requirements, farmers will have to continue following nationally established methods for planting dates and seeding rates, in order to receive subsidies.

Primary objective of my research focused on investigating cover crop planting dates and seeding rates for optimum cover crop density. Ground coverage, spring aboveground biomass,

nitrogen (N) removal, and total soil N at termination as affected by species, planting date, seeding rate, planting method, and their interactions within agricultural systems including no-till corn and soybean fields were evaluated. Cereal rye, barley, wheat, and rye/clover mixes were planted with three seeding rates, up to three planting dates, and two planting methods per site: broadcasted vs. drilled or incorporated with a light disk. Trials were administered at four sites during the 2015-2016 season and three sites during the 2017-2018 season. Results showed no benefit in seeding rates that exceeded 94, 101, and 101 kg/ha (84, 90 and 90 lbs/ac) for monocultures of rye, barley, and wheat, respectively and 45 kg/ha of rye and 17 kg/ha of crimson clover for mixes (40 and 15 lbs/ac). Even lower rates performed similarly for many treatments and outperformed high rates in some. Rye at any date prior to November 1 and rye/clover mixes prior to October 1 are recommended over barley and wheat for better groundcover, biomass, and N removal. Drilled plots produced greater biomass and N removal than broadcasted sites at equal seeding rates, but generally produced similar groundcover. Broadcasted plots seeded at 30% higher rates produced similar biomass as incorporated plots for some treatments, but incorporating seeds is recommended over broadcasting at later dates and for increased groundcover. The most consistent result of this study is that cover crops planted at early dates, prior to October 1, performed better than crops planted at standard dates, prior to October 15, which outperformed the late planted cover crops prior to November 1. For some treatments, cover crops planted at the standard dates performed comparably to early dates, but the late date plots consistently had lower groundcover, biomass, and N removal, regardless of crop, rate, or method.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

COMMON ABBREVIATIONS

BMP: Best Management Practice

CC_Rye: Mix with variable rye rates and a constant crimson clover rate

CWA: Clean Water Act

DNREC: Delaware Natural Resources Environmental Control

DSU: Delaware State University

EPA: Environmental Protection Agency

EQIP: Environmental Quality Incentive Program (An NRCS Program)

HAB: Harmful Algal Bloom

HSD: Honest Significant Difference Test

N: Nitrogen

NASS: National Agricultural Statistics Service

NRCS: Natural Resources Conservation Service (A USDA Agency)

P: Phosphorus

Rye_CC: Mix with variable crimson clover rates and a constant rye rate

UD: University of Delaware

USDA: United States Department of Agriculture

CHAPTER I: INTRODUCTION

1.1. Background

The United States Department of Agriculture Natural Resources Conservation Service (USDA-NRCS) Code 340 defines the Conservation Practice 'Cover Crop' as "crops including grasses, legumes, and forbs used for seasonal cover or other conservation purposes" (NRCS, 2011). Standard benefits of cover crops have been extensively researched and documented in the United States and the northeast region for dozens of different crops and rotations (Clark, 2007). As a result of sufficient peer reviewed publications, NRCS lists the following potential goals or benefits of using cover crops in the Code 340 Conservation Practice Standard:

1. Reduce erosion from wind and water;
2. Increase soil organic matter content;
3. Capture and recycle or distribute nutrients in the soil profile;
4. Promote biological nitrogen fixation and to reduce energy use;
5. Increase biodiversity;
6. Suppress weeds;
7. Manage soil moisture; and
8. Minimize and reduce soil compaction.

Not all applications and varieties of cover crops will actualize all of these benefits, but successful establishment and growth can yield multiple agricultural, environmental, and potentially economic benefits (Bergtold et al., 2017). Although cover crops have many potential benefits, one of the reasons they are promoted so heavily by organizations, such as NRCS, is their potential to capture and recycle nutrients, which can reduce nitrogen (N) leaching and erosion losses including particulate phosphorus (P). Delaware is located within four major watersheds, the Chesapeake Bay, the Delaware Bay, Inland Bays, and the Piedmont Basin (NRCS, 2016). Eutrophication of bays and the associated consequences on wildlife, fisheries,

and tourism have brought increased enthusiasm by the public and governments to limit the influx of nutrients. Additionally, “more than 90 percent of Delaware's Waterways are considered impaired. ‘Impaired waters’ are severely polluted waters that do not meet water quality standards” (U.S. Code 33 § 1313).

Although, these conditions are not entirely attributable to nutrient loss or agriculture practices in general, they have created a public desire to find solutions, including in the agricultural sector. Although farms are not the only sources of nutrient loss, two big sources of nutrient runoff are fertilizer and manure (Yeo et al., 2014; DNREC, n.d.). In both cases, cover crops have the potential to limit erosion, nutrient runoff and leaching (Dabney et al., 2001). This has led to the promotion of many nutrient management practices by organizations such as NRCS, Conservation Districts, and water body protection programs, which include increasing cover crop adoption and improving cover crop management.

Cover crops can potentially provide additional environmental benefits, such as increasing biodiversity, improving habitat, decreasing erosion, and reducing herbicides. These benefits, in addition to nutrient capturing and cycling, have largely justified cover crop subsidy programs in Delaware and in other parts of the nation (Singer et al., 2007), but there are many purely agricultural benefits as well. In some cases, farmers are motivated less by subsidies, and more by the real -world cost-benefits they have seen. Cover crops have been shown to increase organic matter, cation exchange capacity and aggregate stability, while also scavenging N and reducing sediment loss (Dabney et al., 2001). Direct agricultural benefits can also include an increase in yields potentially due to increased organic matter or reduced compaction by using cover crops such as sorghum-sudangrass or tillage radish, respectively. In some cases, herbicide costs can be decreased due to an improvement in weed control with cover crops (Campbell, 1993). Fertilizer

costs can also be potentially reduced using legumes. Some studies have shown that the costs of planting cover crops can be overcome by these financial benefits (Campbell, 1993). Hypothetically, optimizing cover crop management consistently could reduce or eliminate subsidy programs in the future, further justifying continual research. For now, subsidy programs are an integral part in getting widespread farmer adoption of cover crops, so it is important to continually analyze improvements to the subsidy requirements.

The magnitude for both environmental and agricultural benefits is dependent on the success of the cover crops. It is difficult to quantify success with cover crops, but two common parameters are percent groundcover and biomass (González-Esquiva et al., 2017; Snapp et al., 2005). A poor fall measurement of ground cover infers that the soil and soil nutrients will be more vulnerable to leaching, erosion, and runoff during the winter. Poor spring coverage measurements can similarly indicate limited stands, inferring lower environmental and agricultural benefits prior to cash crop planting. Higher spring biomass can indicate higher levels of nutrient retention and weed suppression (Hively et al., 2009; Snapp et al., 2005). Other agricultural and environmental benefits are likewise dependent on establishment and growth of the cover crop. In order to maximize cover crop benefits and minimize cost, optimal seeding rates and planting dates must be known, but this specific focus of cover crop research has not been extensively and continually evaluated in Delaware. Optimal management practices for cover crop species can vary significantly based on site locations and conditions (Vann et al., 2019). This gap in research justifies the need to study how fall cover and spring biomass are affected by seeding rates, planting dates, cover crop species, and seeding methods, as well as the interactions between these factors (Kepfer, 2014).

The cover crop species used in this study were chosen based on farmer and subsidy coordinator preferences. Rye, wheat, and barley are the most common winter grasses grown in Delaware, and crimson clover is one of the most common legumes (Sturgis, 2017). These grasses are frequently used as cover crops because they are reliable and quick establishers. They also can generally produce good biomass amounts and store nutrients well. Crimson clover, like all legumes can fix atmospheric N into the soil. Crimson clover in particular can reliably establish and produce good groundcover. Additionally, all four species are comparably inexpensive, readily available, terminate easily, and have potential weed and insect management benefits (Clark, 2007).

1.2. Problem Statement

Agriculture is a major source of nutrient influx into watersheds, specifically nitrogen and phosphorus. This runoff can drastically decrease water quality by increasing the magnitude of eutrophication (Clark, 2007; Aria et al., 2005). Eutrophication, which can be a natural process, occurs due to an influx of nitrogen and phosphorous. Harmful Algal Blooms (HABs) occur, along with an increase in other aquatic plants, causing overcrowding and an increased competition for sunlight, space, and dissolved oxygen for aquatic species. The HABs can block sunlight for underwater grasses, inhibit the feeding of filter-feeders, create an odorous surface scum, and when the algae die and decomposes, the dissolved oxygen in that area can be depleted. This can lead to hypoxia, which is the depletion of dissolved oxygen, potentially resulting in "dead zones", where most marine life either dies or leaves the area (Rabotyagov et al., 2014). In addition to clear ecological consequences, dead zones can have significant negative effects on fisheries, aquaculture operations, recreation, and tourism. A small percentage of the algae can also be toxic, accumulating in small marine animals, and making its way up the food chain to

marine mammals, birds, and humans, potentially causing illness or death (Rabotyagov et al., 2014).

The federal Clean Water Act (CWA) requires states to create Total Maximum Daily Loads (TMDLs) for various pollutants including nitrogen and phosphorus. The TMDLs represent the upper limit of pollution that can be discharged into a body of water while still meeting water quality standards. All four of Delaware's watersheds have nutrient goals that are must be achieved. Cover crops have been shown to significantly reduce regional agricultural nutrient loss and are a major tool for Delaware to help meet the TMDLs (Yeo et al., 2014; DNREC TMDL, n.d.).

Organizations that offer financial incentives to farmers, such as NRCS, are dependent on research-based guidelines to attempt to achieve cover crop establishment to help reach TMDLs. Seeding rates and planting dates for NRCS' subsidy programs are nationally mandated unless states have research-backed evidence to change them. Some Delaware farmers have suggested to staff at the state NRCS office that planting date deadlines may be earlier and seeding rates may be higher than necessary to produce sufficient ground cover and biomass (Kepfer, 2014). Seeding rate and planting date requirements are dependent on the cover crop species and in some cases, farmers can receive a higher subsidy rate if cover crops are planted by earlier dates and no subsidy if they are planted after the final deadline (Arthurs, 2018). There are many factors that contribute to farmer decisions about if, when, and how to plant fall cover crops. Planting cover crop seed in time to meet subsidy deadlines can be challenging because farmers are subject to the weather conditions each year. Wetter summers and falls can delay cash crop harvests significantly, and therefore delay cover crop planting (Hellevang, 1995). Furthermore, grain farmers receive payment rates that are associated with the moisture content of the grains and how

they relate to market prices. Grains that are above ideal moisture content may require longer drying periods, have shorter shelf-life, greater shrinkage, and/or lower quality; therefore, it is less valuable to buyers (Hellevang, 1995). In some cases, farmers are waiting for moisture content to drop to a certain percentage to receive a higher payment rate. However, this may put farmers in a situation where they must choose between receiving a lower cash crop rate so that they are able to plant cover crops in time to get subsidies or conversely, harvesting later to get a higher cash crop rate and not being able to meet subsidy deadlines. In other cases when a deadline is approaching, it is just not prudent to take harvesting equipment into a wet field because of compaction issues or getting equipment stuck. In many years, especially with the late harvest of soybeans, it is simply not possible to meet national NRCS cover crop planting deadlines. Of the farmers that know they cannot meet the subsidy deadlines, some will still choose to plant cover crops without subsidies, but many farmers will choose not to plant anything (Ma et al., 2010). Hypothetically, if cover crops could be established and grown successfully when planted at later dates, than subsidies could be justified, and farmers could be incentivized to plant more hectares of cover crops. Planting date and seeding rate research is needed in Delaware, not only to better guide local farmers and potentially increase their profits, but also to ideally increase and improve the management of cover crops in the region and participation in conservation programs (Kepfer, 2014).

Although proper cover crop management can potentially pay for itself through soil and production improvements, conservation programs, such as NRCS Environmental Quality Incentive Program (EQIP) can be the ultimate incentive for farmers (Singer, 2007). Legally, EQIP planting dates and seeding rates for specific cover crop species cannot be altered without science-based justification (Table 1-1). Currently, EQIP offers cost-share incentives for early

planting (before October 1), standard planting (October 1-15), and for late planting at a reduced rate (October 16-31) (Arthurs, 2018). Although subsidy rates are not always tied to farmer enrollment, many farmers believe that they should be able to get the higher subsidy rate when planting cover crops by the late planting date (or even later) and still achieve similar establishment levels (Marshall, 2012). Later planting would allow farmers to wait for better weather conditions to plant cover crops or to delay cash crop harvest if desired. Similarly, some farmers believe they are wasting money by planting cover crops at higher seeding rates than needed and that lower rates could produce the same groundcover and biomass as higher rates (Kepfer, 2014).

Table 1-1: NRCS EQIP Planting Dates (Arthurs, 2018).

Cover Crop Species	Planting Date	Reimbursement Rate
Mix	Before October 1	Highest rate
Mix	October 1-15	Second rate
Single Species	October 1-15	Second rate
Rye, Triticale, or Wheat	October 16-31	Second rate

According to the Delaware Natural Resources and Environmental Control (DNREC) Cropland Transect Survey (Sturgis, 2017), the average implementation of cover crops, including both commodity and traditional cover crops on all harvested cropland in the state was greater than 36%. However, splitting the data, about 16.5% of harvested cropland had commodity crops and about 19.5% had traditional cover crops. Commodity cover crops have some of the benefits of traditional cover crops, as they can remove N, limit erosion and even potentially improve yields (Ketterings et al. 2015). However, commodity cover crops do not provide some of the other benefits that traditional covers provide, such as increasing soil organic matter, weed

control, or providing cash crops with a nutrient source, because they are harvested and removed. Traditional cover crops are killed in spring by tilling, rolling, or spraying and residues are left in the field. Traditional cover crops include vetch, tillage radish, and triticale (Clark, 2007) as well as the species studied in this project: wheat, barley, rye, and crimson clover. For 2016, Sussex County had the highest number of hectares planted with cover crops; however, there was a higher percent of harvested cropland with cover crops in Kent County. The percent of traditional cover crops out of total cover crops in 2016 in New Castle, Kent, and Sussex Counties was approximately 42%, 58%, and 60%, respectively. The most common species of cover crops planted were cereal rye, barley, and wheat (Sturgis, 2017)**.**

The data show that there is a lot of cover crop activity throughout the state, but that there is also a lot of harvested land that is not planted in cover crops. Research that can identify improvements to cover crop management and refine subsidy requirements has the potential to increase farmer adoption of cover crops. Farmers do try new varieties and management practices on small plots, but because of the number of variables and their possible interactions, it is difficult to find conclusive results. Additionally, uncontrolled variables, such as weather or site-specific soil conditions, might infer results that would be not be consistent in future plantings. It is recommended for individual farmers to try different treatments throughout their farm over multiple years (Sarrantonio, 1996). On larger scales, it can be difficult to compare different research projects that use even slightly different techniques, technologies, or take place in different microclimates because of the multifactorial interactions of variables (Derpsch et al., 2014). That is why continual, larger scale, random, and replicated trials conducted under local conditions over many years using local farming methods are so important for many different cropping systems. Through long-term intensive research, Best Management Practices (BMPs) for

cover crops grown in Delaware can be improved and refined. Once identified and demonstrated, these BMPs have the potential to encourage farmers currently growing cover crops to learn and improve their management and potentially encourage other farmers to plant cover crops on new lands.

1.3. Research Objectives

Research is needed to identify the interactions of seeding rates and planting dates in Delaware on ground coverage and biomass. A central focus of my thesis research is the 2015-2016 field sites at Delaware State University's Research and Outreach Center in Smyrna, Delaware. However, funding and resources were only available for a single year of study at this site. In order to address year-to-year and site-to-site variability the Smyrna site was a companion project to several University of Delaware (UD) field trials being studied over several years. It is not practical to make statistical comparisons between sites because of variability in local weather and soil conditions, but the results can be compared and contrasted to identify trends and differences. This study will increase our knowledge of cover crop BMPs in Delaware and expand the abilities of agriculture service providers to advise farmers. Following are the specific objectives of my research:

1. Determine the effects and interactions of cover crop species, planting date, seeding rate, and/or planting method on ground coverage, spring biomass production, N removal by the cover crop, and total soil N.
2. Compare results with the University of Delaware field trials to identify any similarities, differences, and patterns in the data. These results will help to identify if there are management

practices that were consistent between years and/or locations, which could potentially lead to future recommendations for farms and subsidy requirements.

1.4. Hypotheses

H_o1: There will be no difference of percent ground cover or plant biomass between seeding rates, seeding dates, cover crop species, planting method, or treatment interactions.

H_a1: There will be a difference of percent ground cover or plant biomass between seeding rates, seeding dates, cover crop species, planting method, or treatment interactions.

H_o2: There will be no difference of percent ground cover or plant biomass between UD and DSU field plots.

H_a2: There will be a difference of percent ground cover or plant biomass between UD and DSU field plots.

CHAPTER II: LITERATURE REVIEW

Cover crops have seen a resurgence in the last couple of decades. This is largely due to subsidy and promotion programs aimed at improving environmental stewardship and agricultural economic productivity (Reeves, 2017). Figure 2-1 shows 2012 national data of cover crop distribution. As it is shown in red, much of Delaware and the Mid-Atlantic are in the highest percentage grouping of 15-56%. However, outside of census data, the actual scale of Delaware farmers' adoption from year-to-year is difficult to accurately quantify and track.

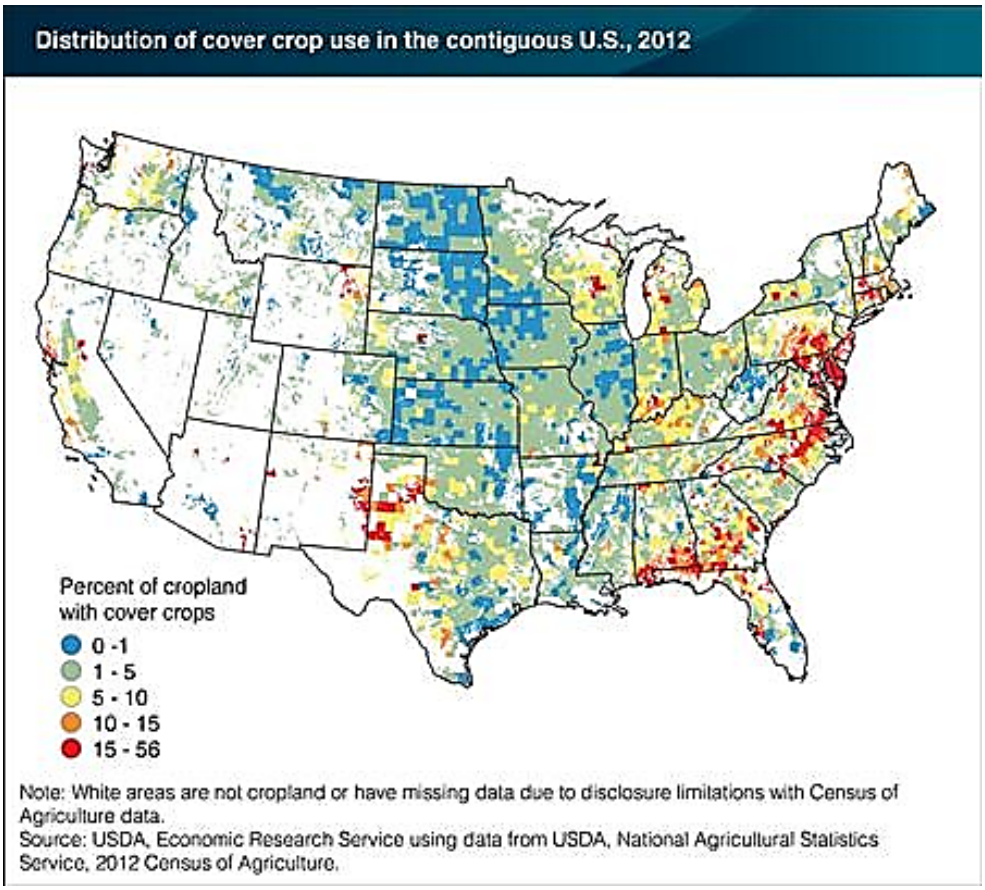

Figure 2-1: Distribution of cover crop use in the contiguous United States (USDA, 2012).

The data displayed in Figures 2-2 through 2-4 as well as in this project, can be used together to help guide subsidy programs to become more attractive to farmers. The first two graphs are based on farmer assistance programs: Delaware Natural Resources Conservation Service (NRCS) and Delaware Conservation Districts (Nelson, 2019). The third organization, Delaware Department of Natural Resources and Environmental Control (DNREC) has attempted to quantify all cover crop plantings in the state to better describe landscape effects on watersheds (Sturgis, 2017). Furthermore, DNREC's survey includes commodity cover crop data, which subsidy programs have not covered uniformly during the years presented. Nevertheless, the three sources graphed below represent a more comprehensive view of cover crop use in Delaware, as well as the challenges associated with recording adoption annually on a landscape and watershed level.

The different sources of data show contrasting trends in Delaware. As depicted in Figure 2-2, the number of hectares reported by NRCS used to grow cover crops started to decline in 2011 and has gradually increased in 2018. However, this data includes all NRCS related farmer assistance programs. When looking only at cover crops subsidized by Delaware's Environmental Quality Incentive Program (EQIP; Figure 2-3), the number of total hectares is expectably lower, but the trends are more variable but increases in 2015. Figure 2-4 shows a general increase of cover crop area subsidized in Delaware since 2005, but with a more recent drop. Accordingly, the Conservation Districts do have a higher number of hectares enrolled in subsidy programs than EQIP, when compared directly. DNREC's transect survey (Tables 2-1, 2-2, and 2-3) began more recently, but portrays a more stable area of cover crop plantings over the last three years. Looking at the three sources of data, DNREC's data clearly shows a significantly greater magnitude of cover crop hectarage, meaning that large areas of cover crops are not receiving

subsidies. More stable cover crop coverage reported by DNREC could be partially attributed to subsidy caps for individual farmers, as well as non-eligible covers such as commodity crops. A current Agricultural and Food Research Initiative (AFRI) study is being led by the University of Delaware to gauge what farmers prioritize when considering signing up for cover crop incentive programs (Thomas, 2016). This information, along with production research results can potentially lead to increased and more stable subsidy enrollment, potentially leading to an increase in actual cover crop hectarage.

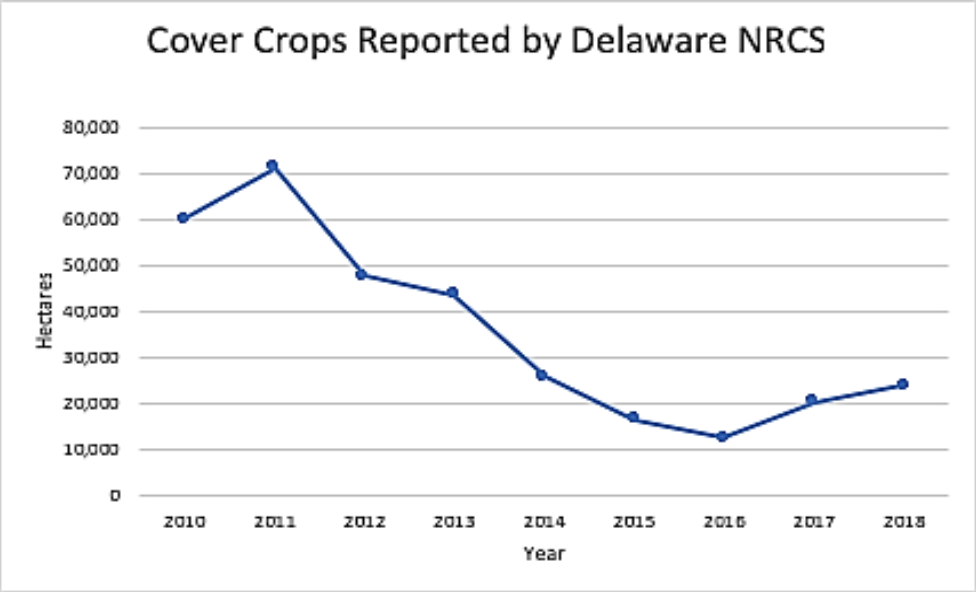

Figure 2-2: Cover crops reported through all NRCS programs in Delaware (Arthurs, 2018).

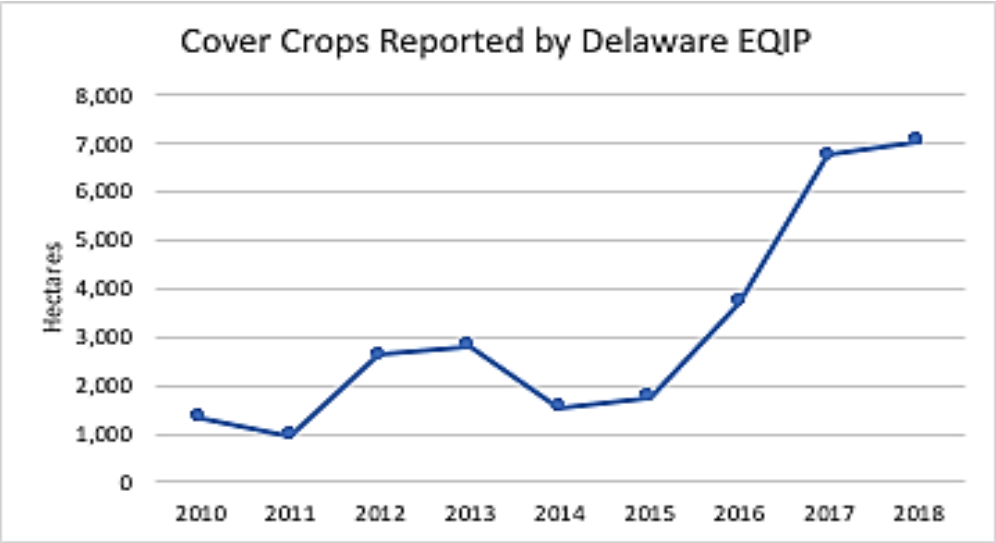

Figure 2-3: Cover crops subsidized by Delaware's Environmental Quality Incentive Program (Arthurs, 2018).

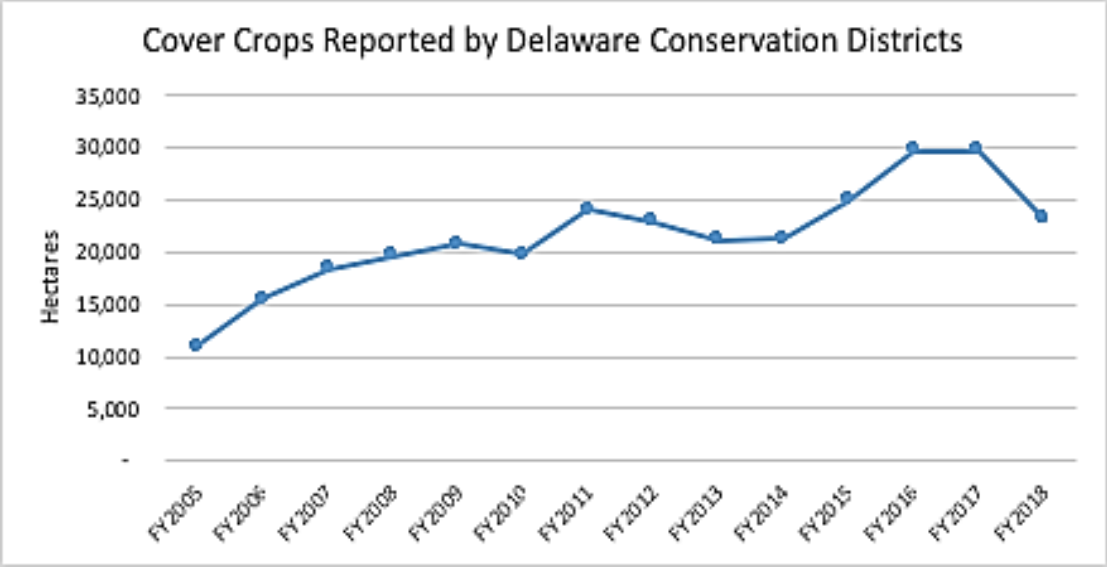

Figure 2-4: Cover crops subsidized by Delaware Conservation Districts (Nelson, 2019).

Table 2-1: 2016 Delaware Natural Resources and Environmental Control Transect Data (Sturgis, 2017). *Harvest Cropland hectares for each county is taken from the USDA NASS 2012 Agricultural Census (USDA NASS, 2012).

2016	New Castle County		Kent County		Sussex County	
	Trad	Comm	Trad	Comm	Trad	Comm
Cover Crop Observations (%)	12.40%	17.00%	25.00%	18.40%	20.70%	13.90%
Harvested Cropland (Hectares)*	21,654		57,367		91,482	
Cover Crop Coverage (Hectares)	2,685	3,681	14,342	10,555	18,936	12,716
Total County Cover Crop (Hectares)	6,366		24,897		31,652	

Table 2-2: 2017 Delaware Natural Resources and Environmental Control Transect Data (Monteith, 2019). *Harvest Cropland Hectares for each county is taken from the USDA NASS 2012 Agricultural Census (USDA NASS, 2012).

2017	New Castle County		Kent County		Sussex County	
	Trad	Comm	Trad	Comm	Trad	Comm
Cover Crop Observations (%)	14.70%	13.50%	26.60%	20.60%	23.80%	14.40%
Harvested Cropland (Hectares)*	21,654		57,367		91,482	
Cover Crop Coverage (Hectares)	2,688	3,683	14,313	10,534	18,915	12,731
Total County Cover Crop (Hectares)	6,371		24,848		31,646	

Table 2-3: 2018 Delaware Natural Resources and Environmental Control Transect Data (Monteith, 2019). *Harvest Cropland Hectares for each county is taken from the USDA NASS 2012 Agricultural Census (USDA NASS, 2012).

2018	New Castle County		Kent County		Sussex County	
	Trad	Comm	Trad	Comm	Trad	Comm
Cover Crop Observations (%)	11.50%	15.80%	16.60%	18.80%	17.40%	19.90%
Harvested Cropland (Hectares)*	21,654		57,367		91,482	
Cover Crop Coverage (Hectares)	2,492	3,427	9,542	10,807	15,878	18,224
Total County Cover Crop (Hectares)	5,920		20,349		34,102	

Increasing cover crop use and improving management in the region can have large watershed impacts. Plot-scale analysis of the effects of cover crops on reducing nutrient loss has been done extensively, but results are inconsistent. However, cereal grain winter cover crops have shown a decrease in N-leaching potential on Mid-Atlantic grain farms (Staver and Brinsfield, 1998). Longer term watershed-level analyses of reducing agriculture nutrient loss using cover crops is more difficult. By necessity, many studies rely on relatively small measurable plots (Dabney, 1998). However, results from smaller scale studies can be extrapolated and combined with landscape level monitoring, via remote sensing and cover crop subsidy enrollment. By using these methods, Hively et al. (2009) found a correlation between spring biomass and nutrient uptake in the Chesapeake Bay Watershed. Additionally, Hively et al. (2009) found that cover crop plantings beyond October 15, had significantly less biomass and nutrient uptake, highlighting the importance of good and timely cover crop establishment for maximizing water quality benefits. In another larger scale project, Yeo et al. (2014) used a

calibrated model based on water quality and satellite measurements to estimate the long-term effectiveness of cover crop management to reduce nitrate loss into the Chesapeake Bay. The results of the Yeo et al. (2014) project showed that cover crops reduced nitrate loss from agricultural fields by 27-67% and that rye was the most effective species.

All cover crops, once established, will utilize and store available N, at least temporarily. Therefore, they can reduce N leaching, by pumping up soil N and storing it in plant tissue. This is not uniformly consistent, but some studies have quantified the maximum actual N uptake by planting cover crops with an abundance of N fertilizer (Jordan et al., 1994). A Maryland study found that following corn harvest, rye recovered more fertilizer N than vetch, crimson clover, or ryegrass, and did so early in spring because of its greater growth in cool weather (Shipley et al., 1992). This could be an additional benefit for rye used in Delaware systems that may terminate cover crops early. In another study, Ditsch et al. (1993) also demonstrated rye's superior ability to recover residual N from fertilizer applications in corn.

Although, not a focus in this Delaware project, cover crops can also help to reduce erosion losses including particulate P, which is the major portion of P loss in cultivated lands (Pietilainen, 1991; Sharpley et al., 2000). However, as the season goes on, the cover crops' ability to limit nutrient loss can become more variable. For example, dissolved P runoff losses can increase when cover crops go through extreme freeze and thaw cycles (Øgaard, 2015). Although, the Mid-Atlantic will not normally observe the -20°C freeze-thaw cycles that was observed in the study by Øgaard (2015), this variability further demonstrates the complexity of nutrient cycles as they relate to cover crops. Liu et al. (2015) found that the amount of P retained varied greatly depending on species and that root biomass was a large factor in this variation. Liu et al. (2015) and Reicosky and Forcella (1998) have shown that different cover crop species can

have significantly dissimilar aboveground to belowground biomass ratios, which can greatly alter P retention. Results like these indicate a potential need for research like this Delaware study to also evaluate P retention, belowground biomass and cover crop nutrient relationships more comprehensively.

Another potential benefit of cover crops is their ability to reduce fertilizer needs for cash crops with N supply and retention, both of which are dependent on cover crop performance. Legumes are often promoted to fix N, while other cover crops can store it until the cash crops can utilize it. However, not all cover crops in all situations perform equally. White et al. (2017) explored the tradeoff complexities associated with N supply, N retention and yield as they relate to soil conditions, seeding rates, and cover crop species. They found that mixes with high non-legume rates can have high N retention levels, but lower N supply and lower maize yields. However, White et al. (2017) concluded that by improving cover crop and soil management, N retention and N supply can both remain high when planting mixes. Unfortunately, plots in the Delaware project were terminated before N supply could be provided, but groundcover and biomass of the mixes could indicate the clover's potential. Another potential issue is N that cover crops store may be immobilized or mineralize too quickly. In other words, species and management practices can affect if the N is plant-available or lost too quickly for assimilation by the cash crops (Rosecrance et al., 2000). Schomberg et al. (2005) in Georgia found variable rates of N mineralization in cotton systems following crimson clover or rye treatments, but concluded that soil heat units could be useful for estimating N mineralization. Results like this in conjunction with this Delaware project's results can potentially improve cover crop and N management for spring cash crops.

The magnitude of potential benefits depends on the levels of establishment and growth of cover crops, which are often quantified by percent groundcover and biomass. The percent of ground coverage is commonly measured to quantify establishment and groundcover protection by analyzing photographs for different color frequencies to estimate percent cover. This method can measure factors such as crops, weeds, and groundcover, which can improve planting, fertilizing, and irrigation efficiencies (González-Esquiva et al., 2017). Percent green can be effectively measured with large aerial watershed-level photographs or with small photographs of representative plot samples using a computer program, Canopeo (Hively et al., 2009; Patrignani et. al., 2015). Additionally, biomass is also often measured in cover crop research because it can infer a greater uptake of nutrients and potentially other benefits. However, it is often not practical to measure entire treatment plots. Therefore, representative quadrant samples are often taken of plots, which can be extrapolated to the whole plot and recorded as kg/ha rates (Gaskin et al., 2015).

Ideal treatments are often identified by greater biomass and/or groundcover samples. Research has shown that ideal treatments are specific for localized areas and optimized seeding rates, planting dates, and species can be identified based on their performance in local conditions. A study done at many sites in the Eastern United States evaluated seeding rates and planting dates for hairy vetch, which produced a wide range of biomass based on location and latitude. They concluded that locations had significantly different ideal seeding rates and emphasized the need for localized cover crop management (Mirsky et al., 2017). Vann et al. (2019) found that seeding rates for legumes and small grain mixes performed considerably different at different sites. Vann et al. (2019) concluded that the species, rates, and ratios that can produce the greatest biomass are specific to localized sites and conditions. Research in upstate

New York showed that triticale biomass and N uptake were significantly affected by planting date, which would alter nutrient management recommendations (Lyons et al., 2017). An Alabama study also found that planting dates and seeding rates at their sites had substantial effects on biomass (Balkcom et al., 2011).

Some studies focus specifically on identifying species that outperform in particular locations such as a Kansas planting date trial that evaluated several native cover crop species' abilities to germinate and perform better in the drier conditions in that area (Schartz et al. 1999). Other studies compare different mixes and monocultures. Vetch-rye mixes have been found to produce as much or more biomass as monocultures of vetch or rye and accumulate as much N as vetch alone (Thapa, 2018). A Mid-Atlantic project found that the rye-grass-legume mixtures produced more biomass than legumes or rye-grass alone (Curran et al., 2018). Murrell et al. (2017) found that planting dates could affect how individual species in mixes can perform. Although this Delaware study evaluated only one legume, which was crimson clover used in a mix with rye, there is significant variability among legumes and various clover species. Den Hollander et al. (2007) compared eight monoculture clover species, resulting in significantly different growth and soil coverage rates, height, and management recommendations. Data from this project should not solely be used to guide the management of other clover species. Noland et al. (2018) also found that species could perform differently based on planting method with some species specifically creating more fall or spring biomass when drilled or incorporated.

In general, research has shown that potential cover crop benefits and results can vary significantly. Among other attributes, cover crops have been shown to increase organic matter, cation exchange capacity and aggregate stability, while also scavenging N and reducing sediment loss. However, these benefits will not always occur and potential negative effects on spring

planted cash crops can exist in drier and cooler conditions. Cover crops can potentially deplete soil water content and slow the rise of soil temperatures, potentially affecting early cash crop growth (Dabney et al., 2001). Bergtold et al. (2017) evaluated the financial aspects of including cover crops in farming systems. Their study concluded that the complexity of research results creates a level of uncertainty for an individual farmer's specific situation. Bergtold (2017) recommended that cover crop research results should be used to guide farmers doing their own small-scale trials before changing management, but that wide spread benefits are possible.

In Delaware, cover crops along with other conservation practices, such as reducing tillage, can particularly be impactful when used in relation to Delaware's three largest agricultural industries: corn, soybeans, and poultry. In 2017 grain corn was planted and harvested on the most number of hectares (72,843 and 69,201 respectively) and produced the most value ($127,860,000). Soybeans were second highest in all categories with 64,750 ha planted and 63,940 ha harvested producing $74,134,000 in value (USDA NASS, 2017). Crop rotations are a common agriculture practice in Delaware that can reduce inputs and pests, and increase yields and profits (Francis et al., 1990). Corn – soybean rotations are perhaps the most commonly used rotation in the Delaware, U.S., and elsewhere, especially when considering similar crops (such as maize and other legumes). Corn – soybean rotations have been shown to produce higher yields compared to monocultures in both tilled and no-tilled management (Erbach, 1982). Cover crops as part of this rotation have further shown benefits, but results can be variable (Villamil et al., 2006).

There were 259,800,000 broiler chickens produced in Delaware in 2017, largely fed by Delaware corn and soybeans (USDA NASS, 2017). Annually, the Delaware poultry industry produces approximately 254 million kg of poultry litter, which includes manure and bedding.

This litter can be a blessing as a source of crop fertilizers, but also a curse as it is a waste product that needs to be disposed of in environmentally acceptable ways. The majority of this litter is spread on agricultural fields, much of which are growing Delaware's two biggest crops: corn and soybeans (UD, 2017). Poultry litter is about equally high in N and P, but some crops, including corn, only need one-third to one-fourth as much P as N. Historical litter applications have created excessive P soils throughout much of the state. This has caused the need for manure regulations in Delaware because soils with excessive P are more vulnerable to P loss (DE Code Ch. 22, §2221; Sims, 2000). An example of such a Delaware regulation is, "Nutrient management plans shall specify the level of nutrient applications that are needed to attain expected crop yields (based on the best 4 out of 7 years). Applications of phosphorus to high phosphorous soils cannot exceed a 3-year crop removal rate. Nitrogen applications cannot exceed the expected yield" (Delaware Code § 2247, b). These factors contribute to farmer nutrient management, which cover crops and conservation tillage can play an important role.

The DNREC 2014 transect survey found that 67% of Delaware cropland used reduced tillage management. There are various levels of tillage activities, but the majority of Delaware cropland, including corn/soybean fields use some level of conservation tillage (Fox and Monteith, 2015). Tillage is used to incorporate materials, disturb weed growth, and prepare seed beds. However, tilling can also decrease soil health through erosion, compaction, and a reduction of microbial activity and nutrient retention. As of 2010, world-wide no-till agriculture was being practiced on about 85.8 million hectares showing that it has been widely accepted as a long-term sustainable agricultural system (Derpsch et al., 2010). Using research-based recommendations, improvements can be made with cover crop management in conjunction with conservation tillage, which can have major impacts on nutrient loss by Delaware's agriculture industries.

CHAPTER III: METHODOLOGY

3.1. Site Descriptions

3.1.1. DSU Trials 2015-2016

A 1.2-ha strip was selected from a 13-ha field at Delaware State University's Research and Outreach Center in Smyrna, Kent County Delaware. The research strip contained a sandy-loam soil, which was mapped as a combination of well-drained Greenwich loam (Typic Hapludults) and Pineyneck loam (Aquic Hapludults; Figure 3-1; NRCS Web Soil Survey, 2018). Sandy loam soils are representative of much of Delaware but are less sandy than soils found in southern. Prior to planting cover crops, the entire 13-ha field was planted in an early maturing corn variety so that it was more likely to be harvested before the early cover crop planting deadline of October 1; corn was harvested in late September 2015. Corn residue remained on the soil surface after harvesting and the field was not tilled. Lime was applied throughout the entire 13-ha plot after the corn was harvested, including the research area, in accordance with regular management. Fertilizer was not applied to the cover crops. Cover crop plots were established in a 1.2-ha strip, which was located at the north edge of the field, adjacent to a strip of mowed grass (Figure 3-1). This area was selected because it allowed access to the plots without interfering with other farm activities. There was a 3 m buffer, which remained as corn stubble between the treatment area and the rest of the field, which was planted in commodity winter wheat.

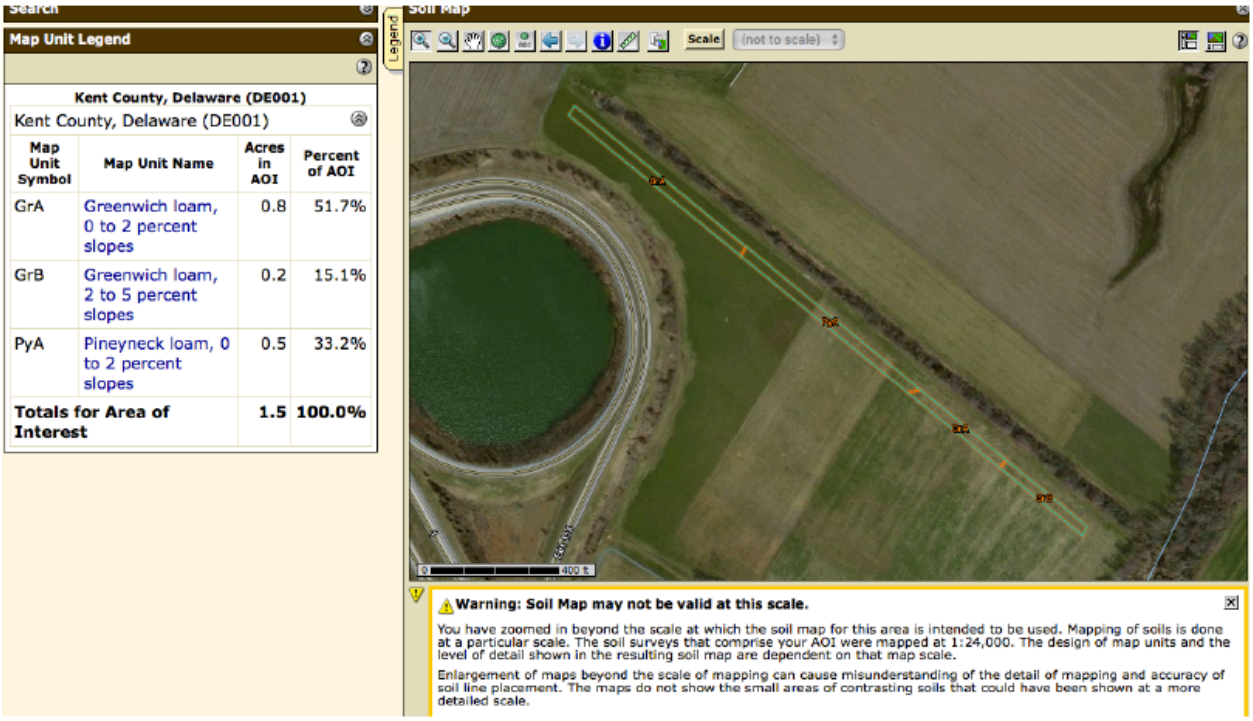

Figure 3-1: Web Soil Survey of DSU Site, Smyrna, Delaware. The 1.3 ha strip is outlined with sections marked as Greenwich or Pineyneck (NRCS, 2018).

Each replication area was 1.5 m × 15 m with 1.5 m gaps separating plots (Figure 3-1). As guided by NRCS, the treatments were two planting types (broadcast and drilled), three planting dates (early/before October 1; standard/before October 15; and late/before October 31), and three seeding rates (low, medium, and high) for cover crop planting varieties (cereal rye, barley, wheat, and a rye/crimson clover mix). This resulted in 72 treatments with three replications resulting in 216 treatment units. There was a 3 m buffer, which remained as corn stubble between the treatment area and the rest of the field, which was used for wheat harvest. This resulted in an overall plot area of 660 m × 20 m or 1.32 hectares.

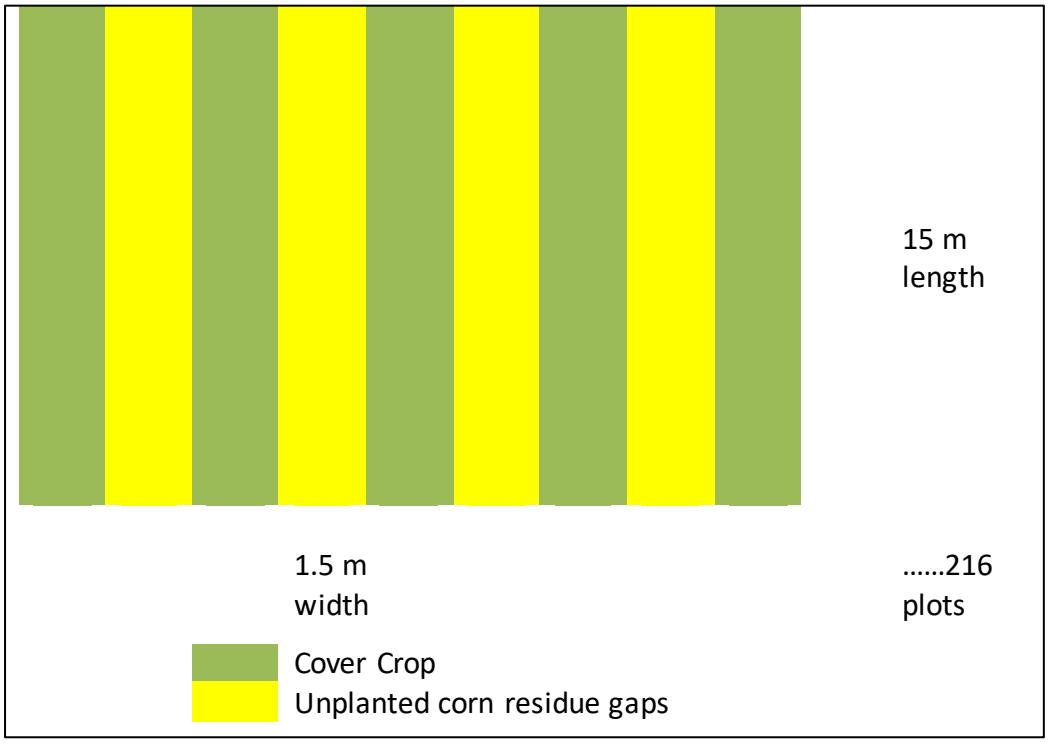

Figure 3-2: Plot Layout for DSU and UD Sites

Rye, barley, and wheat are the three most common cover crops in Delaware (Sturgis, 2017) and were recommended by NRCS along with a rye/clover mix to be evaluated (Kepfer, 2014). A no-till grain drill was used to plant all plots into the corn residue. For drilled plots, the calibrated drill was lowered so that seeds were introduced directly into the seedbed. For broadcast plots, the drill was raised just above the ground so that the seeds were broadcasted onto the ground surface. Table 3-1 shows the seeding rates at three different levels as recommended by NRCS (NRCS, n.d., Kepfer, 2014). Treatments were assigned randomly. Following planting of each species, all remaining seeds were vacuumed out of the no-till grain drill seed bin to ensure only the appropriate species was planted in each plot. The actual 2015 early, standard, and late planting dates were September 30, October 13, and October 30, respectively.

Table 3-1: Seeding Rates for DSU Site.

Seedling Rate (kg/hectare)				
Rate Description	**Cereal Rye**	**Barley**	**Wheat**	**Rye/Crimson Clover**
Low	63	67	67	22/11
Medium	94	101	101	45/11
High	126	135	135	67/11

3.1.2. University of Delaware Trials: 2015-2018

The University of Delaware conducted similar trials to evaluate cover crop species, planting method, seeding rate, and planting date in 2014, 2015, and 2017 at multiple field sites in Sussex County. Treatment combinations were arranged in a randomized complete block design with individual 1.5 m × 15 m plots; a 1.5 m gap separated plots. During all three years, three monocultures were planted (cereal rye, barley, and wheat) and two mixes of rye/crimson clover (one with static clover rates and one with static rye rates; Table 3-2). Two planting methods were used: broadcast and incorporation with light disking (differing from DSU drilled plots). Three seeding rates were used for each species with the seeding rate for broadcast seeded plots being increased by 30%. Fields were located on cooperator farms and at the University of Delaware's Carvel Research and Education Center in Georgetown, Delaware. Farmer cooperators in the project chose to remain anonymous and those field sites are only described by the town in which they are located. Not all treatments were planted for all UD trials for all years, due to logistical issues, such as weather and available resources. Termination dates for cooperator trials were determined by the farmers. Due to funding gaps, not all data was able to be collected for all treatments in all UD trials.

Table 3-2: Seeding Rates for UD Sites.

	Seedling Rate (kg/hectare)				
Rate Description	Cereal Rye	Barley	Wheat	Rye/Crimson Clover	Rye/Crimson Clover
Low	63	67	67	22/11	45/6
Medium	94	101	101	45/11	45/17
High	126	135	135	67/11	45/22

University of Delaware Trials: 2015-2016

Three field sites with four replications per treatment combination were planted in Sussex County, Delaware during the 2015-2016 season. On-farm sites were located in Laurel (UD Site 1-L-2016) and Millsboro (UD Site 3-M-2016); one site was at the University of Delaware Carvel Research Station in Georgetown (UD Site 2-C-2016). There were three planting dates in Laurel: Early (September 9), Standard (October 1), and Late (October 20). There was one planting date at Carvel (Oct 8) and one planting date in Millsboro (Oct 21). The Laurel and Millsboro field sites were dominated by Klej loamy sand soils (Aquic Quartzipsamments) and the Carvel plot was a Pepperbox loamy sand (Arenic Paleudults).

University of Delaware Trials: 2017-2018

For the 2017-2018 season, on-farm sites were planted in Georgetown (UD Site 1-G-2018), on September 11 (Early) and October 18 (Late) and in Millsboro (UD Site-3-M-2018) on October 19. The Georgetown cooperator field site had a loamy Pepperbox-Rosedale complex soil. The Millsboro cooperator field site had a coarse-loamy Hammington sandy loam soil. Cover crop trials were also planted at the University of Delaware Carvel Center (UD Site-2-C-2018) on September 9, 2017), which has Pepperbox loamy sand. The same treatments were used as in previous years. Soil and plant samples were done prior to termination in late March for on-farm trials and by late April for the Carvel trials.

3.2. Groundcover Analysis

Plot subsamples were photographed using a "light box" that was made to block out all ambient light so that lighting in each picture was uniform. One side of a box was removed and rectangle was cut out of the opposite side of the box in the exact shape of the camera. In the plots, the light box was turned upside down and the camera was inserted in the hole, blocking all ambient light. The DSU plots were photographed in early December to measure fall ground cover. Spring photos were not taken due to extremely heavy growth that made analyzing photographs impossible. The UD plots were photographed in late fall and/or early spring depending on plot conditions and logistics, such as funding and resource availability at the time.

Photos of DSU plots were taken with a Canon Rebel with the flash on in a location in each plot that is representative of the whole plot. It is not possible to take completely randomized subsamples because plot coverage can be significantly different within a single plot, so the results could be very skewed in certain situations. For example, a plot could have a significant stand throughout the plot except for a small area that did not establish and if that area was randomly chosen, the results would be greatly skewed. It is not possible to take photos of the entire plots (without a drone) so a representative subsample was used. This requires judgment by the sample collectors, but it is not subject to treatment bias because the plots were not labeled, and the researchers did not know which treatments they were testing. The pictures were analyzed using Canopeo, and application that measures the percent of green coverage; Canopeo has been found the be very effective and faster than other programs (Patrignani et. Al., 2015). A drawback of using programs like Canopeo is that it is detecting green and cannot differentiate between weeds and cover crops. However, in the DSU plots, there was heavy corn residue covering the surface, and even the gaps between plots that were not planted into, had no weed pressure.

Looking at the photos by eye also showed that there was minimal weed pressure throughout the plots. Some UD plots had heavy weed pressure, which could potentially skew results to show that plots that actually had poor cover crop establishment still had adequate groundcover percentages because of weed encroachment (personal observation).

3.3. Spring Aboveground Biomass Collection and Plant N-removal

Spring biomass was measured by taking a representative subsample from each plot. As with measuring percent ground cover, it is not possible to take randomized subsamples because plot coverage can be significantly different within a single plot so the results could be very skewed in certain situations. For this reason, representative quadrant samples are often taken of plots, which can be extrapolated to the whole plot and then to kg per hectare (Gaskin et al., 2015). For both UD and DSU plots, a 0.457 m × 0.457 m square was made using PVC pipes (0.209 m^2). The square was put on the ground in a representative location and the cover crops were trimmed at ground level. The cover crops were dried and weighed to record final biomass of each sample.

Additionally, plant tissue samples from each plot were submitted to the University of Delaware Soil Testing Program and tested for the total N by combustion. The total N removal was calculated by multiplying the N in the plant tissue sample by the amount of above ground biomass. Due to low cover crop and high weed establishment at the UD farmer-cooperative sites, biomass samples were taken from all early planting date blocks, and only one block from the other dates.

3.4 Soil Sampling

Soil samples were collected from all trials prior to cover crop termination. Four 0-15 cm and four 15-30-cm soil samples were taken from every plot. The four samples from the same plot

and depth were combined, dried and a subsample was tested for N by combustion by the University of Delaware Soils Lab. Total Nitrogen was measured because it can provide a more stable measurement and is less affected by short term effects, such as with rainfall.

3.5. Data Analysis

The data for ground cover percentage, aboveground biomass, plant tissue N (N removal) and total soil N were analyzed using a mixed model ANOVA with date, method, rate, seed species, (and soil depth for soil N) as the fixed effects and replicate as a random effect. Mean separations were completed using Tukey's Honest Significant Difference (HSD) test at alpha = 0.05 except for soil N, which used alpha = 0.10. Data in figures and tables show that treatments with the same letter label do not significantly differ. The DSU plots were designed as a 4 x 3 x 3 x 2 full factorial with three replications (4 species/mixes, 3 planting dates, 3 seeding rates, and 2 planting methods). The UD trials had up to 5 varieties/mixes, 3 planting dates, 3 seeding rates, 2 planting methods and 4 replications, but not all treatments were evaluated at each location each year and data collection was not always possible for all treatment combinations. If treatment interactions were found, treatments that had results without significant differences were grouped and contrasted with interactions that showed significant differences. Data that was not normally distributed was log-transformed prior to ANOVA and mean comparisons; graphs were generated using untransformed data. When data was not available from all replicated treatments, statistical analysis was not completed due to the lack of replication. Table 3-3 shows the variable that were evaluated at each site.

Table 3-3: Variables evaluated for each research site.

SITE	Fall coverage	Spring coverage	Biomass	N removal	Soil N
DSU Site-2016	✓	✗	✓	✓	✓
UD Site 1-L-2016	✓	✓	✓	✓	✓
UD Site 2-C-2016	✓	✓	✓	✗	✗
UD Site3-M-2016	✓	✓	✗	✗	✗
UD Site 1-G-2018	✗	✓	✓	✓	✓
UD Site 2-C-2018	✗	✓	✓	✓	✓
UD Site 3-G-2018	✗	✓	✗	✗	✗

CHAPTER IV: RESEARCH FINDINGS

4.1. DSU 2015-2016 (DSU Site-2016)

4.1.1. Groundcover

The DSU site had significant differences in fall coverage due to planting dates and crop species as well as interactions between planting date and planting method. There were no three or four-way interactions. The DSU plot showed a clear decline in late fall ground cover percentage for each subsequent planting. For both broadcast and drilled cover crops, the early planting date (September 30) had significantly more groundcover (73.3% coverage) than plots planted by the standard date (October 13; 49.7% coverage); both the early and standard planting resulted in significantly more coverage than the late planting (October 30; 26.8%; Figure 4-1 and Table A-1). At the early and late dates, there was not a significant difference between broadcast and drilled plots. Conversely, at the standard planting date, the drilled cover crops covered significant more of the plot (55.2%) than the broadcast planted cover crops (44.1%). Among all treatments, the early planting date had higher ground coverage than the standard which had higher coverage than the late (Figure 4-2 and Table A-2). Comparing species directly (Figure 4-3 and Table A-3), there was no significant difference in fall cover between barley (50.2%), rye (55.1%), and the rye/clover mix (51.1%). However, wheat plots had significantly less cover (43.3%) than the other species or mix (mean 52.2%) across all planting dates, seeding rates, and methods.

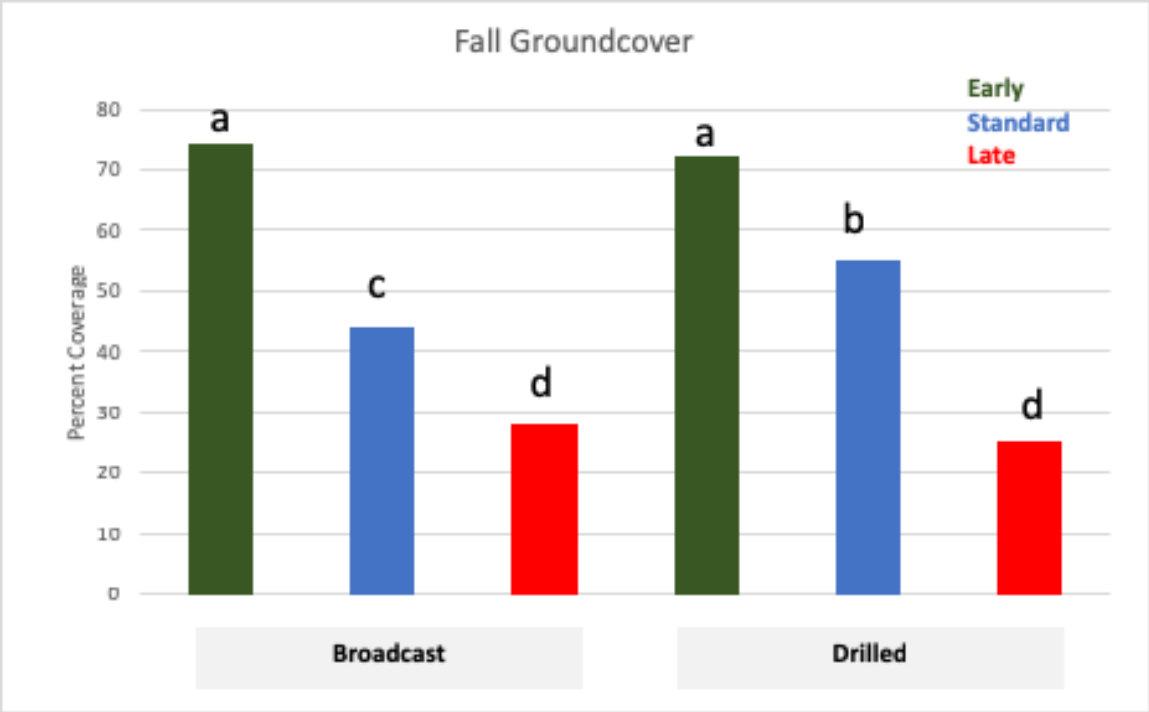

Figure 4-1: Planting date x planting method interaction effects on percent fall ground coverage at the DSU site as estimated from photographs taken in December 2015 by Canopeo.

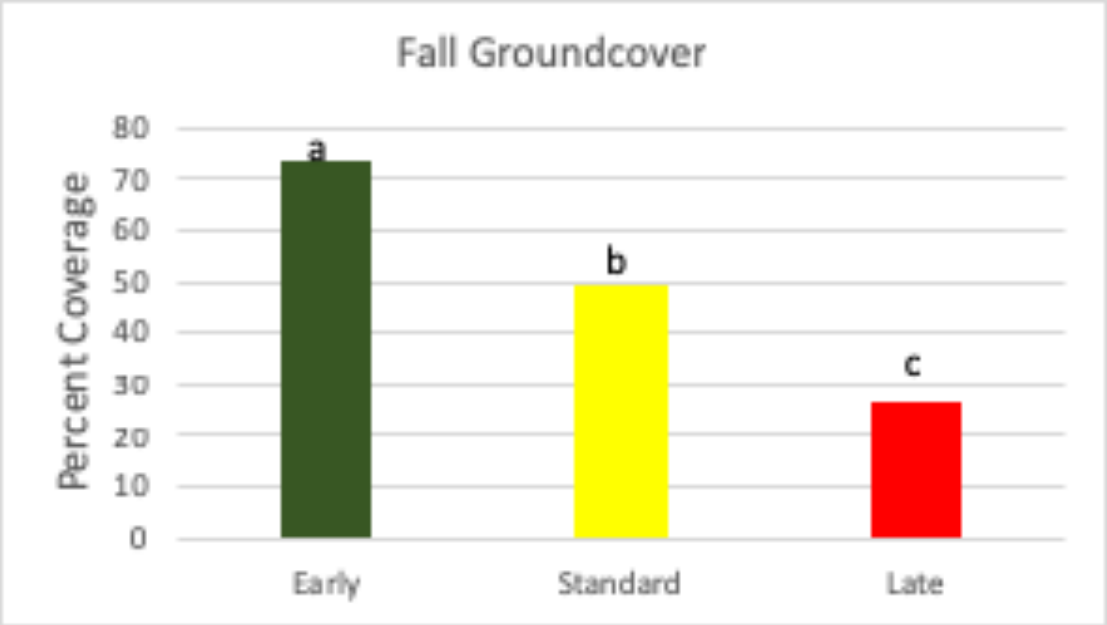

Figure 4-2: Planting date effects on percent fall ground coverage at the DSU site as estimated from photographs taken in December 2015 by Canopeo.

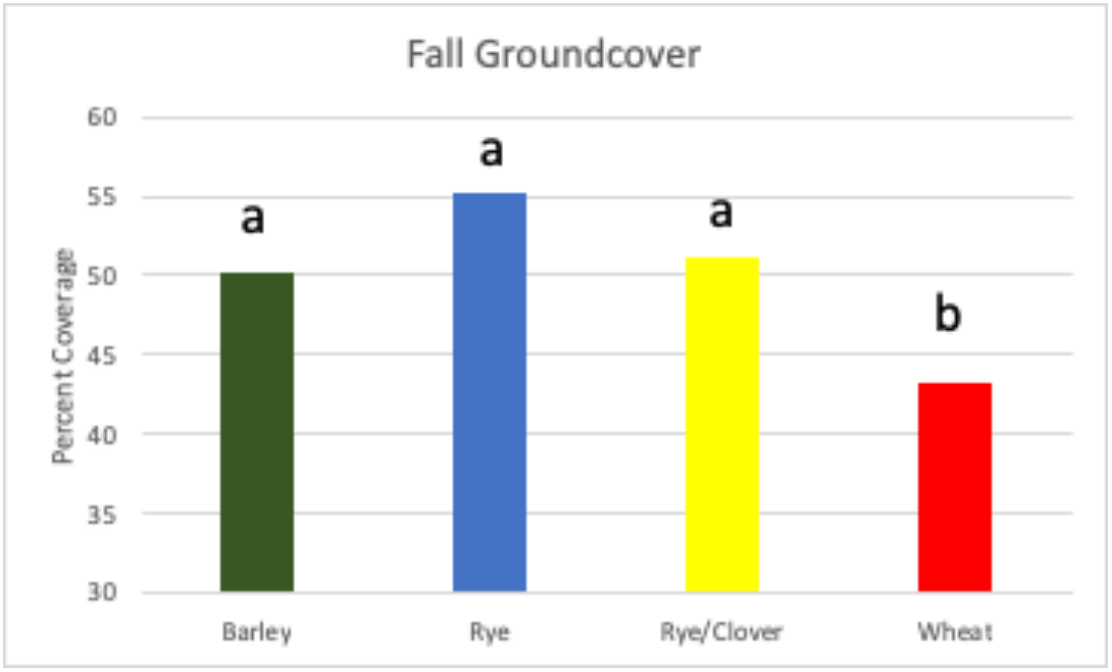

Figure 4-3: Species effects on percent fall ground coverage at the DSU site as estimated from photographs taken in December 2015 by Canopeo.

4.1.2. Spring Aboveground Biomass

Spring dry biomass production was significantly influenced by seeding method; there were also significant seeding rate × planting date and species × planting date interactions. There were no significant three or four-way interactions. In contrast to the fall ground coverage, drilled plots produced significantly more biomass than broadcasting (7,086 and 5,431 kg/ha, respectively) across all other treatments (Figure 4-4 and Table A-4).

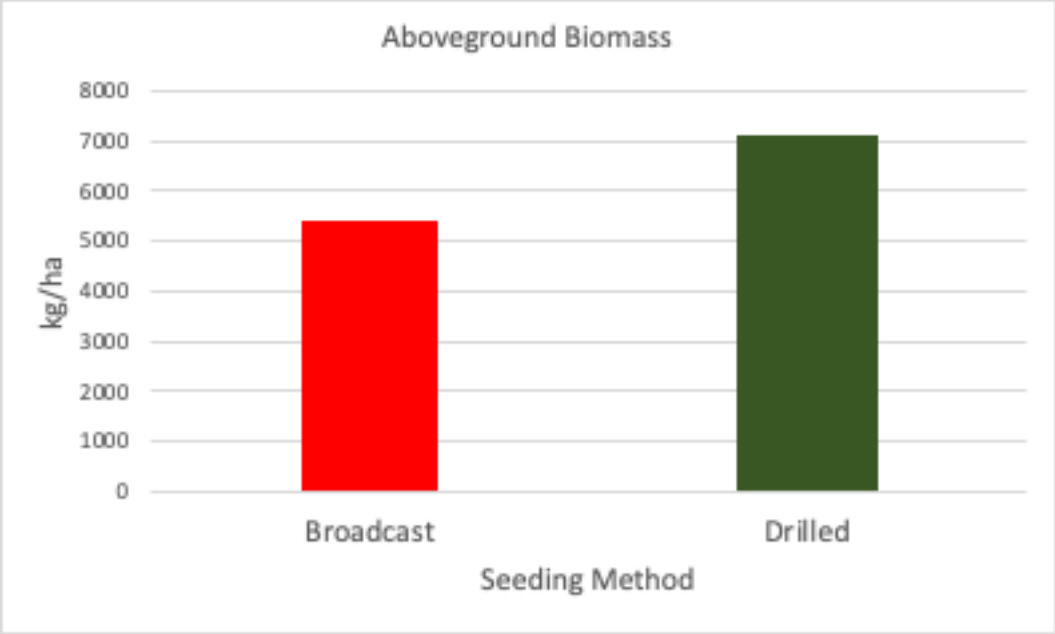

Figure 4-4: Planting method effects on dried aboveground biomass collected from the DSU site in April 2016.

For planting date x seeding rate interactions, the cover crops planted early at the low seeding rate produced more dry spring biomass (9,785 kg/ha) than all other planting date × seeding rate combinations except for the medium seeding rates planted at the early and standard dates (Figure 4-5 and Table A-5). For crops planted by the late date, the low and medium (2,871 kg/ha) seeding rates produced statistically less dry spring biomass (2,710 and 2,871 kg/ha, respectively) than all other seeding rates planted at the early and standard dates. The high seeding rate planted by the late date had statistically similar biomass as high and low seeding rates planted by the standard date (4,305, 6,299 and 6,660 kg/ha, respectively).

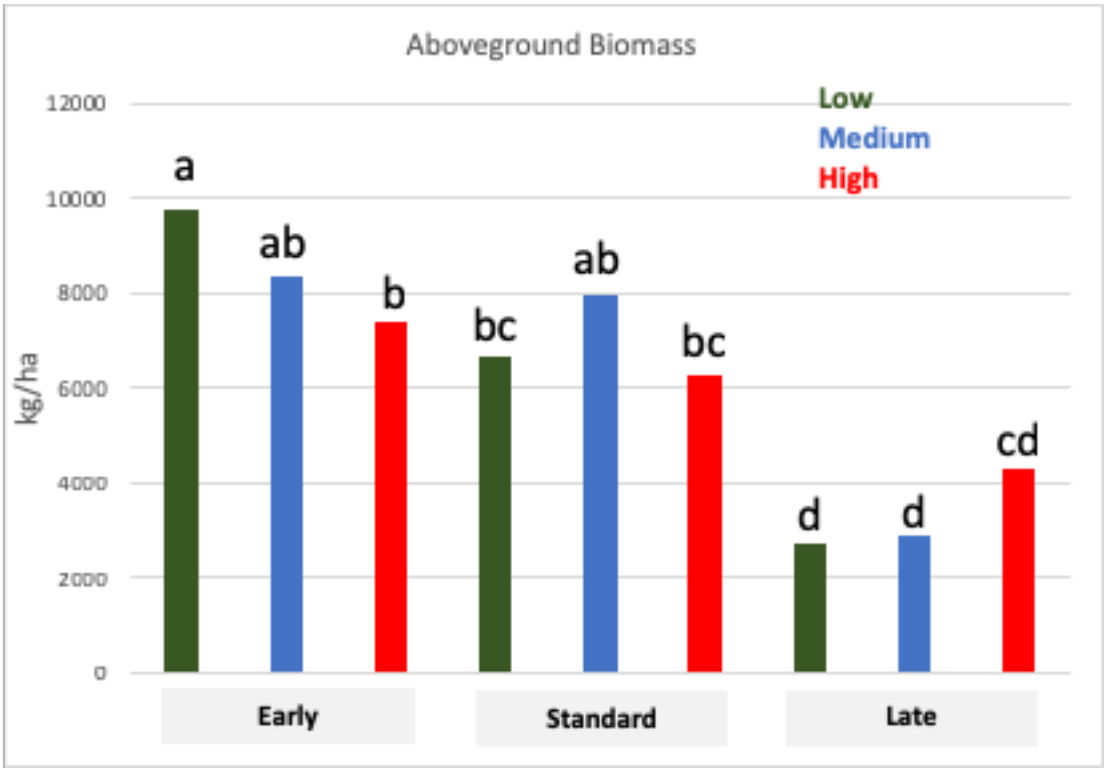

Figure 4-5: Seeding rate and planting date interaction effects on dried aboveground biomass collected from the DSU site in April 2016

Crop species × rate interactions showed that at the early planted rye (10,580 kg/ha) and rye/clover (10,074 kg/ha) produced greater dry spring biomass than all species × planting date combinations (Figure 4-6 and Table A-6). Cover crop species did not have a significant effect on biomass for late planted cover crops. For all crop species, the late date performed significantly worse than other planting dates, except wheat, which performed similarly to the standard date.

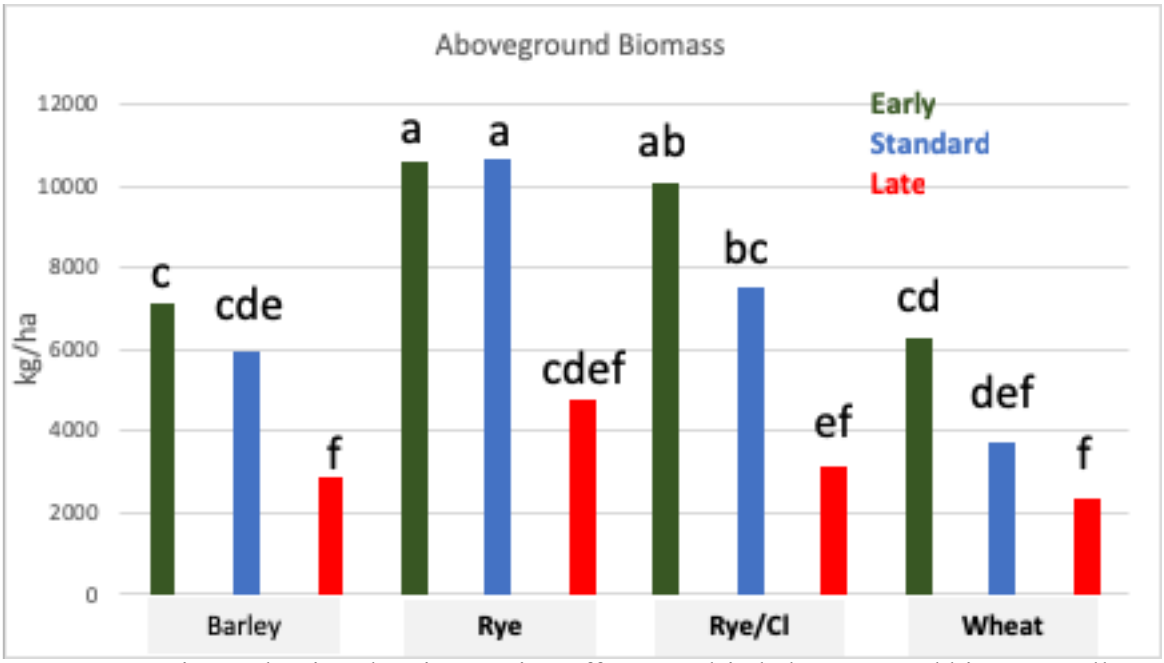

Figure 4-6: Species x planting date interaction effects on dried aboveground biomass collected from the DSU site in April 2016

4.1.3. Spring Nitrogen Removal

Spring N removal by cover crops is related to cover crop biomass because a greater biomass indicates a greater potential to remove N. Planting method effects were similar on N removal as biomass. Drilled plots produced approximately 30% greater biomass and removed 30% more N than broadcasted plots (Figure 4-7 and Table A-7).

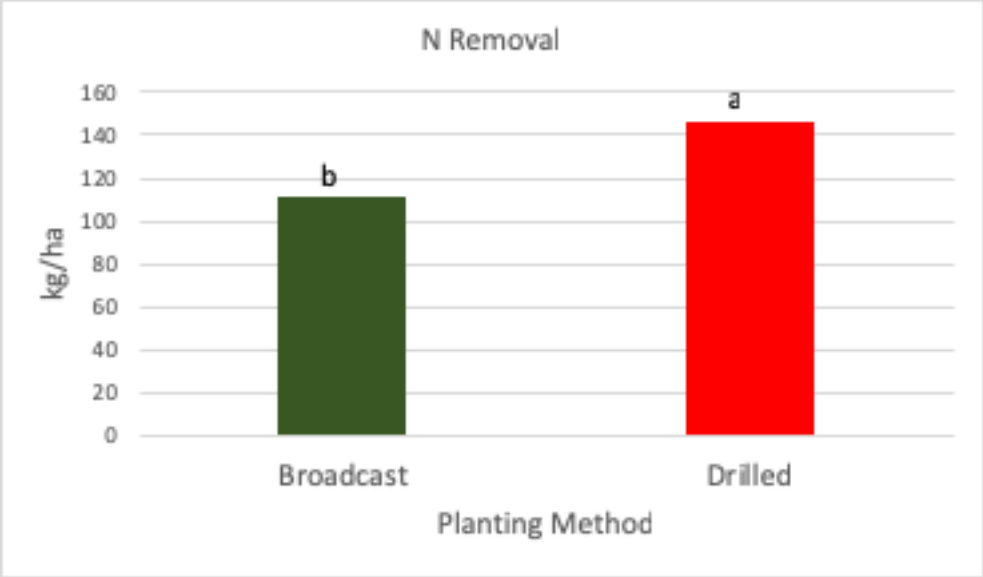

Figure 4-7: Planting method effects on N removal at the DSU site

Seeding rate × planting date interactions on N removal were similar to those reported for biomass (Figure 4-8 and Table A-8). The low seeding rate at the early planting date (212 kg/ha) resulted in higher N removal than most other seeding rate × planting date combinations, except for the early and standard plantings at the medium seeding rates at the early and standard dates and the standard planting at the low rate. The standard and late planting dates had similar N removal between rates, but at the early date, the high seeding rates had less N removal than the low seeding rates (143 kg/ha and 212 kg/ha, respectively).

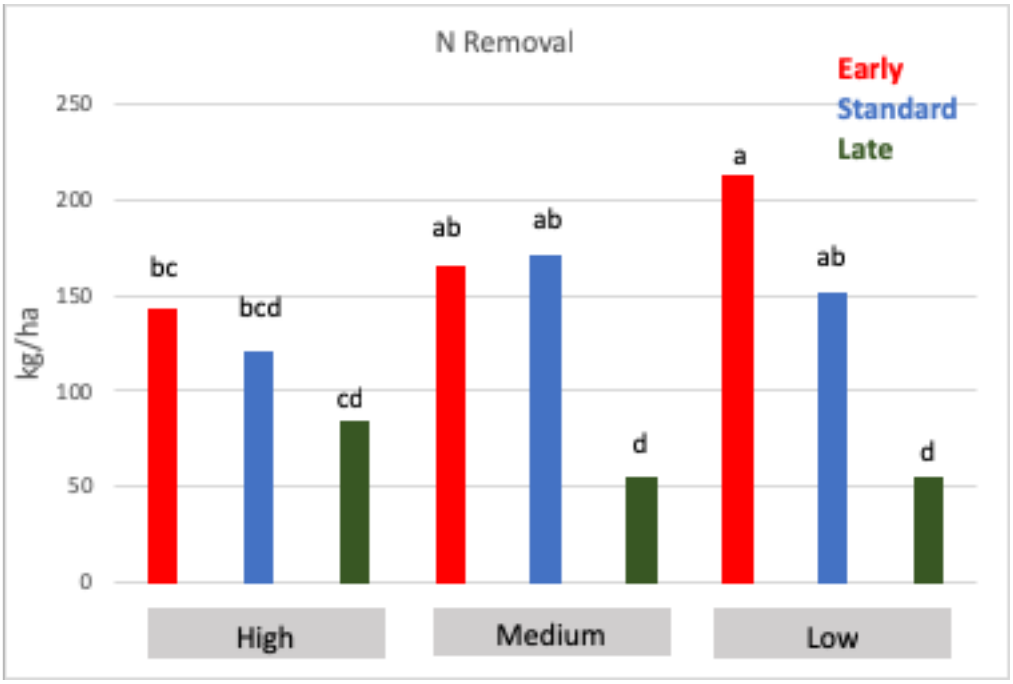

Figure 4-8: Seeding rate and planting date interaction effects on N removal at the DSU site

Crop species × planting date interactions on N removal had some differences to those reported on biomass. While late planted wheat and barley had less biomass than early planted wheat and barley, these interactions resulted in statistically similar N removal, indicating that the late planted wheat and barley had a greater N removal to biomass ratio (Figure 4-9 and Table A-9). Early and standard planted rye, as well as early and standard planted rye/clover mixes had greater N removal than other species × planting date combinations.

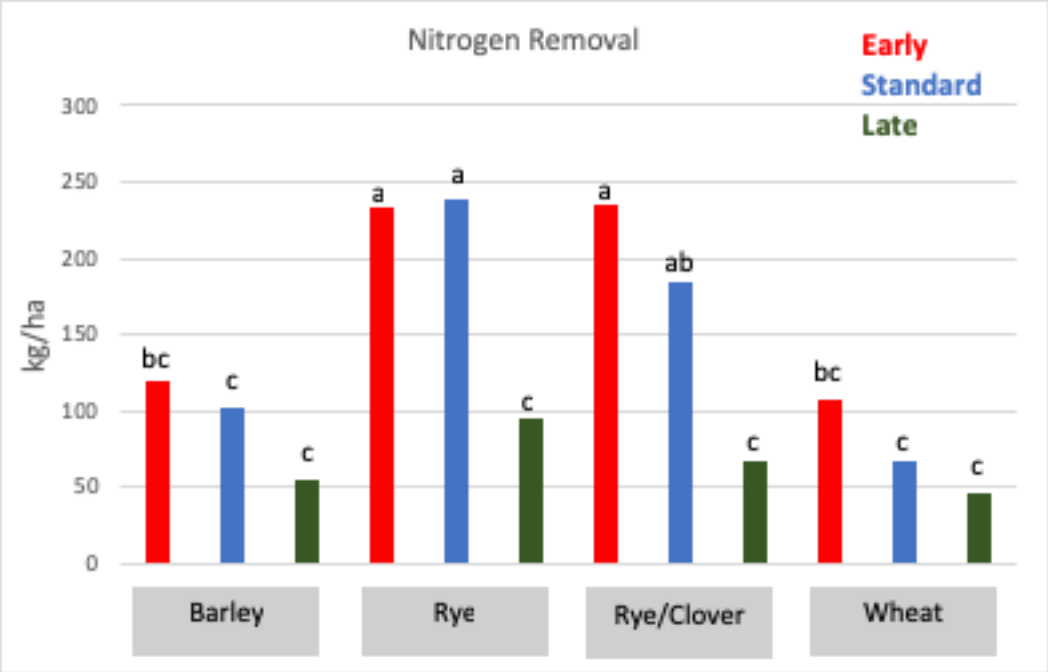

Figure 4-9: Species and planting date interaction effects on N removal at the DSU site.

4.1.4. Total Soil Nitrogen

The 0-15 cm samples showed 4-way interactions effect on soil N. However, out of the 72 treatment interaction combinations, only one (early drilled rye at high seeding rate) was shown to have significantly lower soil total N (0.1187 kg/ha) than the other treatments (Table A-10). Although this treatment combination did not have significantly higher biomass or N removal than all other 71 treatment combinations, it was towards the upper end. Therefore, it is plausible to relate a higher cover crop growth to less soil N remaining in the shallow soil, for which its roots could reach, but this relationship is not always consistent among other treatments and interactions. Furthermore, when comparing the total soil N at 0-15 cm in the early drilled rye at the high seeding rate, the three replications for this treatment interaction were the three lowest results among all interactions.

Only planting method was shown to have an effect on total soil N at the 15-30 cm depth. Drilled plots had significantly more total soil N than broadcasted (Figure 4-10 and Table A-11).

Broadcast plots did have lower biomass and N removal, so it is plausible to relate this to a greater amount of N remaining in the soil.

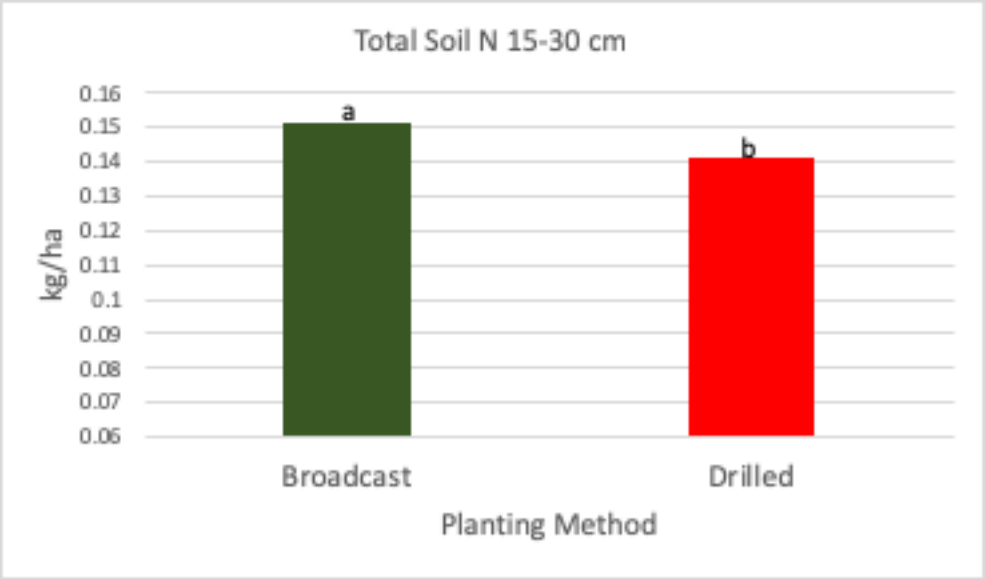

Figure 4-10: Planting method effects on Total Soil N from 15-30 cm samples collected at the DSU site in April, 2016.

4.2. UD Site 1-L-2016

4.2.1. Groundcover

Log-transformed data for fall and spring groundcover showed significant differences. The early plantings produced significantly more fall ground cover among all cover crop species than the standard and late dates. Additionally, at the early planting, wheat provided less cover than the four other species/mixes. There was not a significant difference between late and standard dates or between crops for barley, rye, wheat, and the variable rye/static clover mix (Rye_CC). However, the variable clover/static rye mix (CC_Rye) did result in less fall cover when planted at the late date compared to the standard planted mix. Also, the CC_Rye mix, as well as wheat, had less fall coverage than standard date plantings of Rye_CC, rye, and barley (Figure 4-11). Method x date interactions produced an effect that showed incorporated plots at the standard date

had greater fall cover than incorporated plots at the late date. However, broadcasted plots at the standard and late planting dates had similar results. For each of the three dates individually, the method did not have a significant effect on fall cover (Figure 4-12). There were also seeding rate x planting date interactions that affected fall coverage (Figure 4-13). The early planting dates produced similar coverage, regardless of seeding rate and produced more coverage than later dates, also regardless of seeding rates. This is significant because it implies that whenever a farmer is able to plant, it does not matter which seeding rate is used. An exception to this is at the late date, when the lowest seeding rate performed worse than all other treatments.

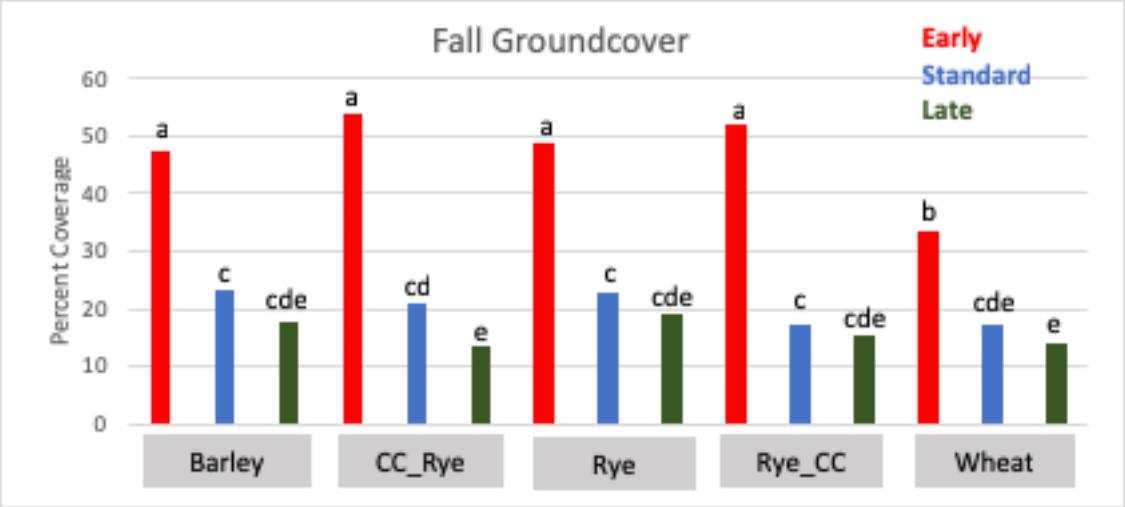

Figure 4-11: Cover crop species x planting date interaction effects on percent fall ground coverage at UD Site 1-L-2016 as estimated from photographs taken in December 2015 by Canopeo (Mean separations were completed on log-transformed data).

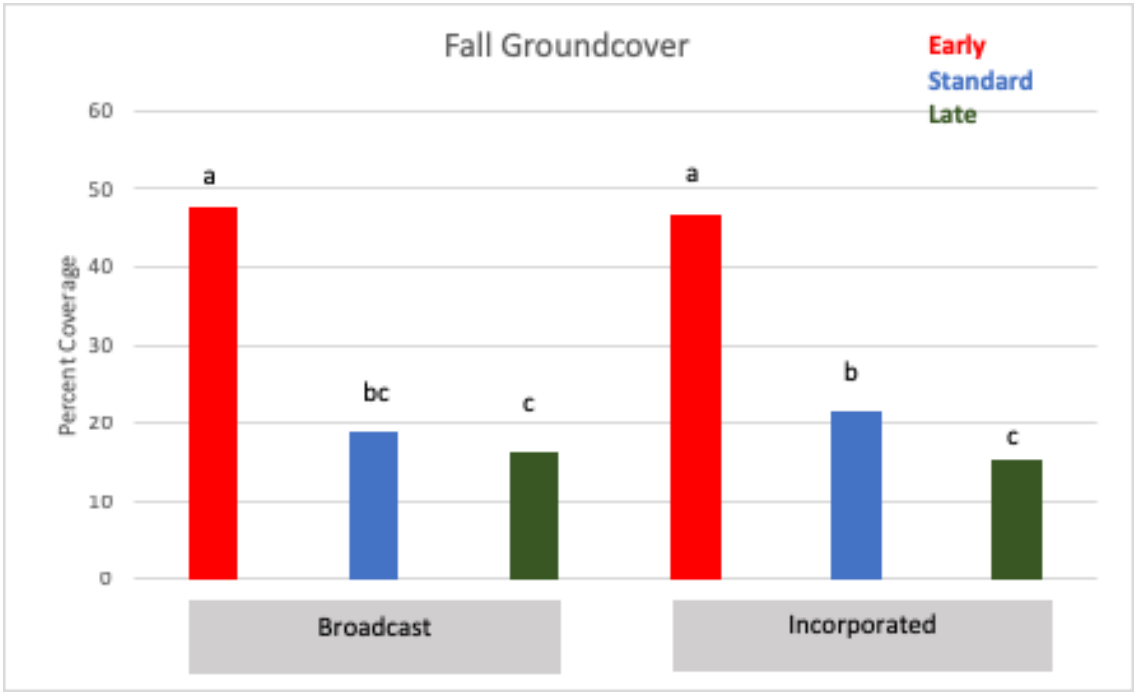

Figure 4-12: Planting method x planting date interaction effects on percent fall ground coverage at UD Site 1-L-2016 as estimated from photographs taken in December 2015 by Canopeo (Mean separations were completed on log-transformed data).

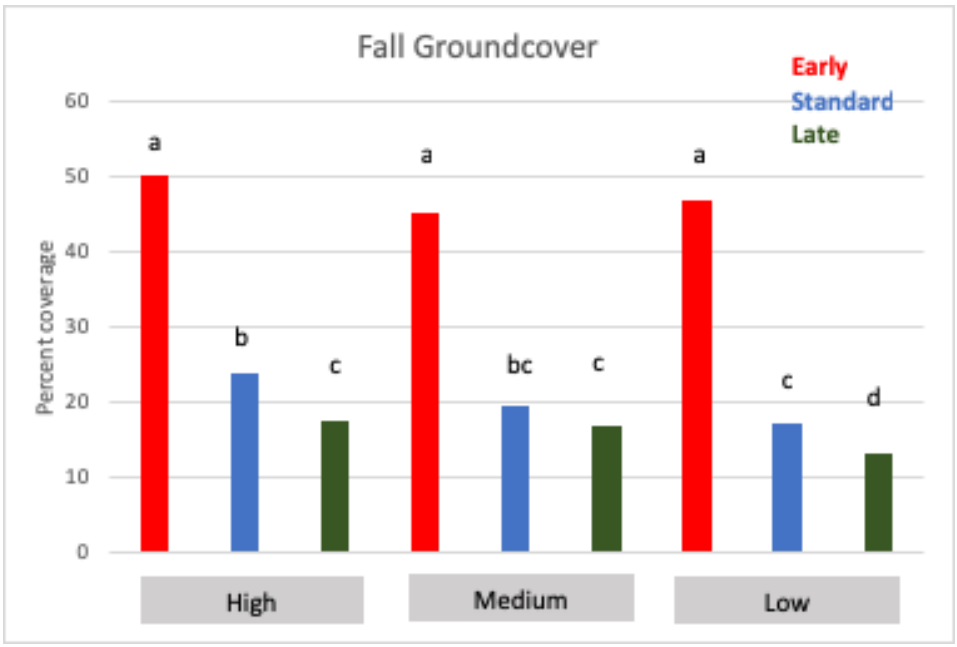

Figure 4-13: Seeding rate x planting date interaction effects on percent fall ground coverage at UD Site 1-L-2016 as estimated from photographs taken in December 2015 by Canopeo (Mean separations were completed on log-transformed data)

Spring groundcover results were generally similar to fall coverage, but there were some notable differences. Again, early planting dates produced more spring coverage than late dates among all species/mixes, but only significantly more than standard dates for rye and both rye-clover mixes (Figure 4-14). Unlike fall coverage, wheat planted at the early date did not have less spring coverage and all five species/mixes had similar coverage. The variable rye/static clover mix planted at the late date had less spring coverage than most other treatment combinations. At high and low seeding rates, the planting method did not significantly affect spring cover (Figure 4-15). However, broadcasting at the medium rate produced less spring coverage than broadcasting at the high rate and incorporating at the high and medium rates.

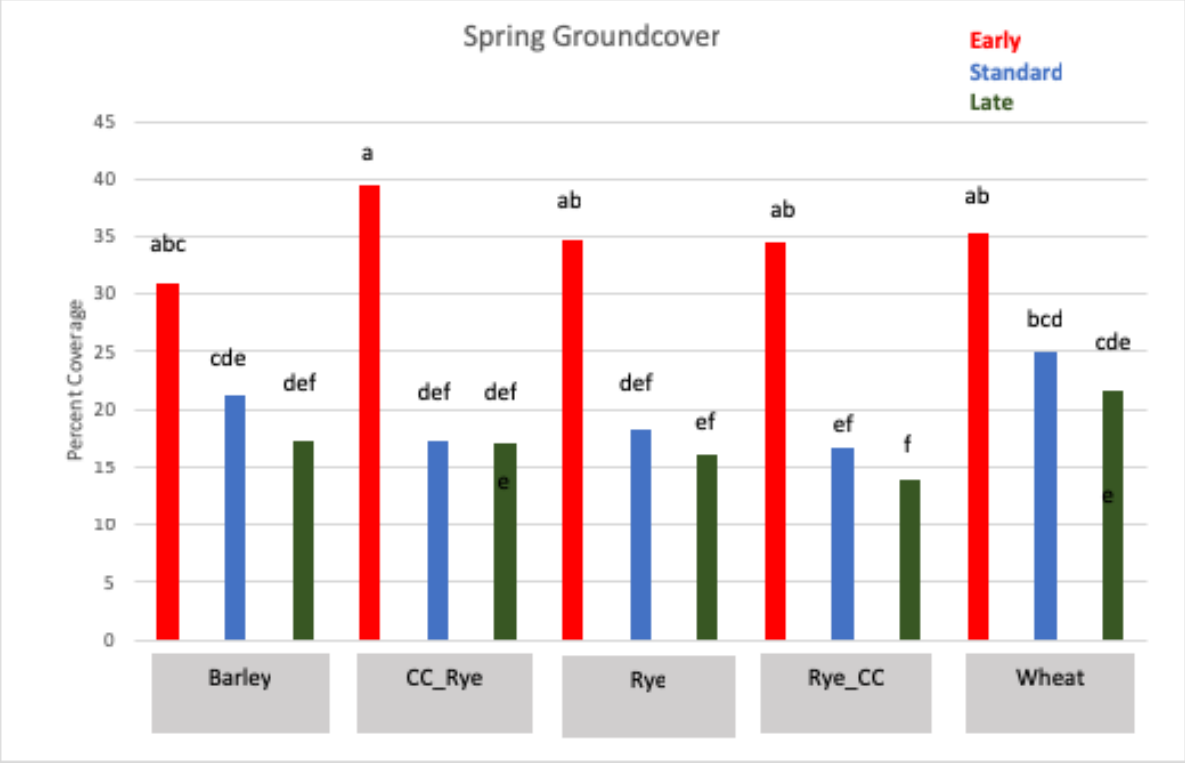

Figure 4-14: Species x planting date interaction effects on percent spring ground coverage at UD Site 1-L-2016 as estimated from photographs taken in spring 2015 by Canopeo (significant differences determined from log-transformed data).

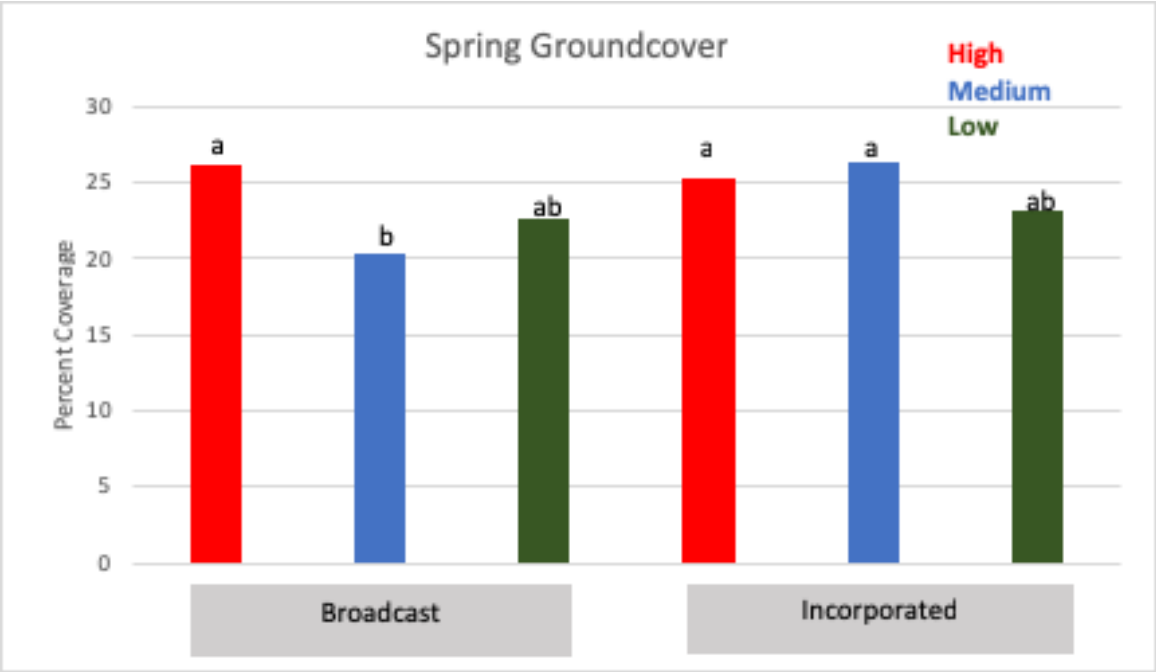

Figure 4-15: Planting method x seeding rate interaction effects on percent spring ground coverage at UD Site 1-L-2016 as estimated from photographs taken in spring 2015 by Canopeo (significant differences determined from log-transformed data).

4.2.2. Spring Aboveground Biomass

Aboveground biomass results for this year at this site showed that crop species had little effect at each planting date. In fact, at the standard and late planting dates, there was no significant difference of biomass between species. However, at the early planting date wheat had less biomass than the variable clover/static rye mix (Figures 4-16, 4-17, and 4-18 and Tables A-12, A-13, and A-14).

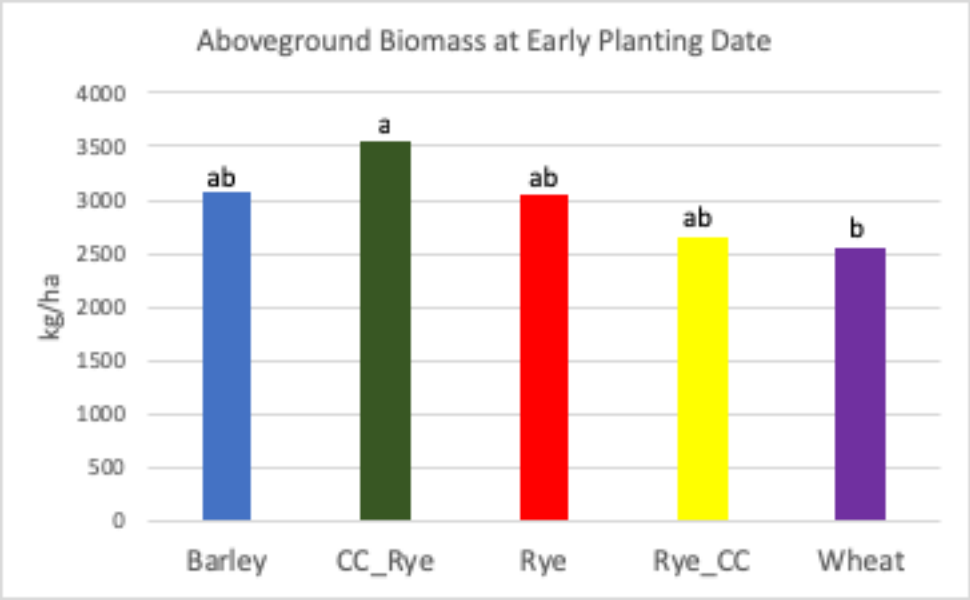

Figure 4-16: Species effects on dried aboveground biomass for crops planted on September 9, 2015 at UD Site 1-L-2016, collected in spring, 2016.

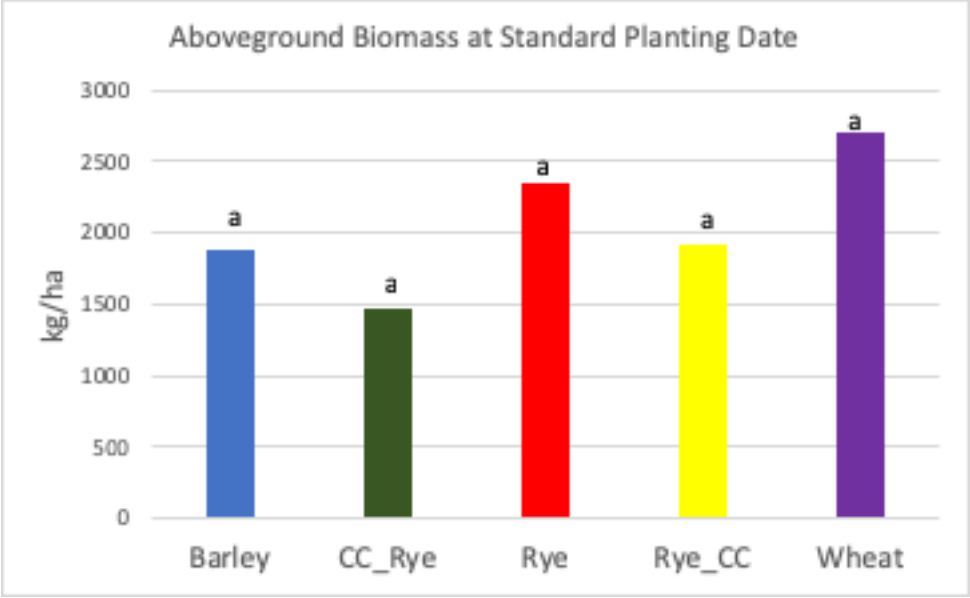

Figure 4-17: Species effects on dried aboveground biomass for crops planted on October 1, 2015 at UD Site 1-L-2016, collected in spring, 2016.

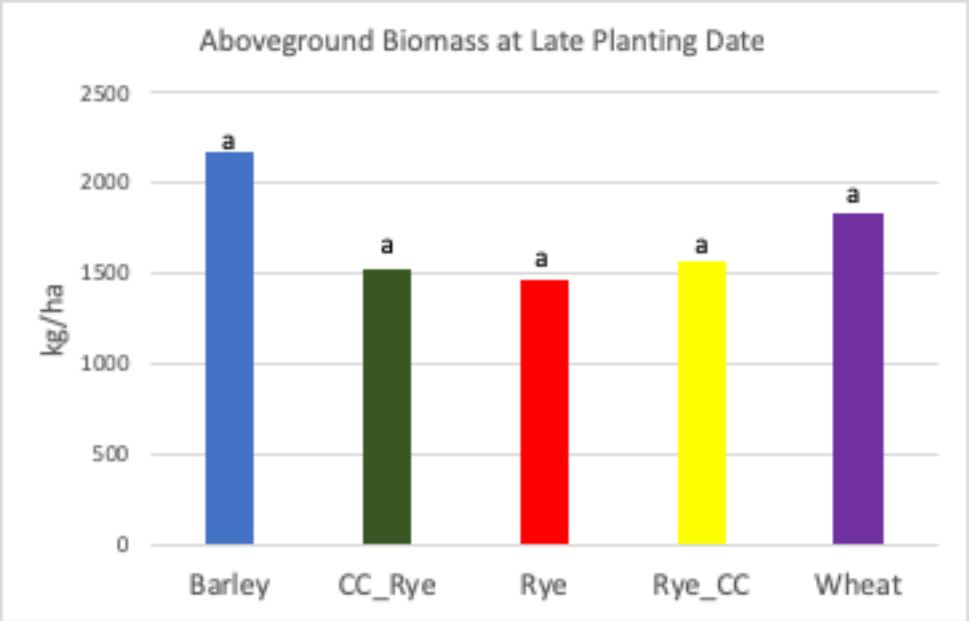

Figure 4-18: Species effects on dried aboveground biomass for crops planted on October 20, 2015 at UD Site 1-L-2016, collected in spring, 2016.

4.2.3. Spring Nitrogen Removal

Again, N removal by cover crops is inherently tied to their biomass. Therefore, the data for N removal showed similar results with no significant differences between cover crop species at the standard and late dates. Also similar to biomass results, wheat had less N removal than CC_Rye, but in this case the variable rye/static clover mix also had significantly less N removal than CC_Rye (Figures 4-19, 4-20 and 4-21 and Tables A-15, A-16, and A-17).

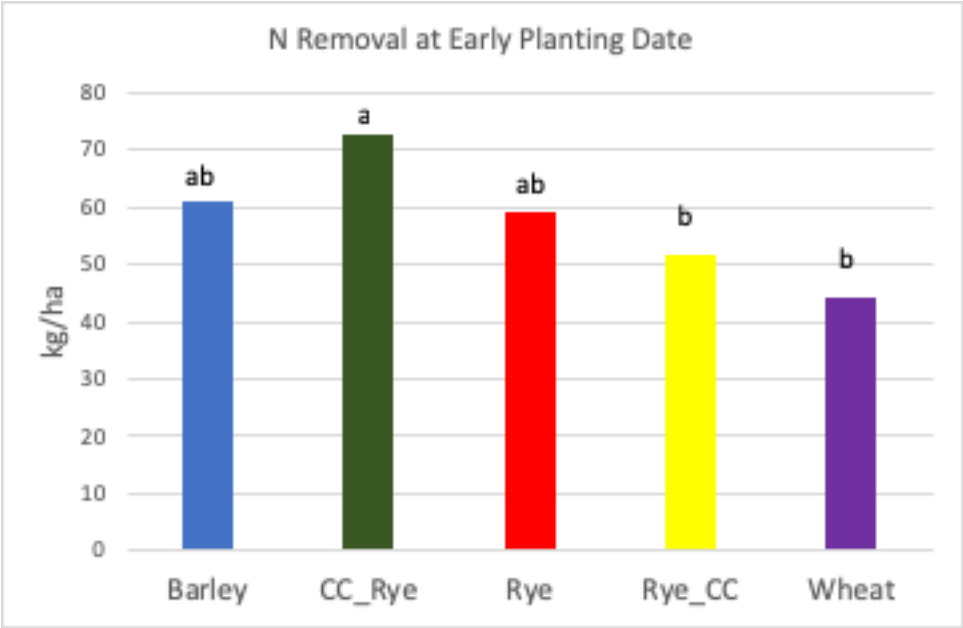

Figure 4-19: Species effects on N removal for crops planted on September 9, 2015 at UD Site 1-L-2016, collected in spring, 2016.

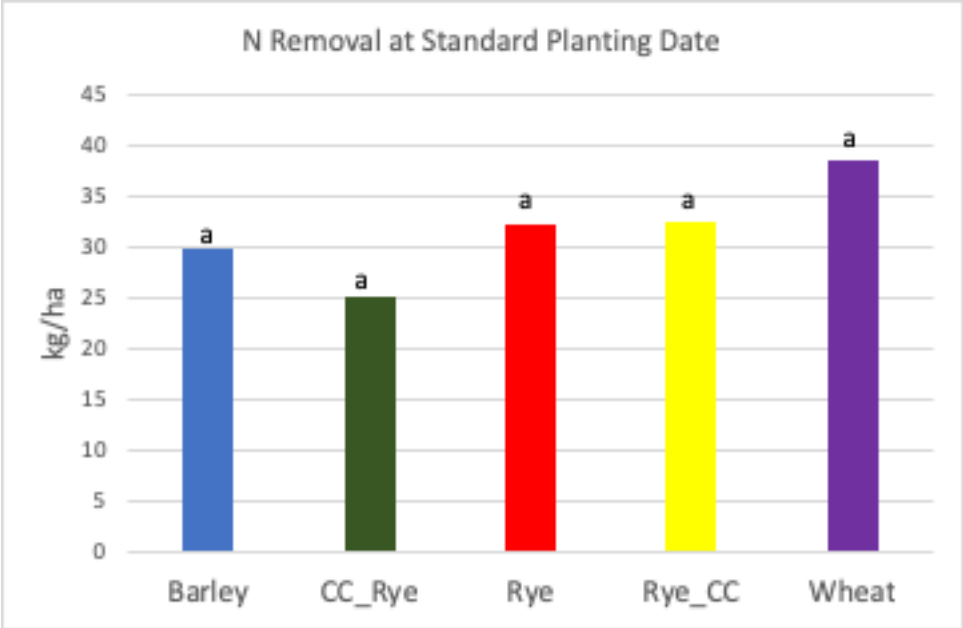

Figure 4-20: Species effects on N removal for crops planted on October 1, 2015 at UD Site 1-L-2016, collected in spring, 2016.

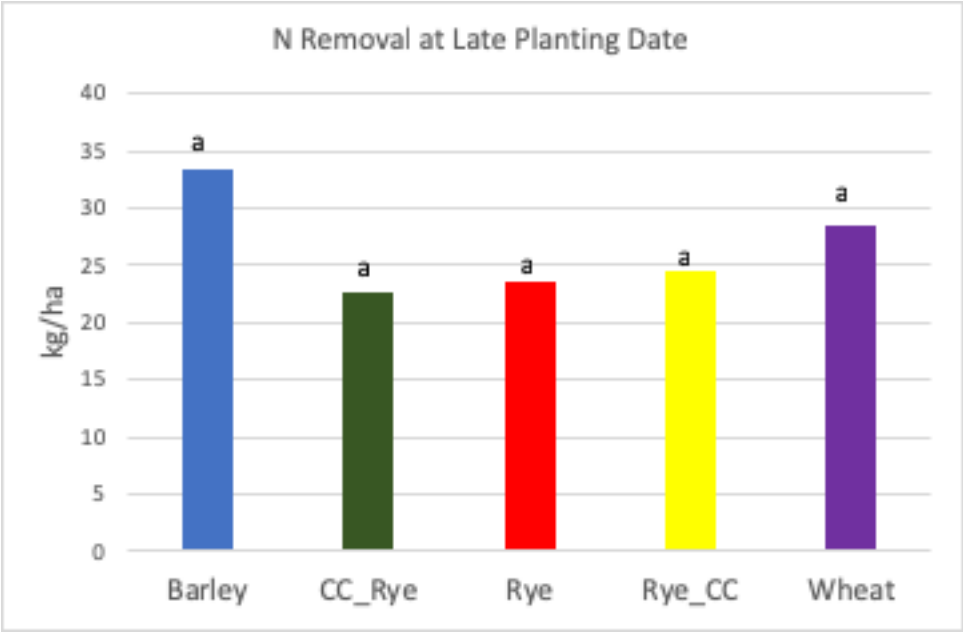

Figure 4-21: Species effects on N removal for crops planted on October 20, 2015 at UD Site 1-L-2016, collected in spring, 2016.

4.2.4. Total Soil Nitrogen

For 0-15 cm samples, the only significant species effect was that barley plots had significantly lower soil N than rye (Figure 4-22 and Table A-18). All other treatments effects and interactions were not statistically significant. No treatments or interactions had any significant effects on total soil N for 15-30 cm samples (Figures 4-23 and 4-24; Tables A-19 and A-20).

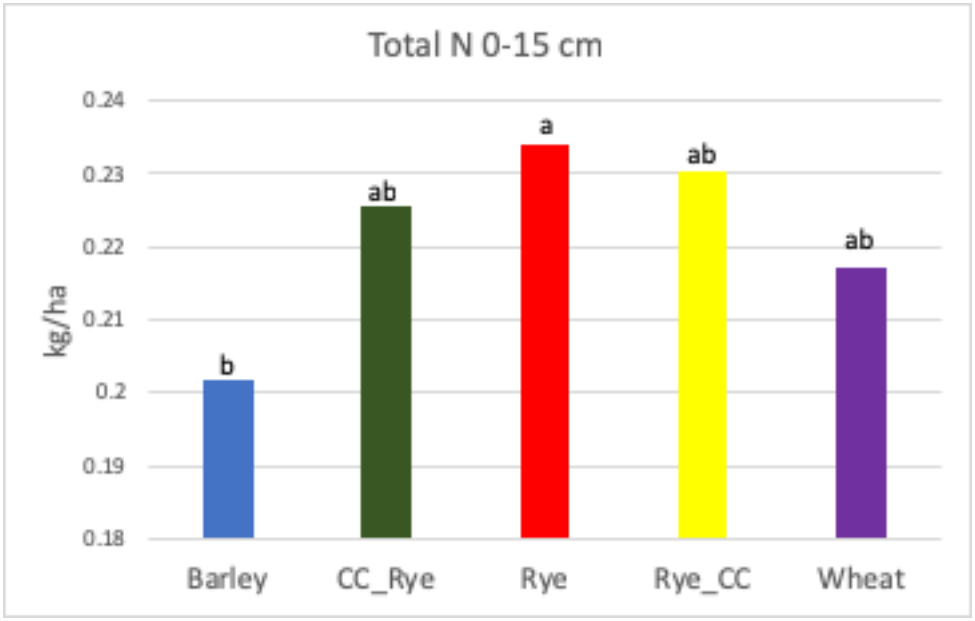

Figure 4-22: Species effects on total Soil N from 0-15 cm samples collected in spring, 2016 at UD Site 1-L-2016.

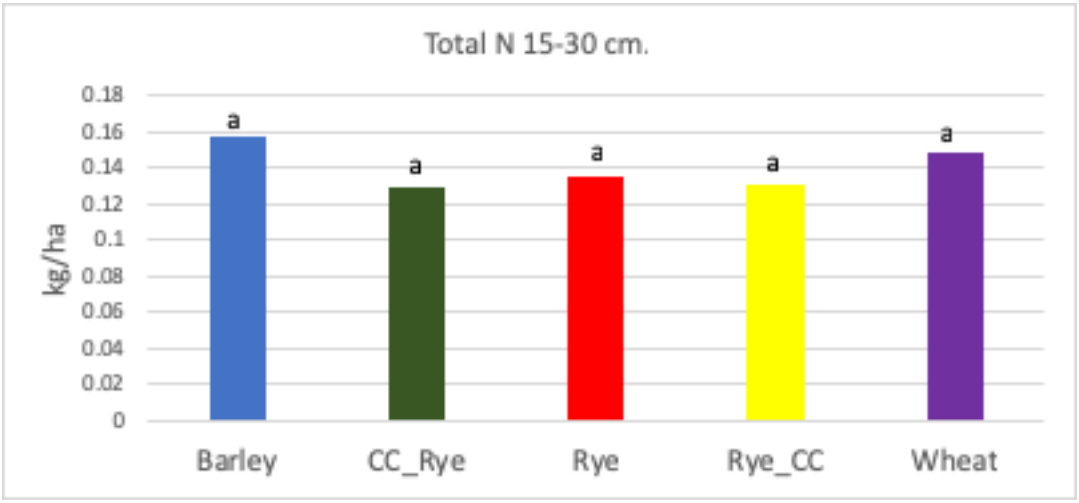

Figure 4-23: Species effects on total Soil N from 15-30 cm samples collected in spring, 2016 at UD Site 1-L-2016

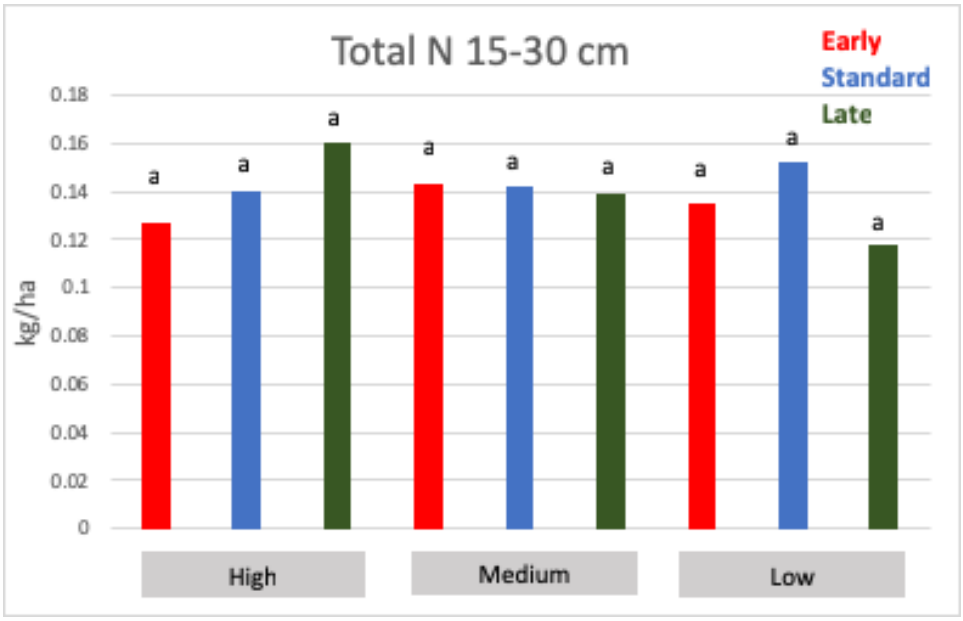

Figure 4-24: Seeding rate x planting date interaction effects on total Soil N from 15-30 cm samples collected in spring, 2016 at UD Site 1-L-2016

4.3. UD Site 2-C-2016

4.3.1. Groundcover

The low seeding rate resulted in lower fall cover than the medium and high seeding rates (Figure 4-25 and Table A-21). This effect was not as clear for spring coverage due to a significant crop x rate interaction. There was no rate effect on barley, rye, wheat, and the Rye_CC mix. However, the CC_Rye planted at the high seeding rate resulted in better spring coverage than when this mix planted the low seeding rate. Additionally, both rye/crimson clover mixes had greater spring coverage than the other three species, regardless of seeding rate with the exception of the CC_Rye mix when planted at the low rate; coverage for this mix was similar to the rye crop planted at the medium seeding rate (Figure 4-28 and A-24).

Fall coverage at this site also showed a crop x method interaction (Figure 4-26 and A-22), where broadcasted rye resulted in significantly less cover than when rye seed was incorporated. In addition, incorporating rye and rye/crimson clover mixes produced more fall cover than

planting barley or wheat with either method. Conversely, spring ground cover was not affected by planting method (Figure 4-27 and Table A-23).

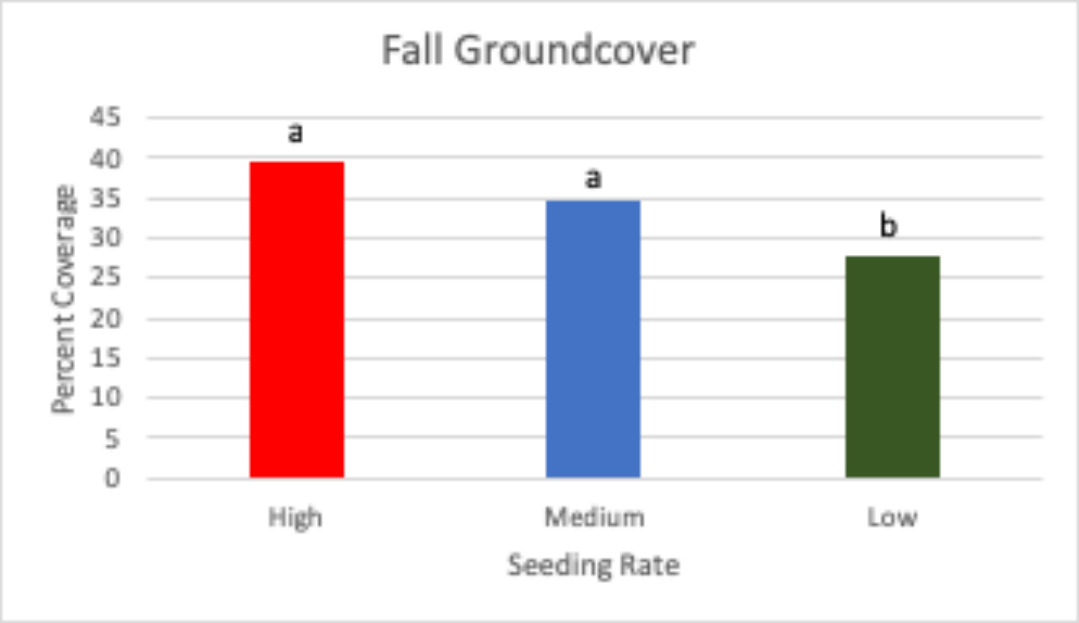

Figure 4-25: Seeding rate effects on percent fall ground coverage at UD Site-2-C-2016 as estimated from photographs taken in December 2015 by Canopeo

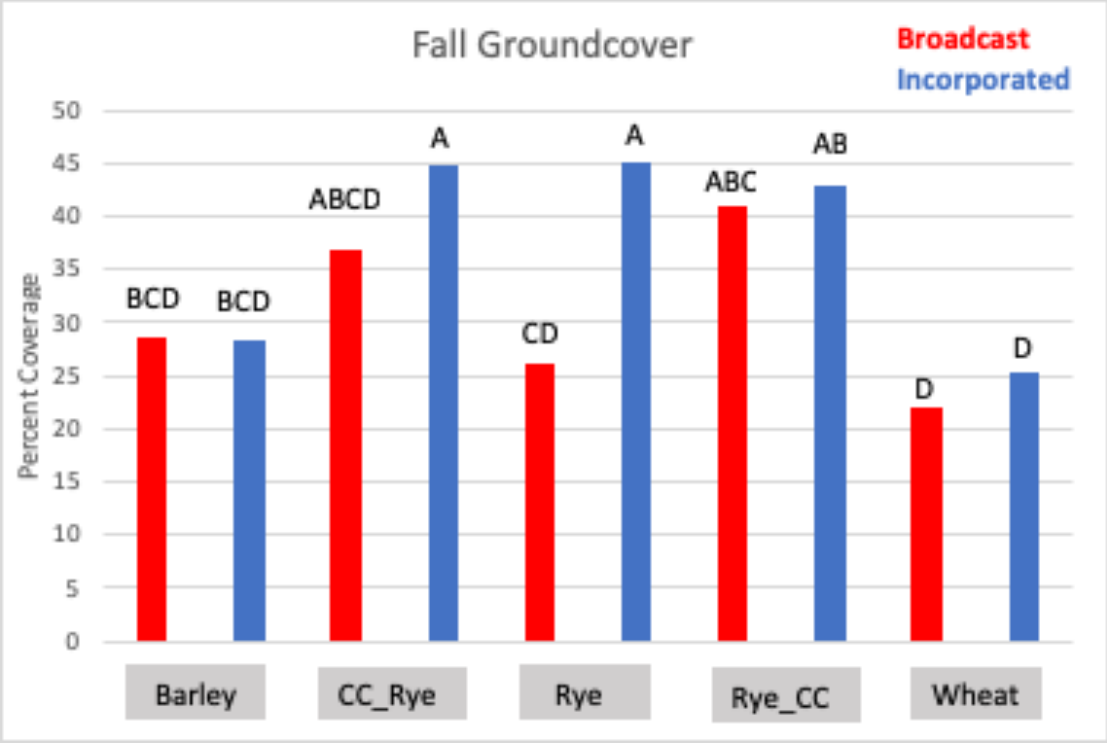

Figure 4-26: Species x planting method effects on percent fall ground coverage at UD Site-2-C-2016 as estimated from photographs taken in December 2015 by Canopeo.

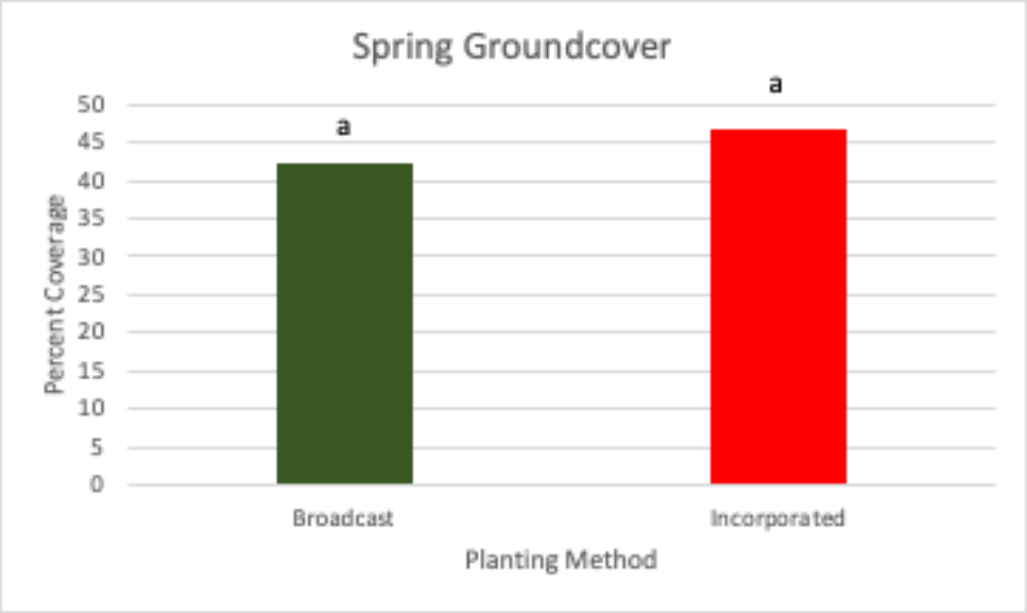

Figure 4-27: Planting method effects on percent spring ground coverage at UD Site-2-C-2016 as estimated from photographs taken in spring 2016 by Canopeo

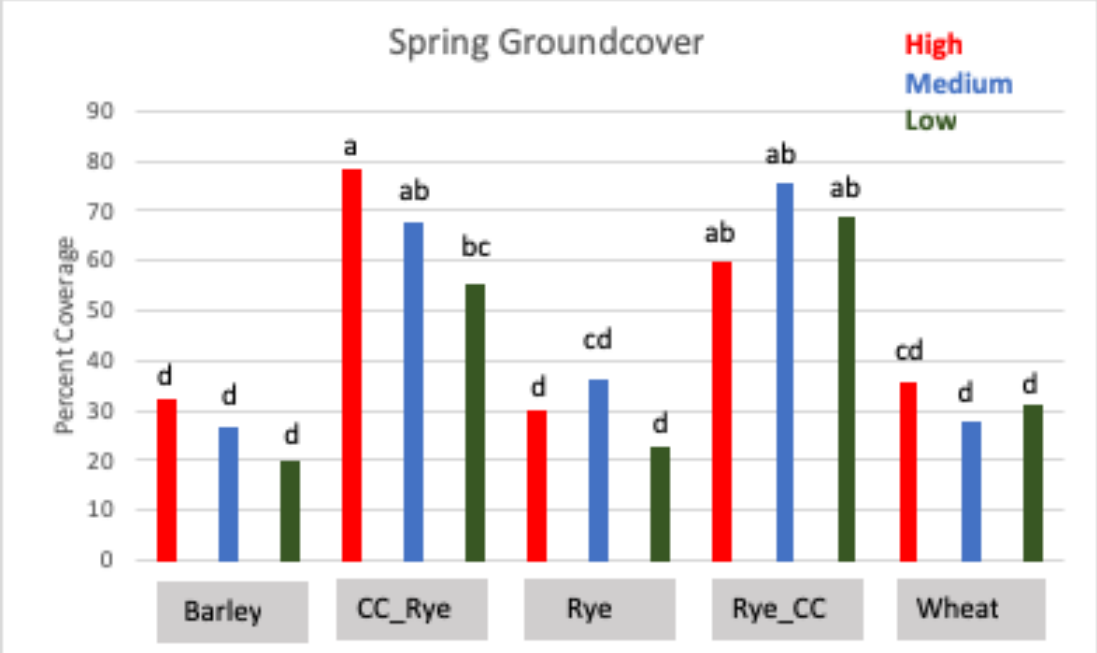

Figure 4-28: Species x seeding rate effects on percent spring ground coverage at UD Site-2-C-2016 as estimated from photographs taken in spring 2016 by Canopeo

4.3.2. Spring Aboveground Biomass

Biomass production at this site was not affected by seeding rate or planting method; no treatment interactions were significant. Only cover crop species affected aboveground biomass measurements, where all three monocultures produced less biomass than the two rye and crimson clover mixes (Figure 4-29 and Table A-25).

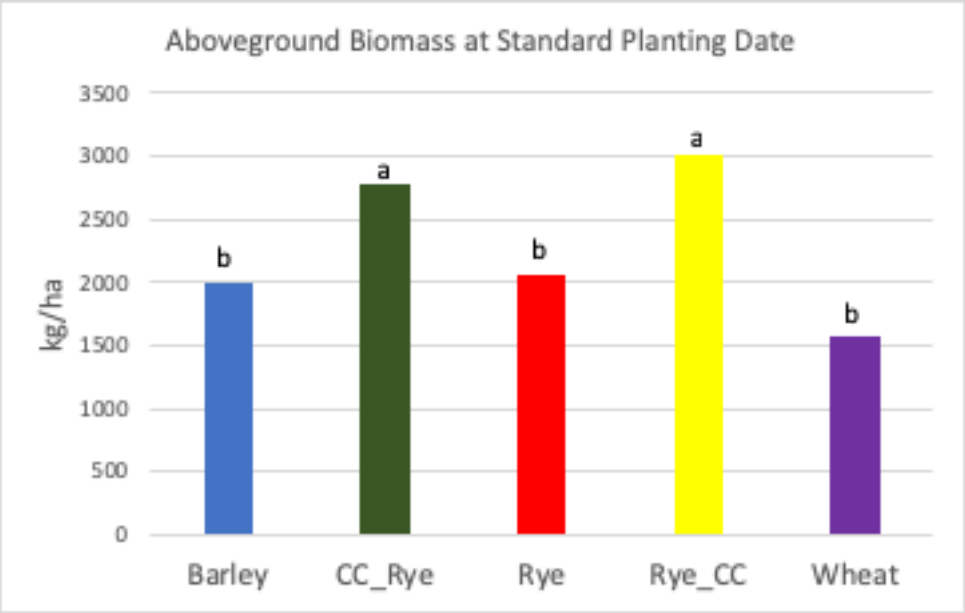

Figure 4-29: Species effects on dried aboveground biomass for crops planted on October 8, 2015 collected in spring, 2016 at UD Site-2-C-2016

4.4. UD Site 3-M-2016

4.4.1. Groundcover

Crop species did not show effects on fall or spring coverage (Figures 4-30 and 4-31 and Tables A-26 and A-27). Furthermore, only planting methods significantly affected fall coverage; no other treatment effects or interactions were significant. Cover crop seeds that were incorporated into the soil when planted produced about 26% more fall cover than seeds that were broadcasted, even though seeding rates for broadcasted seed were increased by 30% (Figure 4-32 and Table A-28). This potentially indicates higher germination rates because of the greater seed

to soil contact in incorporated plots. However, we reported no treatment effects or interactions on spring coverage, suggesting that fall coverage did not influence spring coverage, potentially because of spring weed coverage.

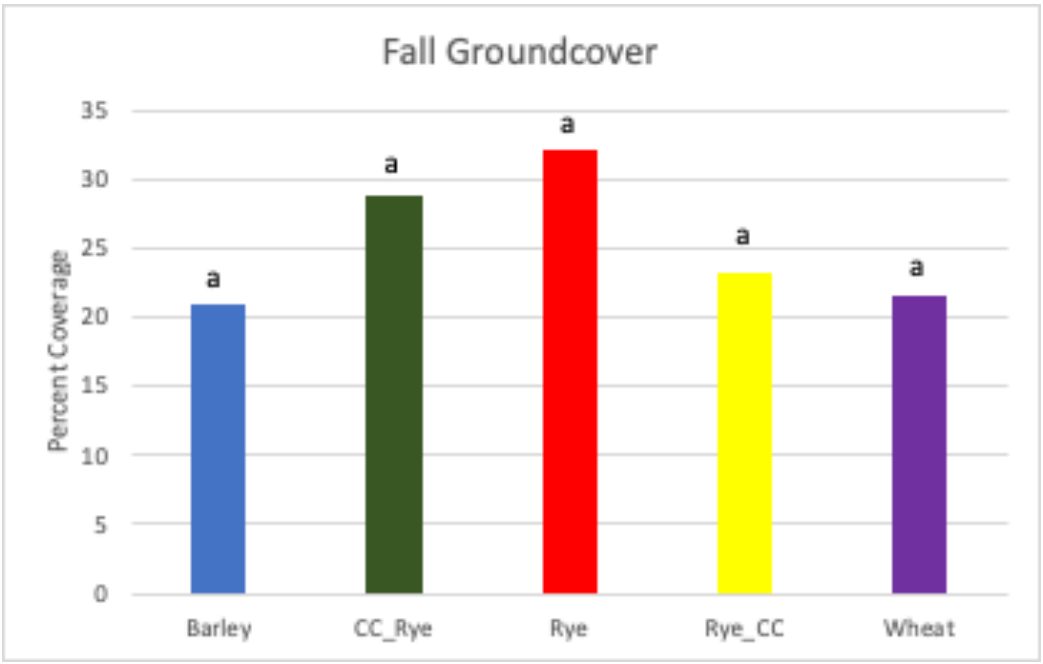

Figure 4-30: Species effects on percent fall ground coverage at UD Site-3-M-2016 as estimated from photographs taken in December 2015 by Canopeo.

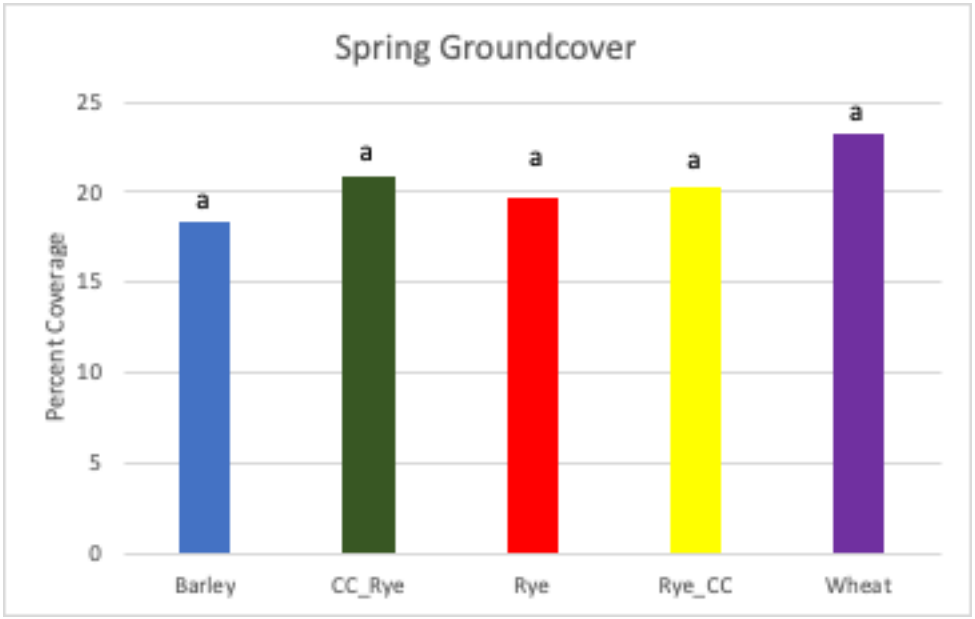

Figure 4-31: Species effects on percent spring ground coverage at UD Site-3-M-2016 as estimated from photographs taken in spring 2015 by Canopeo.

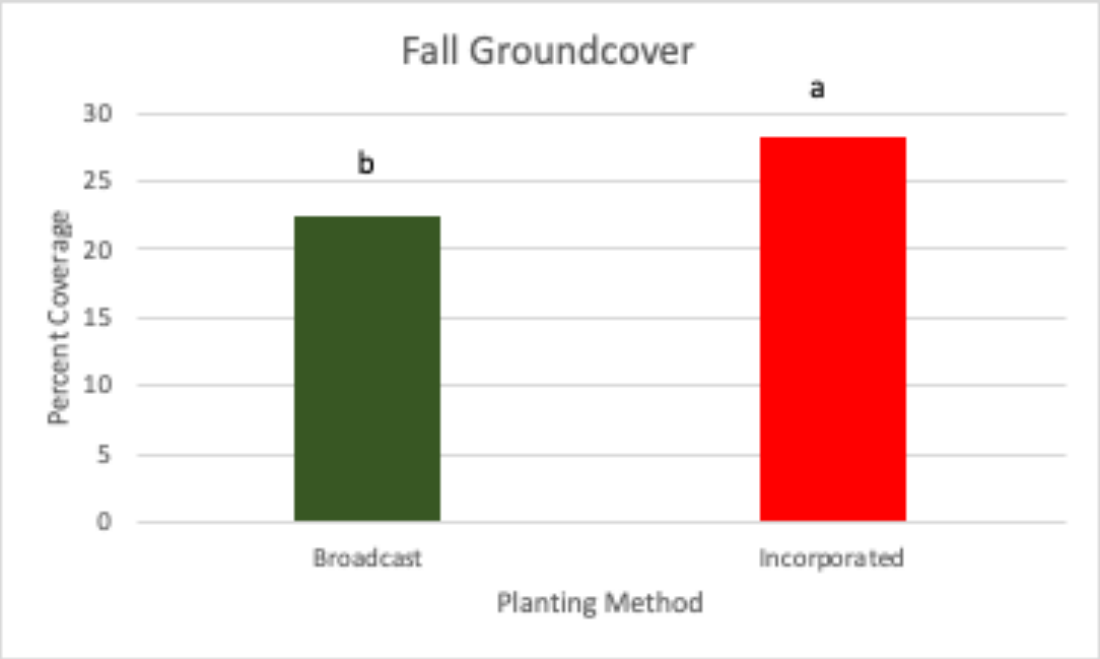

Figure 4-32: Species effects on percent fall ground coverage at UD Site-3-M-2016 as estimated from photographs taken in December 2015 by Canopeo

4.5 UD Site 1-G-2018

4.5.1. Groundcover

Fall groundcover was not assessed at this site due to a lapse in funding. Spring coverage data showed four-way interactions, but it was difficult to describe all significant interactions (Table A-29). Therefore, the data was separated by treatments to facilitate discussion of the treatment effects. At the early planting dates, both sets of rye/clover mixes had higher spring groundcover than any monoculture. Barley had significantly less spring coverage than all other species at this planting date (Figure 4-33 and Table A-30).

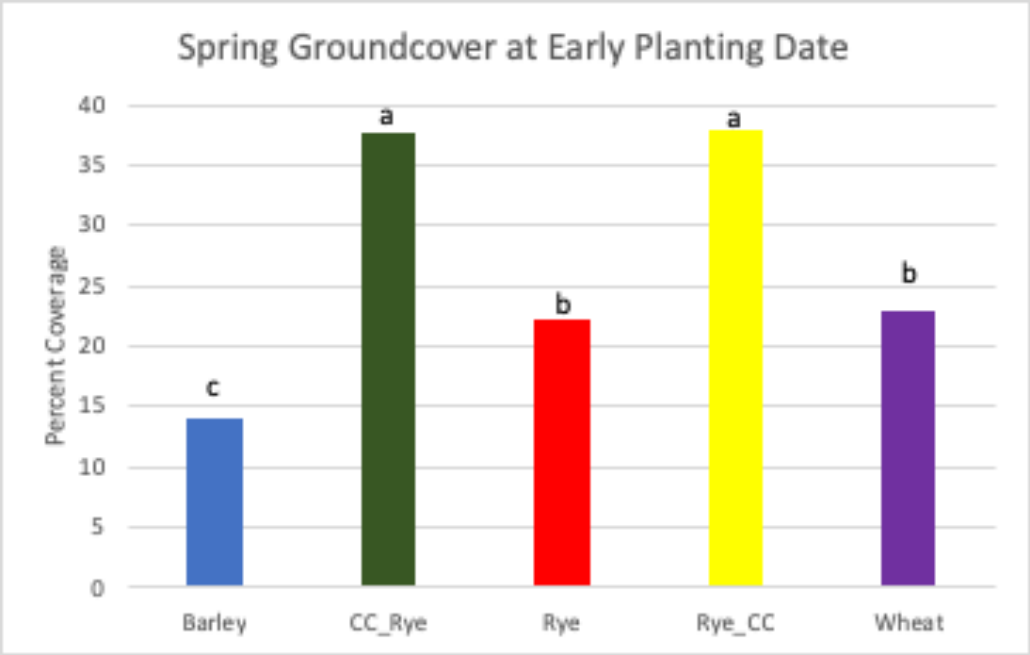

Figure 4-33: Species effects on percent spring ground coverage at UD Site-1-G-2018 as estimated from photographs taken in spring 2018 by Canopeo.

At the late planting date, the log-transformed data showed three-way crop x method x rate interactions. Due to the large number of interactions, Figure 4-34 isolates the highest and lowest performing treatments, showing spring coverage percentages (Table A-31). The Rye_CC mix (static clover and variable rye rates) when incorporated at the high rate outperformed the greatest number of other treatment combinations and barley at the high rate when broadcasted performed worse than the greatest number of treatment combinations. Furthermore, the four best performing treatment interactions were incorporated and the five worst were broadcasted, but method did not consistently affect other interaction results. Also, the high rates of Rye_CC and wheat were top performers when incorporated, but worst performers when broadcasted. When separated by crop, all five species had statistically higher coverage for the early planting date over the late date (Figure 4-35 and Table A-32). Also, notable is the rate x method interactions

across all planting dates had no significant effect on barley and rye coverage (Figures 4-36 and 4-37 and Tables A-33 and A-34).

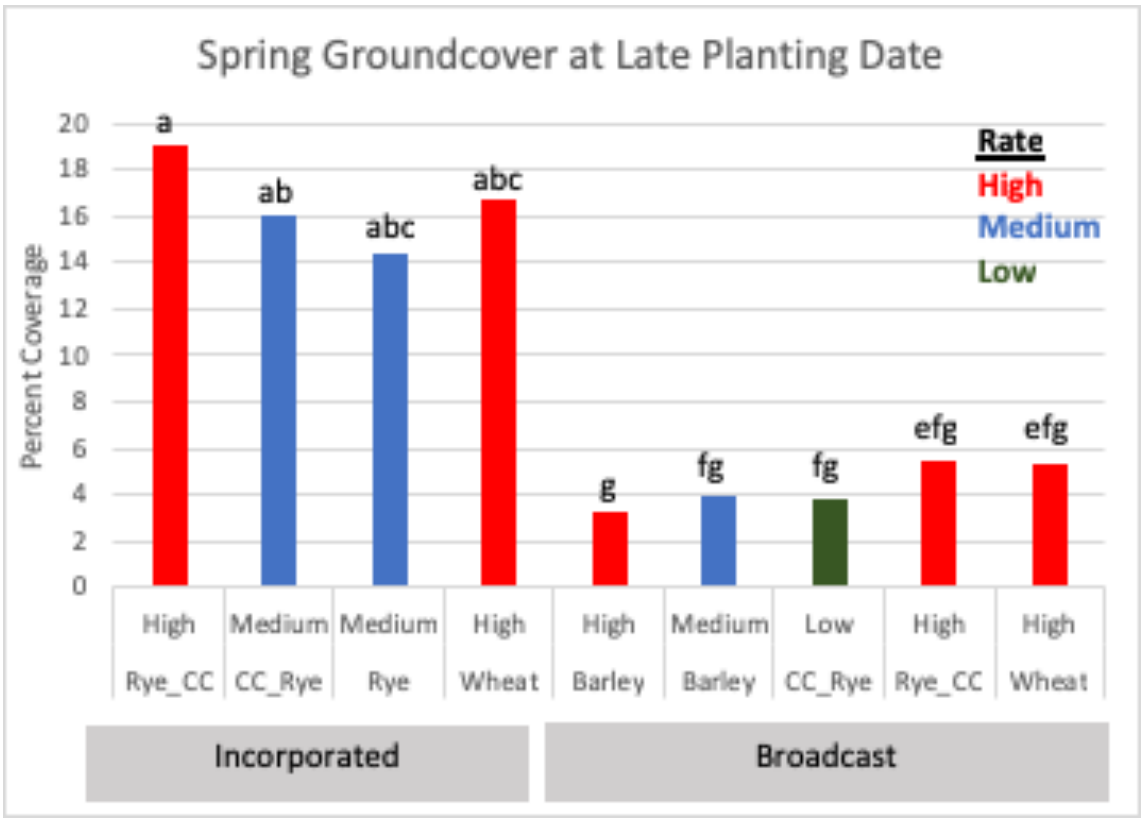

Figure 4-34: Effects of selected treatment interactions on percent spring ground coverage at UD Site-1-G-2018 for crops planted on October 18, 2017 as estimated from photographs taken in spring 2018 by Canopeo.

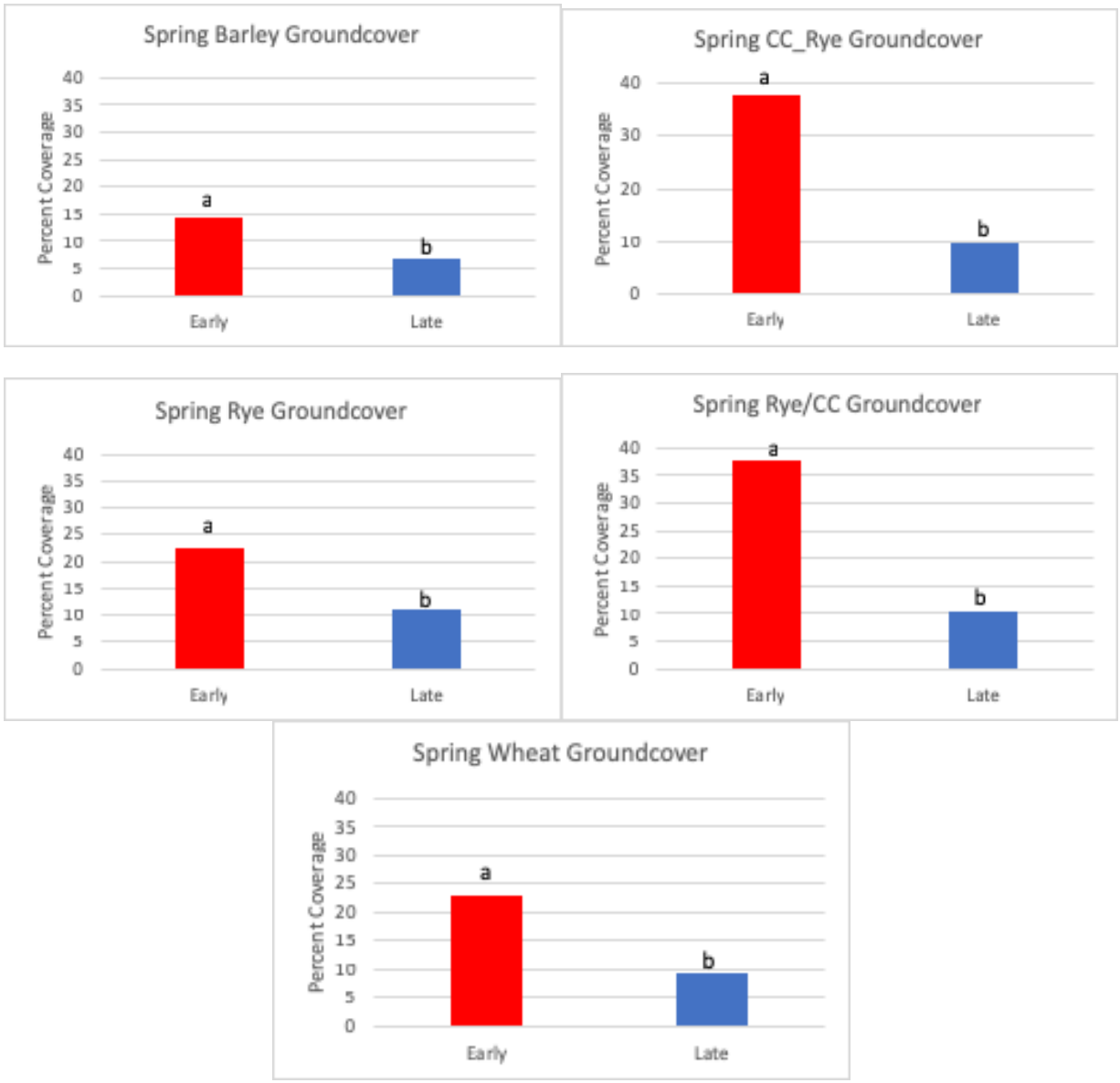

Figure 4-35. Planting date effects on percent spring ground coverage at UD Site-1-G-2018 for crops planted on October 18, 2017 as estimated from photographs taken in spring 2018 by Canopeo. Planting dates were planted on September 11, 2017 and October 18, 2017.

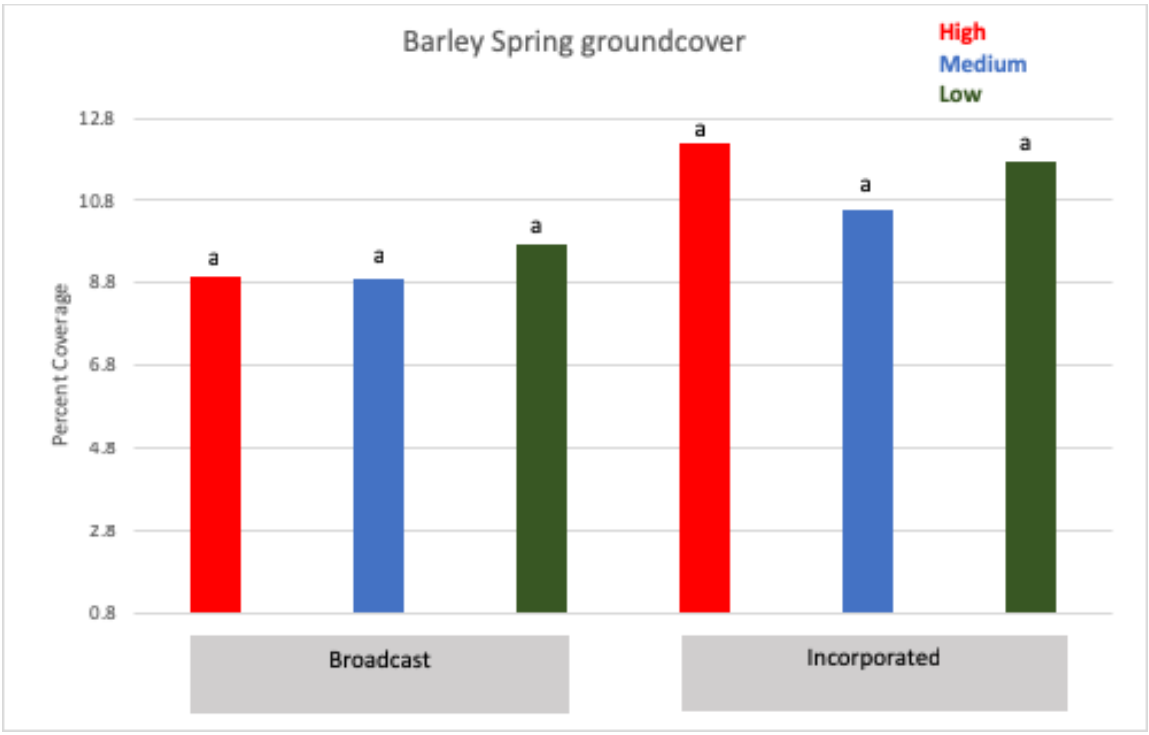

Figure 4-36: Planting method x seeding rate interaction effects on percent spring ground coverage at UD Site-1-G-2018 for barley as estimated from photographs taken in spring 2018 by Canopeo.

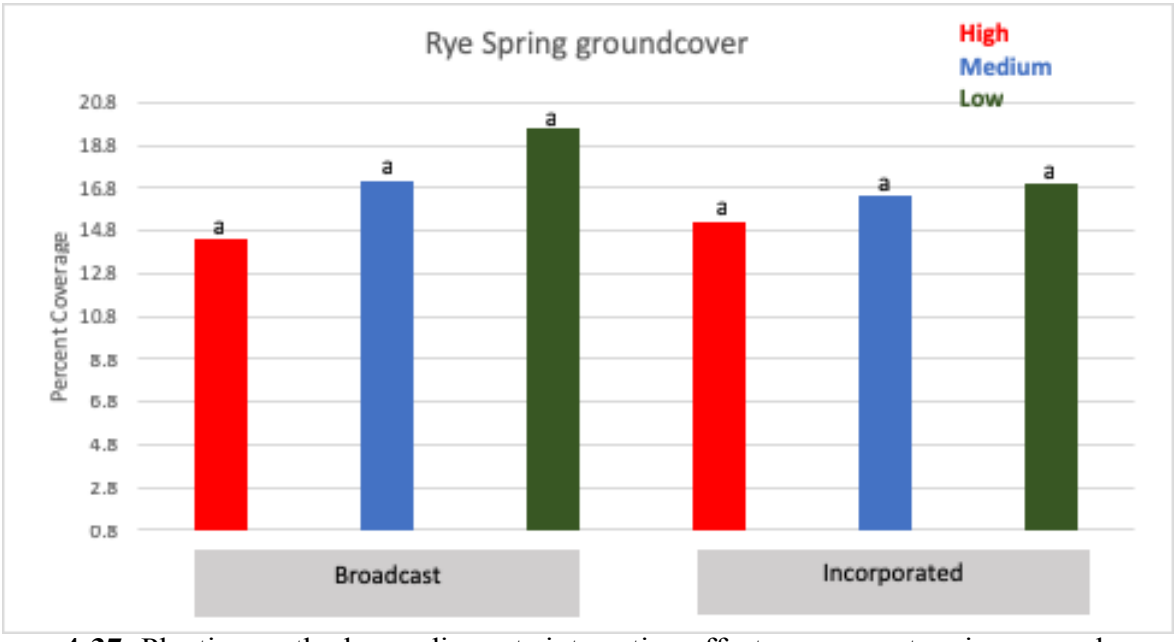

Figure 4-37: Planting method x seeding rate interaction effects on percent spring ground coverage at UD Site-1-G-2018 for rye as estimated from photographs taken in spring 2018 by Canopeo.

Across all three seeding rates, the crop x time interactions showed that the early planting dates for both sets of clover/rye mixes resulted in more spring coverage than all other treatments (Figures 4-38, 4-39, and 4-40 and Tables A-35, A-36, and A-37). Early planted rye and wheat each produced more spring coverage than all remaining monoculture treatment combinations. However, there were minor differences between seeding rates. At high rates, late planted barley had less coverage than early planted barley. At medium rates, late planted barley had less coverage than early planted barley and the late planted rye. And at low rates, barley and the two mixes at the late date performed worse than the early planted barley.

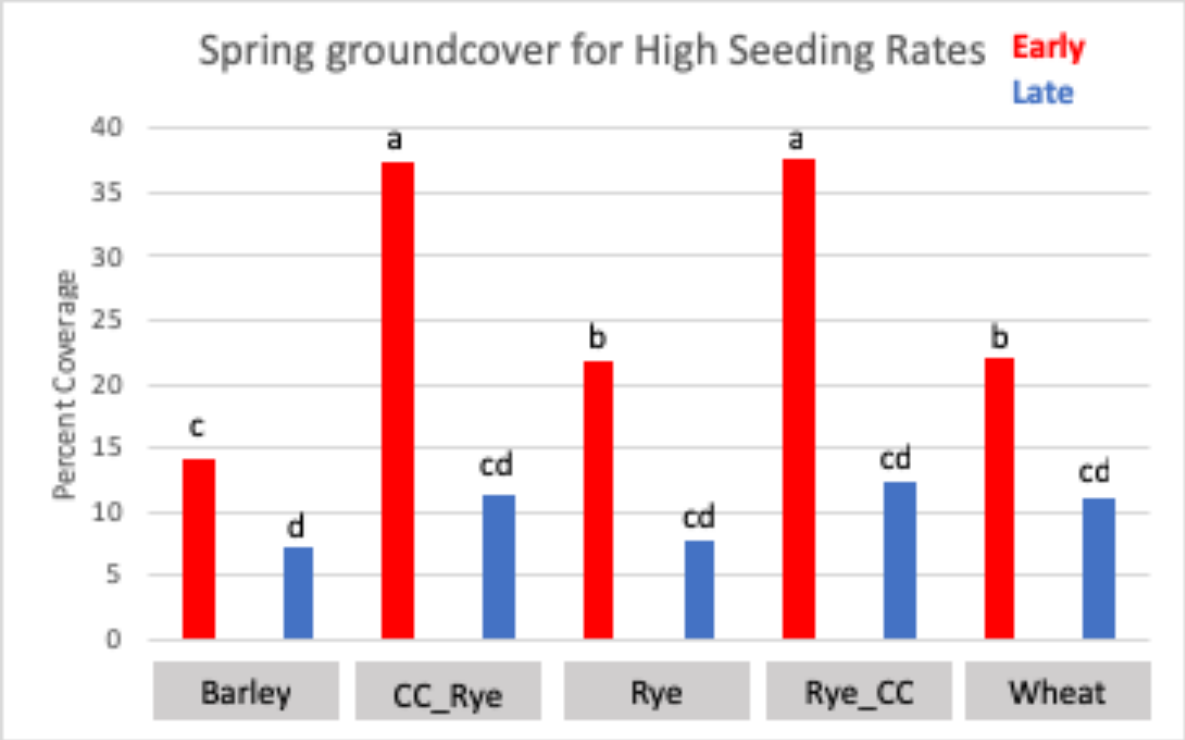

Figure 4-38: Species x planting date interaction effects on percent spring ground coverage at UD Site-1-G-2018 for cover crops planted with **high seeding rates** as estimated from photographs taken in spring 2018 by Canopeo. The early date was planted on September 11, 2017 and the late date was planted on October 18, 2017.

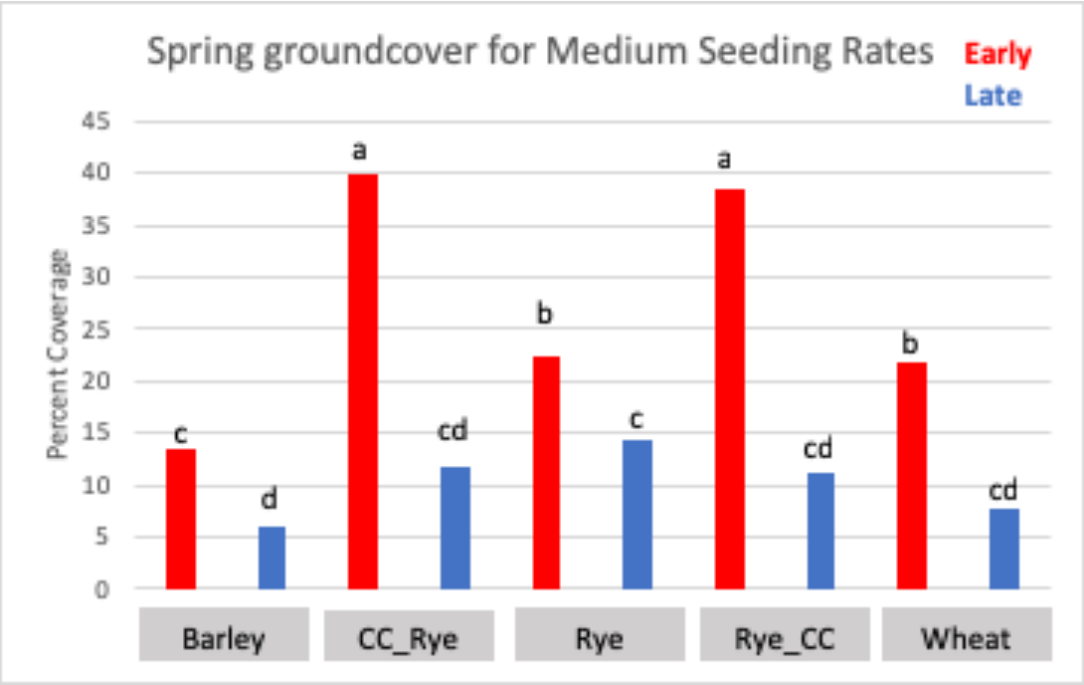

Figure 4-39: Species x planting date interaction effects on percent spring ground coverage at UD Site-1-G-2018 for cover crops planted with **medium seeding rates** as estimated from photographs taken in spring 2018 by Canopeo. The early date was planted on September 11, 2017 and the late date was planted on October 18, 2017.

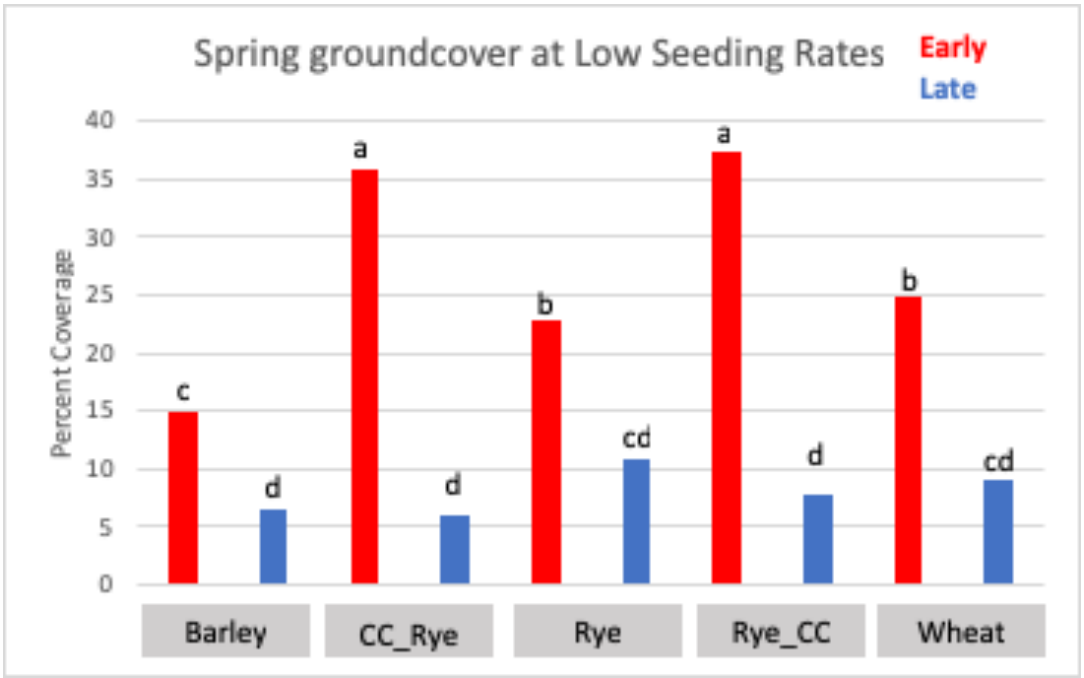

Figure 4-40: Species x planting date interaction effects on percent spring ground coverage at UD Site-1-G-2018 for cover crops planted with **low seeding rates** as estimated from photographs taken in spring 2018 by Canopeo. The early date was planted on September 11, 2017 and the late date was planted on October 18, 2017.

The high seeding rate treatments also resulted in a crop x method x time interaction effect on spring coverage (Figure 4-41 and Table A-38). The most notable observation here is that at the late planting date, Rye_CC and wheat had lower spring coverage when broadcasted. The other species and mixes did not show this same effect; no species or mix had a difference in spring coverage due to planting method when planted early. Also, for high seeding rates, the early planted rye/crimson clover mixes outperformed all other treatments, regardless of planting method.

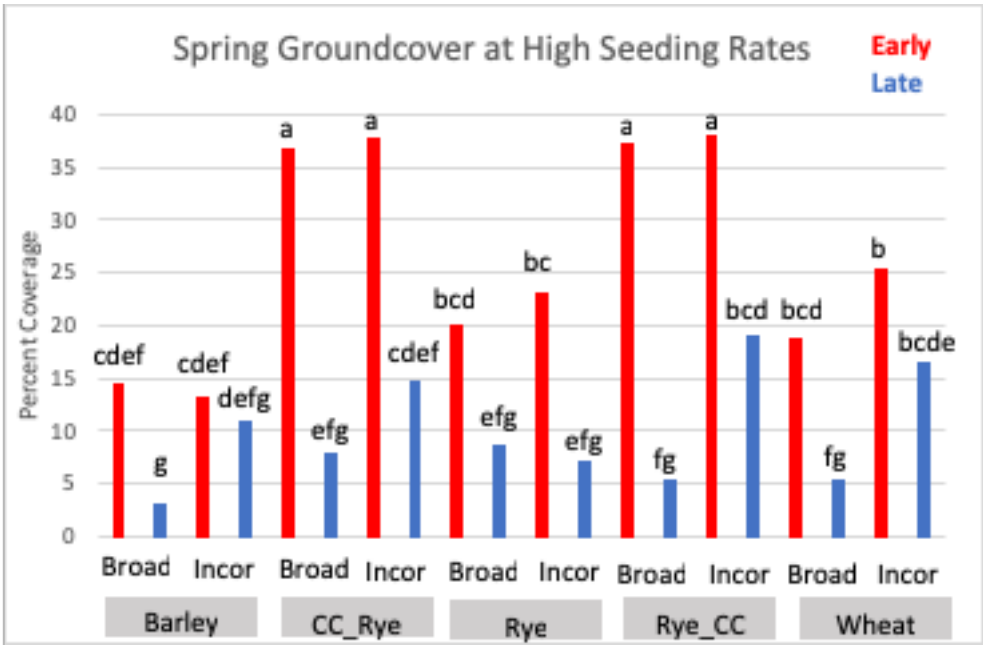

Figure 4-41: Crop, method, and planting date interaction effects on percent spring ground coverage for cover crops planted with **high seeding rates** at Site 1-G-2018 as estimated from photographs taken in spring 2018 by Canopeo. The early date was planted on September 11, 2017 and the late date was planted on October 18, 2017.

4.5.2. Spring Aboveground Biomass

The only method x rate interaction effects on biomass were that broadcasted crops at the high rate had less biomass than crops incorporated at the low rate (Figure 4-42 and Table A-39). If determining which seeding rate to use for each crop, the data from this site shows that for

barley, rye, Rye_CC, and wheat, there was no significant difference in biomass between seeding rates. However, the variable clover/static rye (CC_Rye) mix had higher biomass when planted at the low seeding rate when compared to the high seeding rate. All other interactions produced similar biomass to each other (Figure 4-43 and Table A-40).

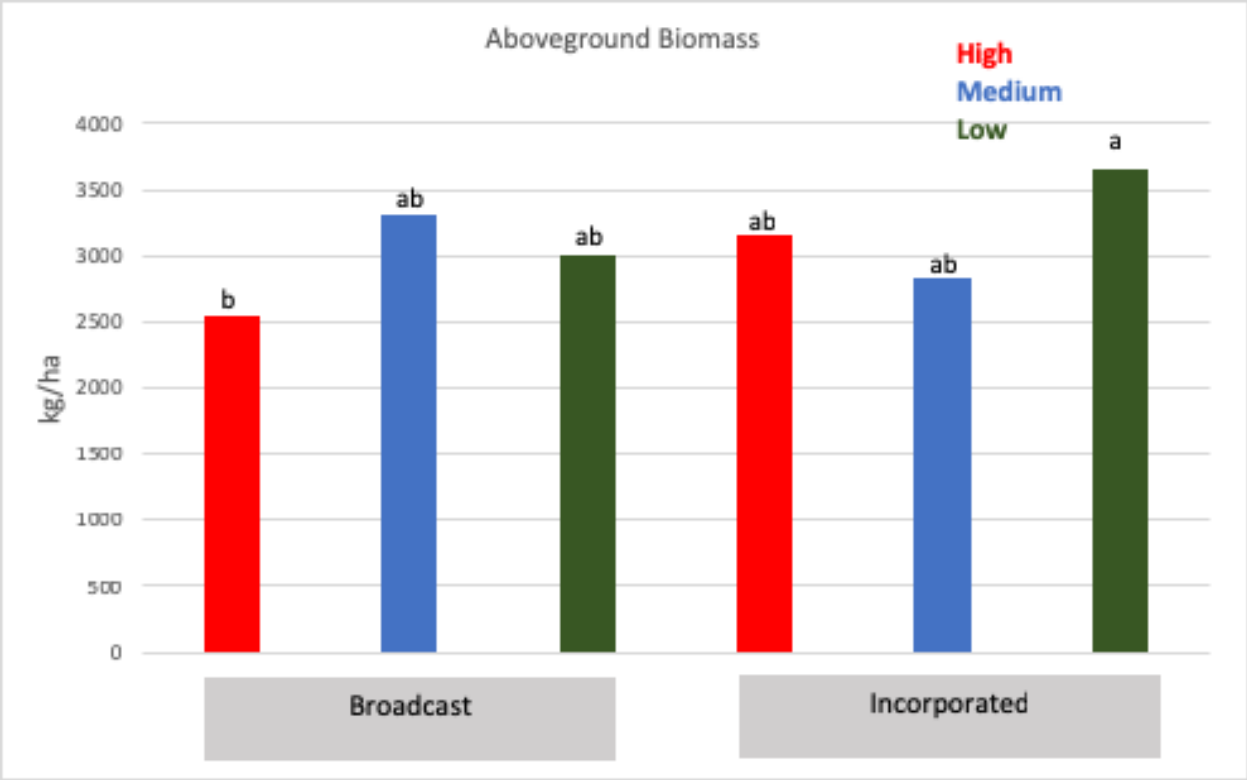

Figure 4-42: Planting method x seeding rate interaction effects on dried above ground biomass at UD Site 1-G-2018.

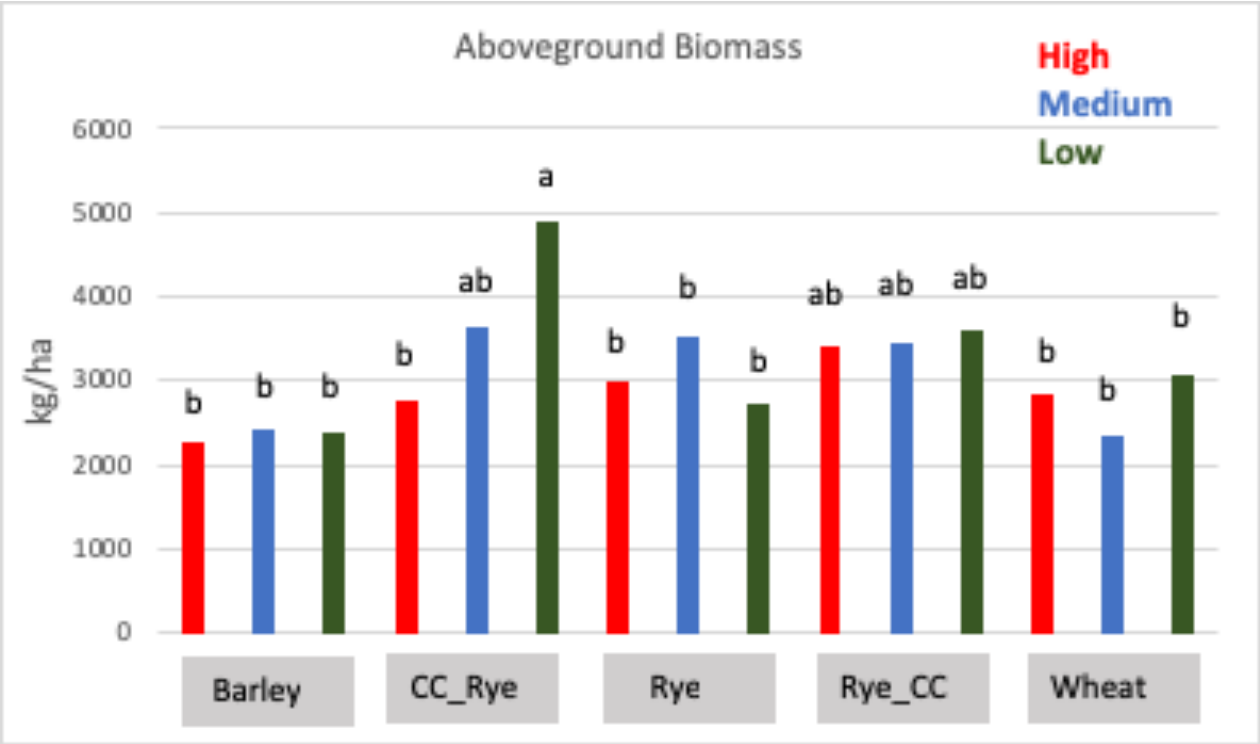

Figure 4-43: Species and seeding rate interaction effects on dried above ground biomass at UD Site 1-G-2018.

4.5.3. Spring Nitrogen Removal

Spring N removal was affected by crop species only; no other treatment effects or interactions were statistically significant. Barley and wheat removed less N in biomass than the two mixes. The CC_Rye (variable clover) had greater N removal than the rye monoculture (Figures 4-44 and 4-45 and Tables A-41 and A-42).

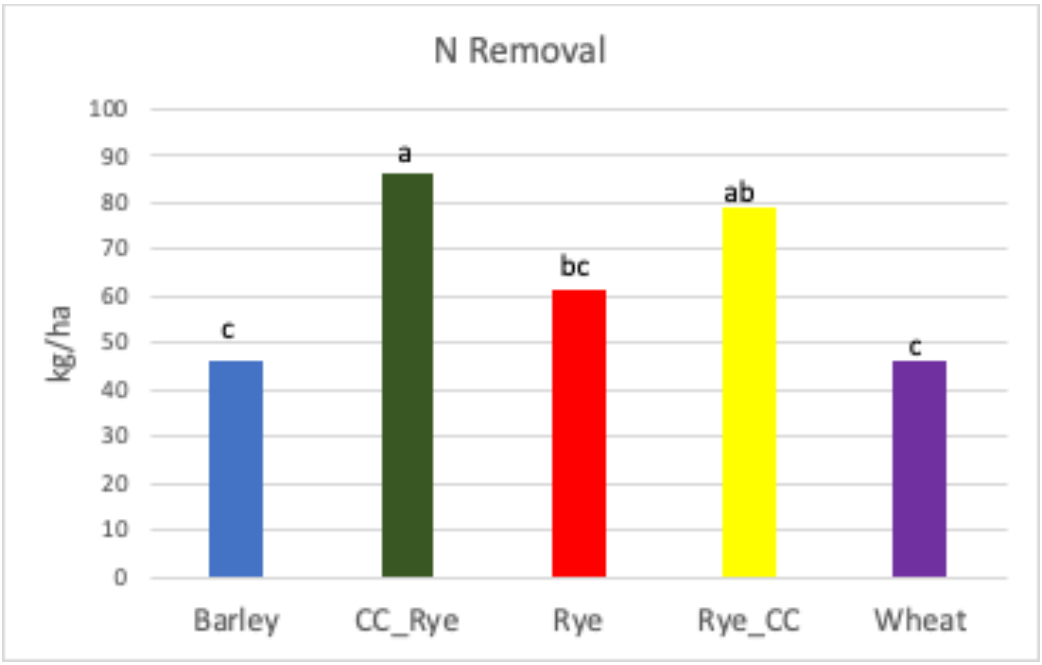

Figure 4-44: Species effects on N removal from samples collected at UD Site-1-G-2018 in spring, 2018.

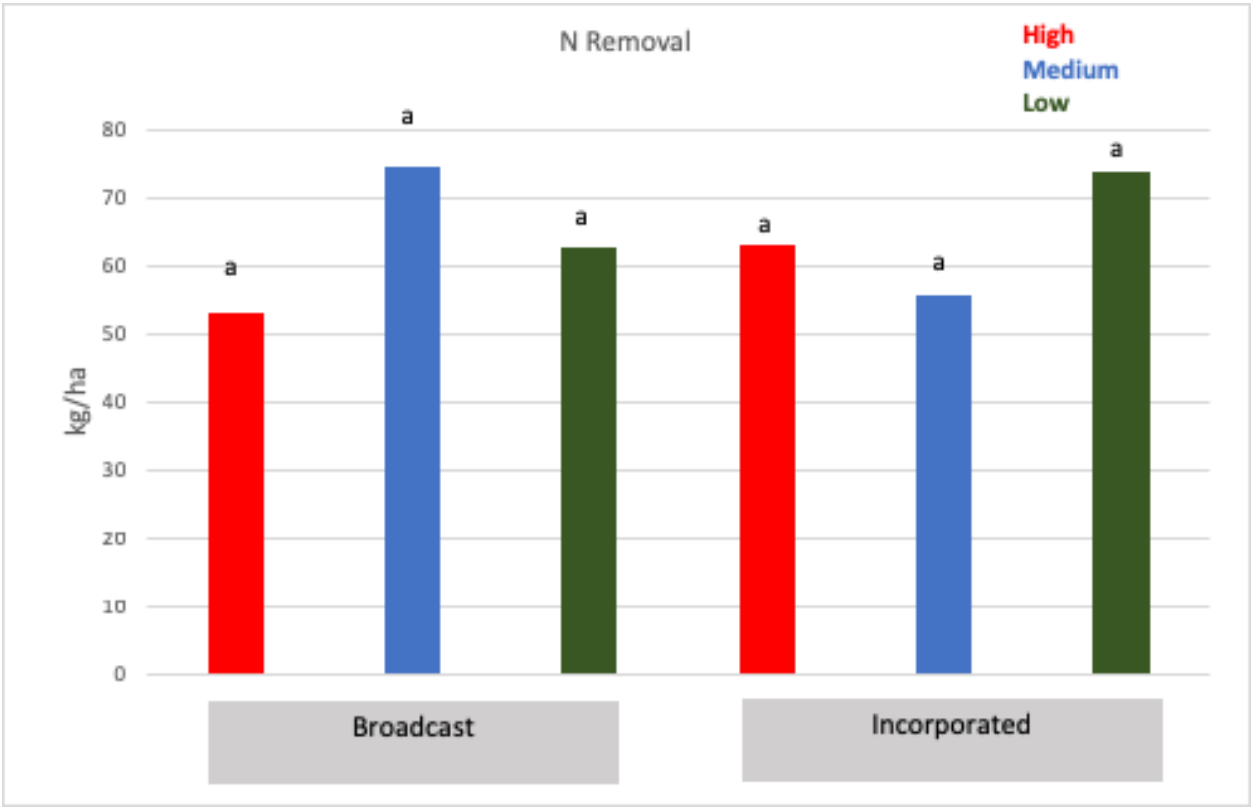

Figure 4-45: Planting method and seeding rate effects on N removal from samples collected at UD Site-1-G-2018 in spring, 2018.

4.5.4. Total Soil Nitrogen

For both 0-15 cm and 15-30 cm soil samples, there was no treatment effects on total soil N (Figures 4-46 through 4-51 and Tables A-43 through A-48).

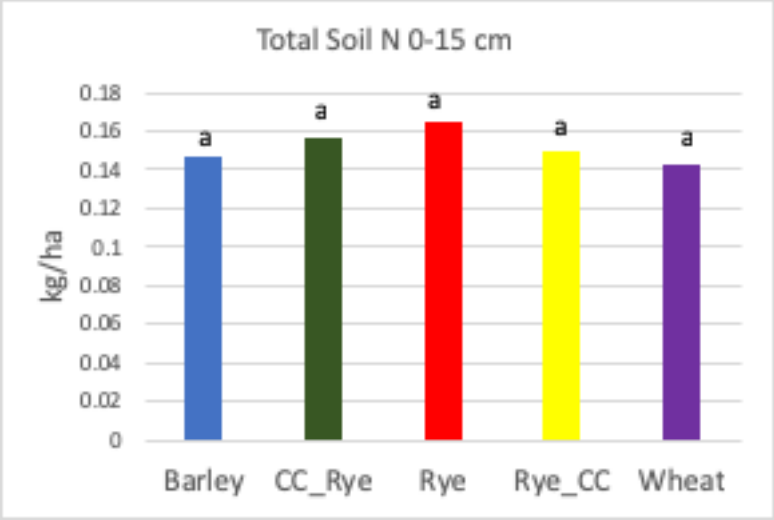

Figure 4-46: Species effects on total Soil N from 0-15 cm samples collected at UD Site-1-G-2018 in Spring, 2018.

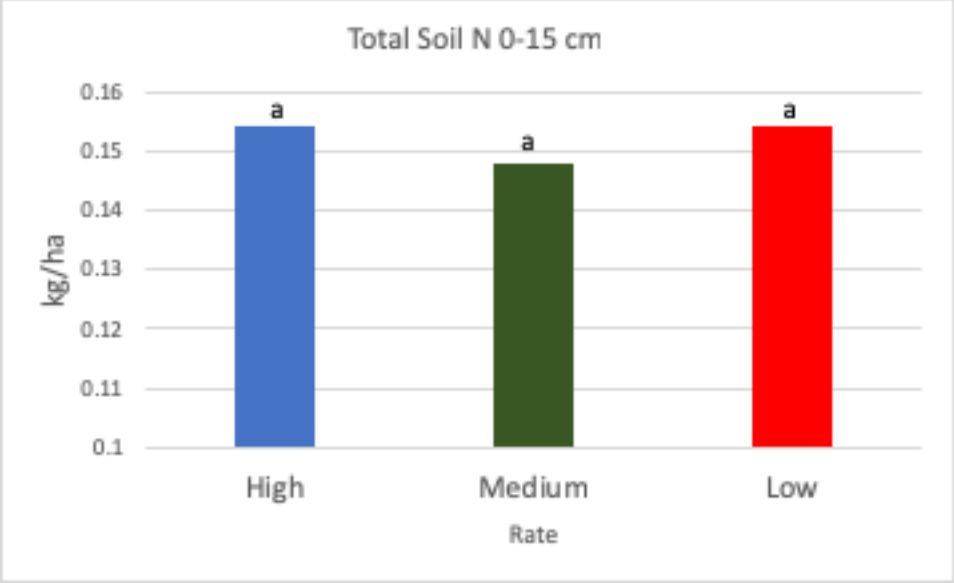

Figure 4-47: Seeding rate effects on total Soil N from 0-15 cm samples collected at UD Site-1-G-2018 in Spring, 2018.

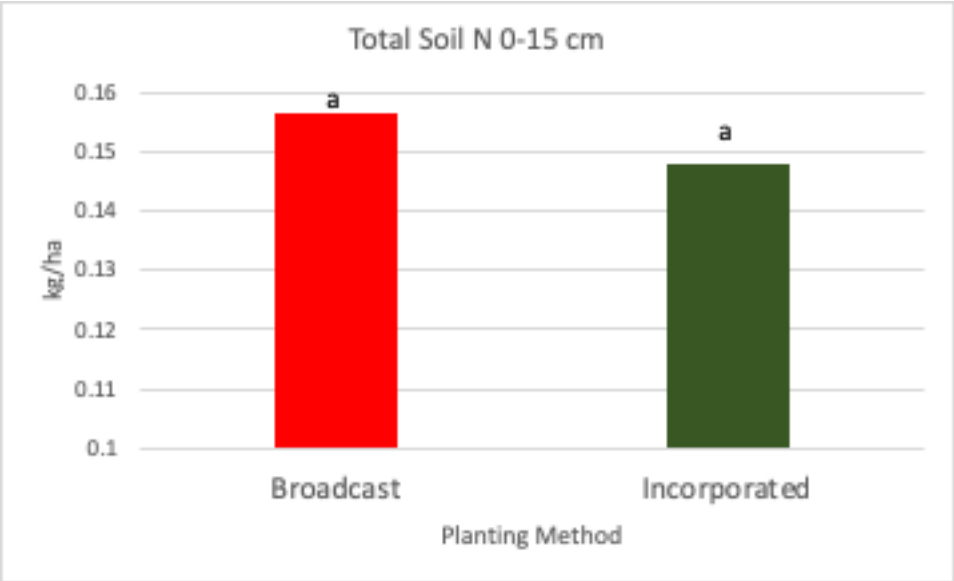

Figure 4-48: Planting method effects on total Soil N from 0-15 cm samples collected at UD Site-1-G-2018 in Spring, 2018.

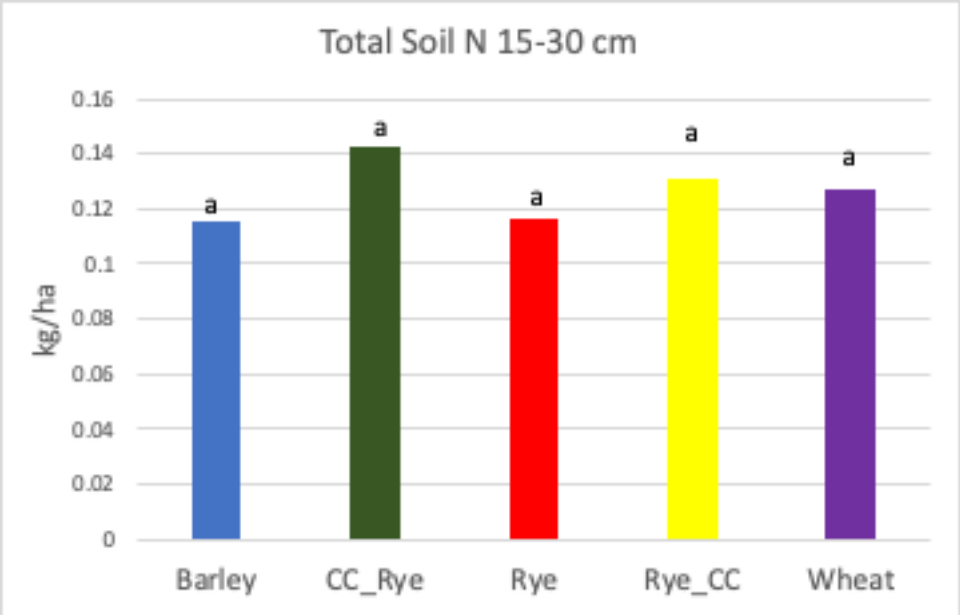

Figure 4-49: Species effects on total Soil N from 15-30 cm samples collected at UD Site-1-G-2018 in Spring, 2018.

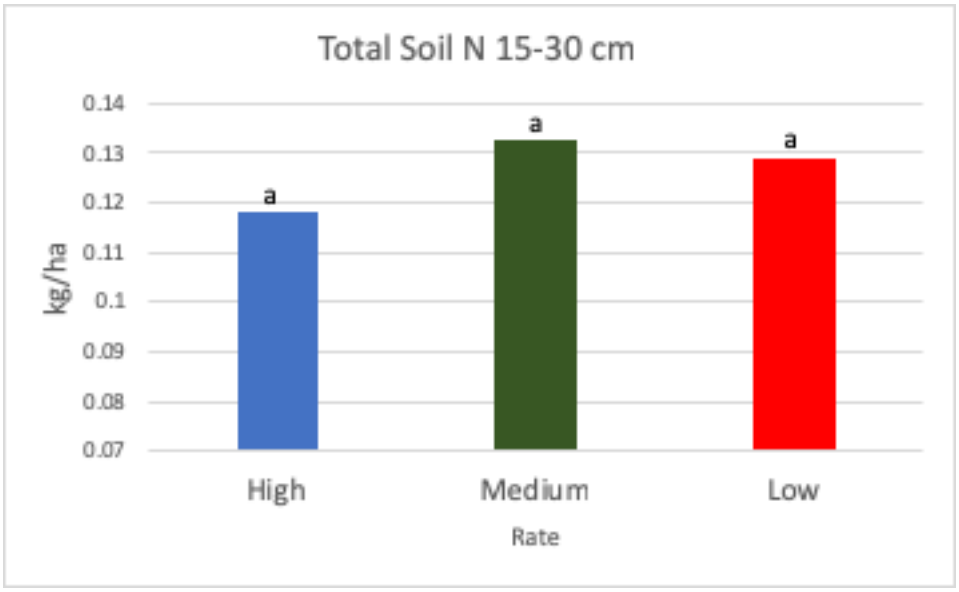

Figure 4-50: Seeding rate effects on total Soil N from 15-30 cm samples collected at UD Site-1-G-2018 in Spring, 2018.

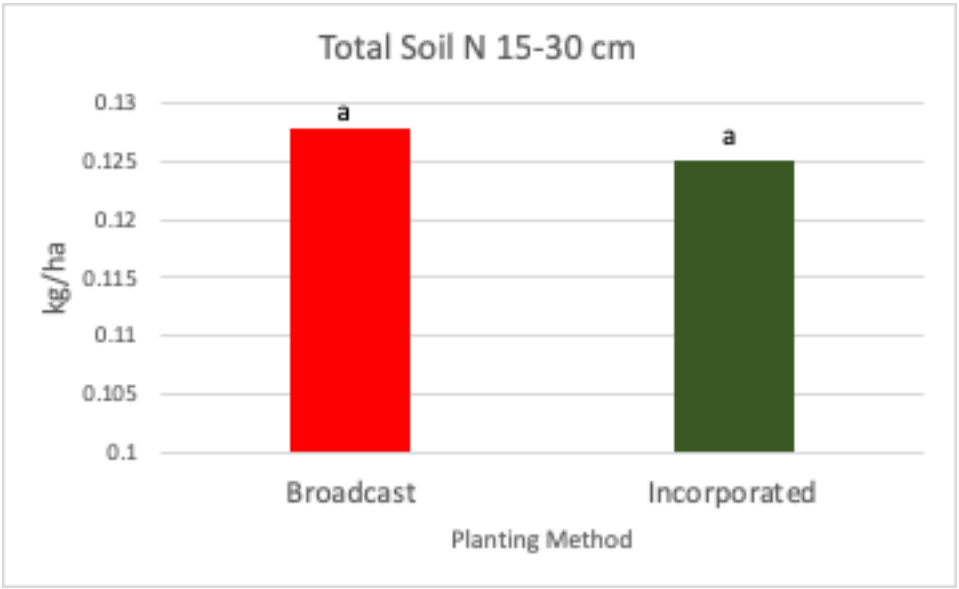

Figure 4-51: Planting method effects on total Soil N from 15-30 cm samples collected at UD Site-1-G-2018 in Spring, 2018.

4.6. UD Site 2-C-2018

4.6.1. Groundcover

Fall coverage data was not collected due to a funding gap lapse. As reported for other sites, spring coverage was significantly affected by planting method. Incorporated plots had

approximately 41% greater spring coverage than broadcasted (Figure 4-52 and A-49). There was also a species x seeding rate interaction on spring coverage. Interestingly, all three monocultures were not affected by seeding rate. Conversely, both mixes performed similarly when planted at the high and medium rates; both rates outperformed the low rates. Also, the low rate of both mixes outperformed all rates of barley. Lastly, the medium and low rates of rye had greater spring coverage than barley, but the high rate of rye performed similarly to all three rates of barley (Figure 4-53 and A-50).

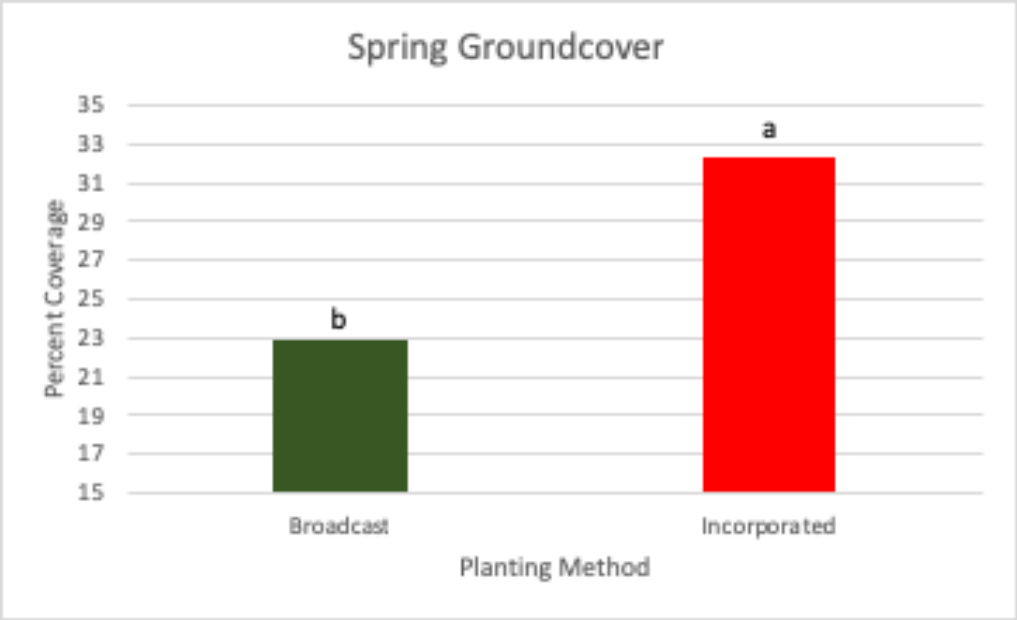

Figure 4-52: Planting method effects on percent spring ground coverage at UD Site-2-C-2018 for rye as estimated from photographs taken in spring 2018 by Canopeo.

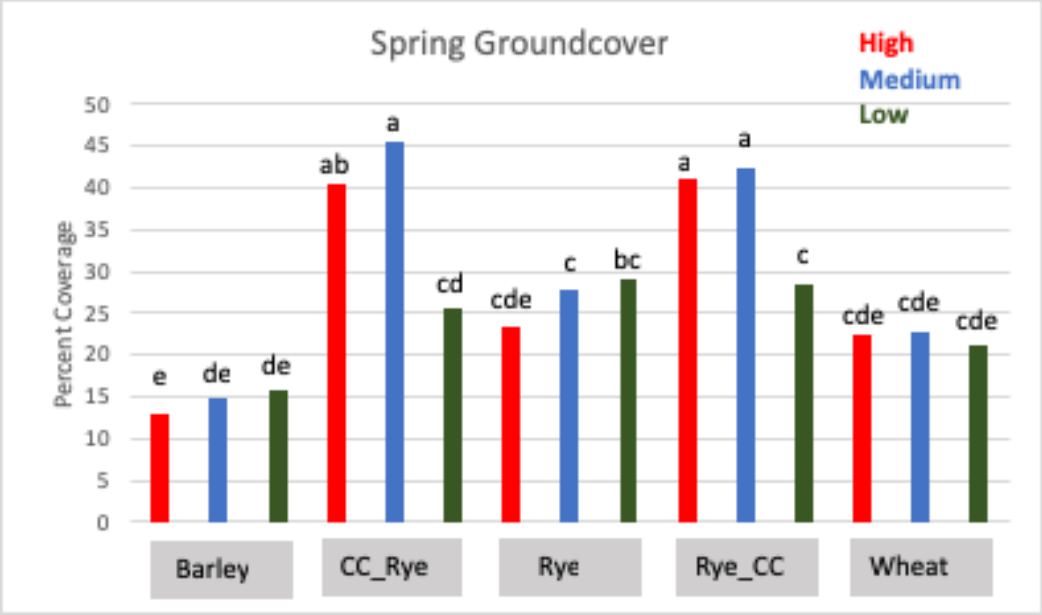

Figure 4-53: Species x seeding rate interaction effects on percent spring ground coverage at UD Site-2-C-2018 for rye as estimated from photographs taken in spring 2018 by Canopeo

4.6.2. Spring Aboveground Biomass

Method and crop species affected biomass at this site. When seed was incorporated, plots produced about 16% greater biomass than when seed was broadcasted. Wheat and barley plantings produced significantly less biomass than both mixes; rye performed similarly to the mixes (Figures 4-54 and 4-55 and Tables A-51 and A-52).

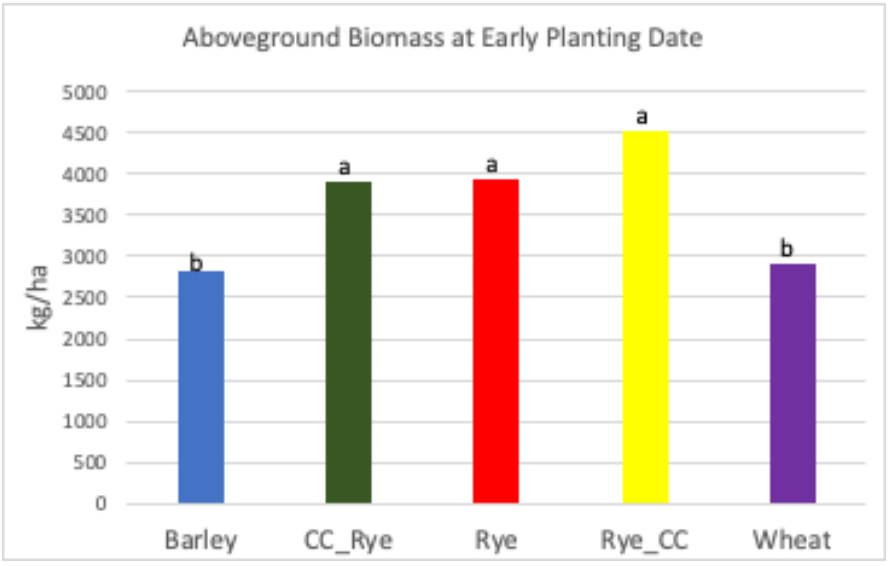

Figure 4-54: Species effects on dried above ground biomass for crops planted on September 9, 2017 at UD Site 2-C-2018.

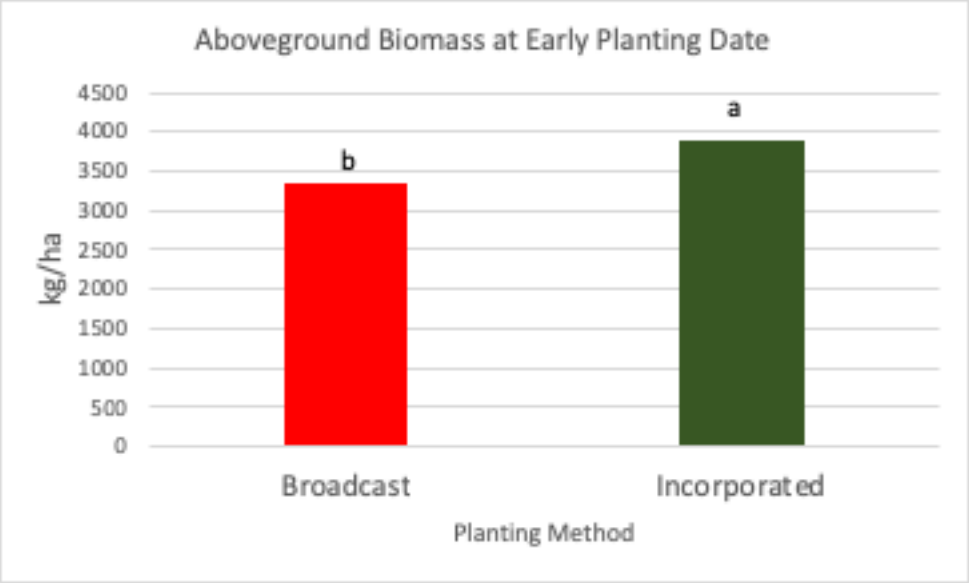

Figure 4-55: Planting method effects on dried above ground biomass for crops planted on September 9, 2017 at UD Site 2-C-2018.

4.6.3. Spring Nitrogen Removal

Like biomass results at this site, barley and wheat plots had less N removal than the other crops or the mixes. Interestingly, even though rye plots had similar biomass as the mixes, they had significantly lower N removal (Figure 4-56 and Table A-53). And again, incorporated plots had greater N removal than broadcasted, in this case, about 20% more (Figure 4-57 and Table A-54).

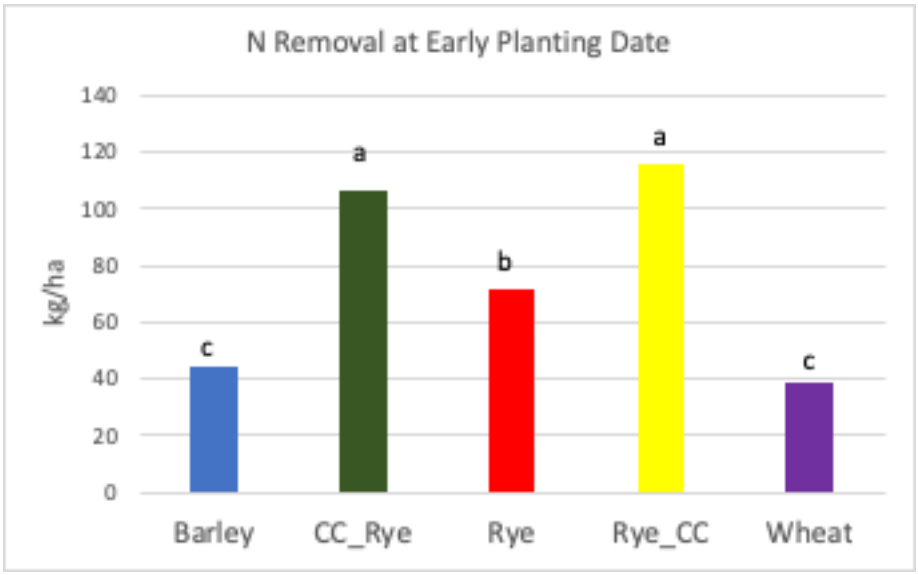

Figure 4-56: Species effects on N removal for crops planted on September 9, 2017 at UD Site 2-C-2018.

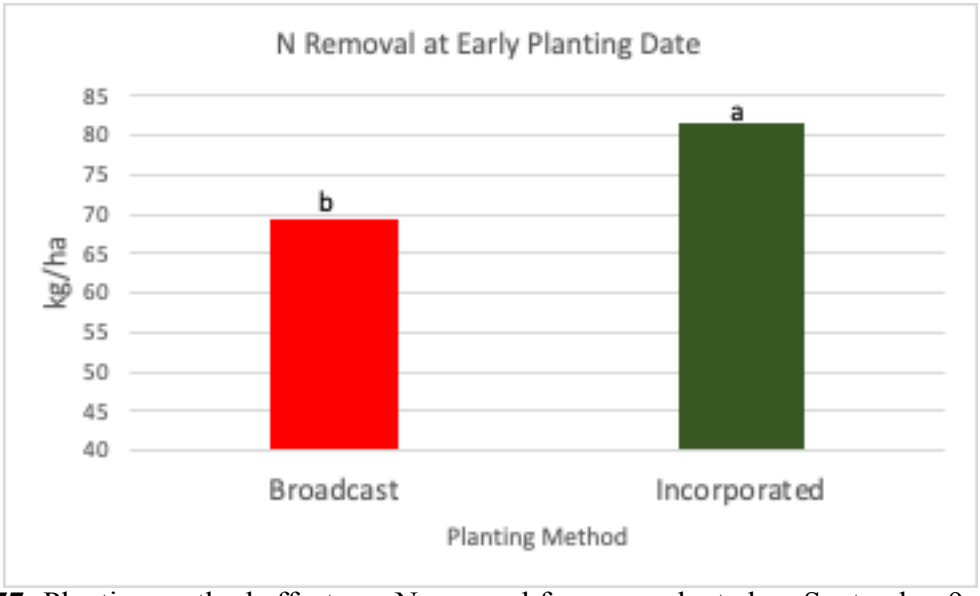

Figure 4-57: Planting method effects on N removal for crops planted on September 9, 2017 at UD Site 2-C-2018.

4.6.4 Total Soil Nitrogen

For both 0-15 cm and 15-30 cm samples, there was no treatment effects or interactions related to total soil N (Figures 4-58 through 4-63 and Tables A-55 through A-60).

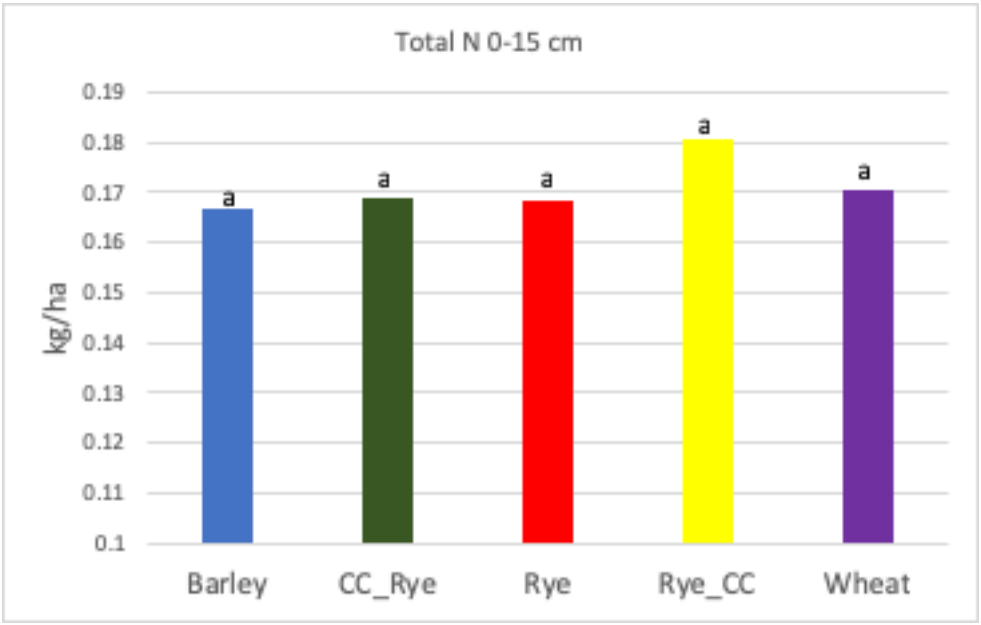

Figure 4-58: Species effects on total Soil N from 0-15 cm samples collected at UD Site-2-C-2018 in Spring 2018

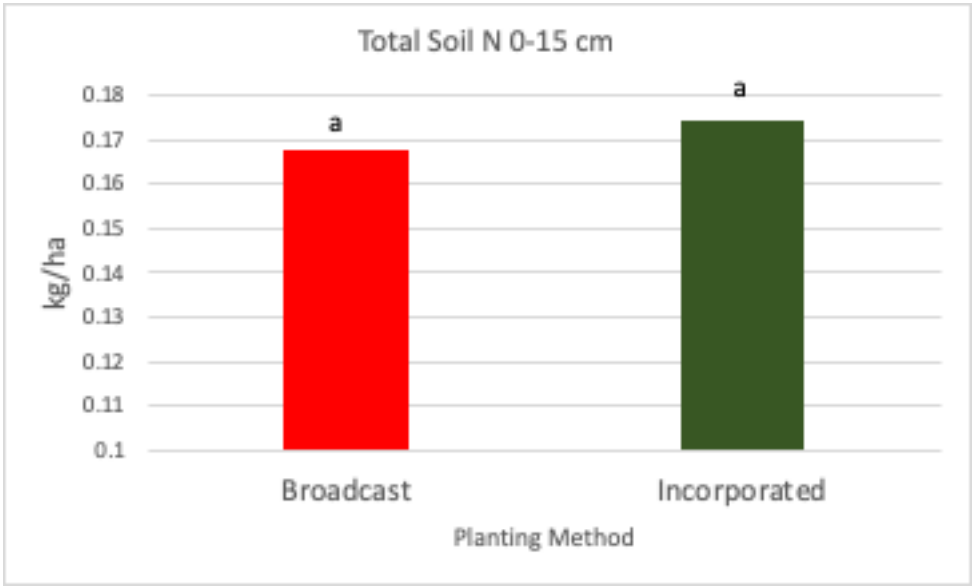

Figure 4-59: Planting method effects on total Soil N from 0-15 cm samples collected at UD Site-2-C-2018 in Spring 2018.

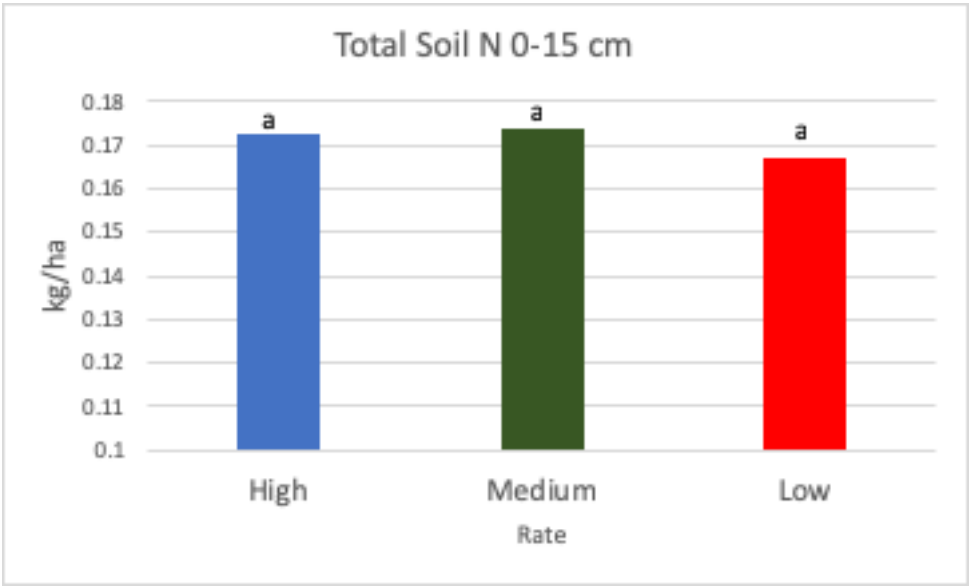

Figure 4-60: Seeding rate effects on total Soil N from 0-15 cm samples collected at UD Site-2-C-2018 in Spring 2018.

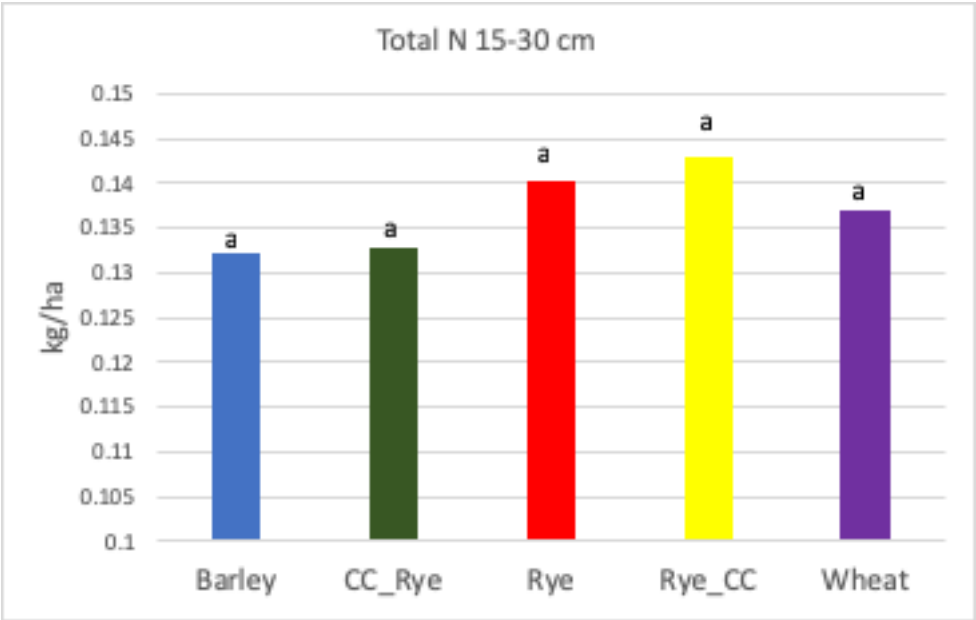

Figure 4-61: Species effects on total Soil N from 15-30 cm samples collected at UD Site-2-C-2018 in Spring 2018.

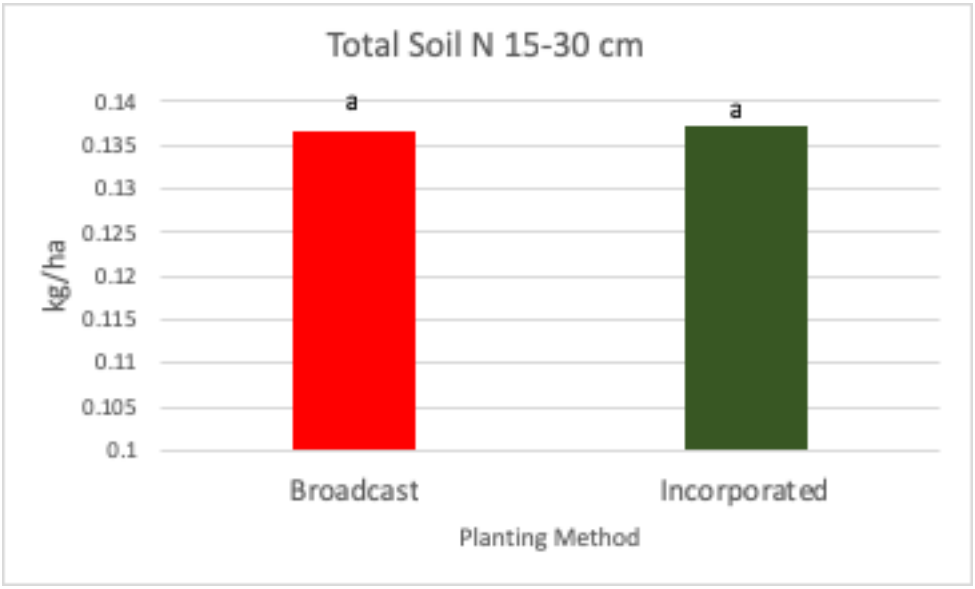

Figure 4-62: Planting method effects on total Soil N from 15-30 cm samples collected at UD Site-2-C-2018 in Spring 2018.

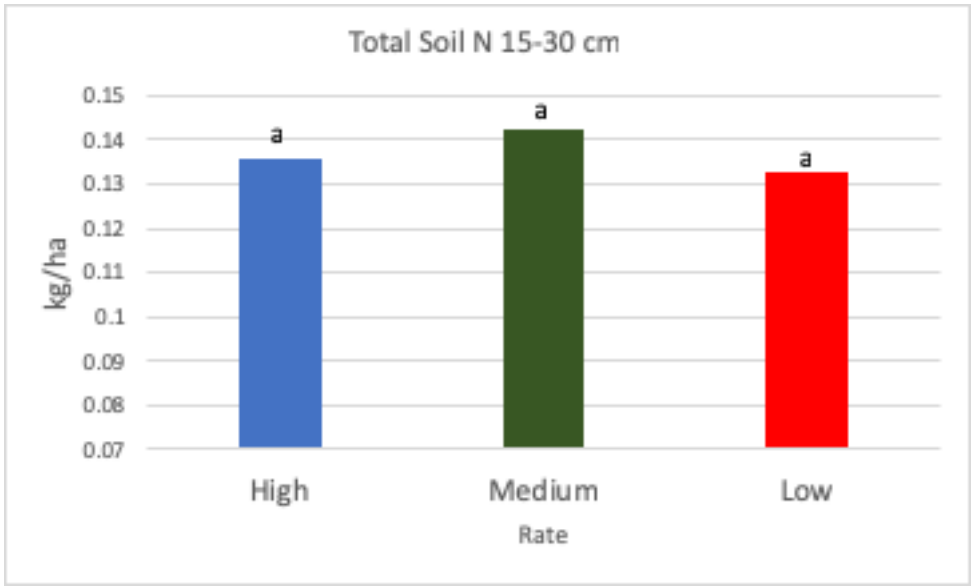

Figure 4-63 Seeding rate effects on total Soil N from 15-30 cm samples collected at UD Site-2-C-2018 in Spring 2018.

4.7. UD Site 3-M-2018

4.7.1. Groundcover

Due to funding and resource restrictions, only spring ground coverage data was collected and analyzed for this site. At this site, there were no species, rate, or treatment interaction effects

on coverage, except for planting method. Incorporated plots again showed greater spring coverage than broadcasted, with incorporated seed covering about 12.7% more (Figure 4-64 and Table A-61).

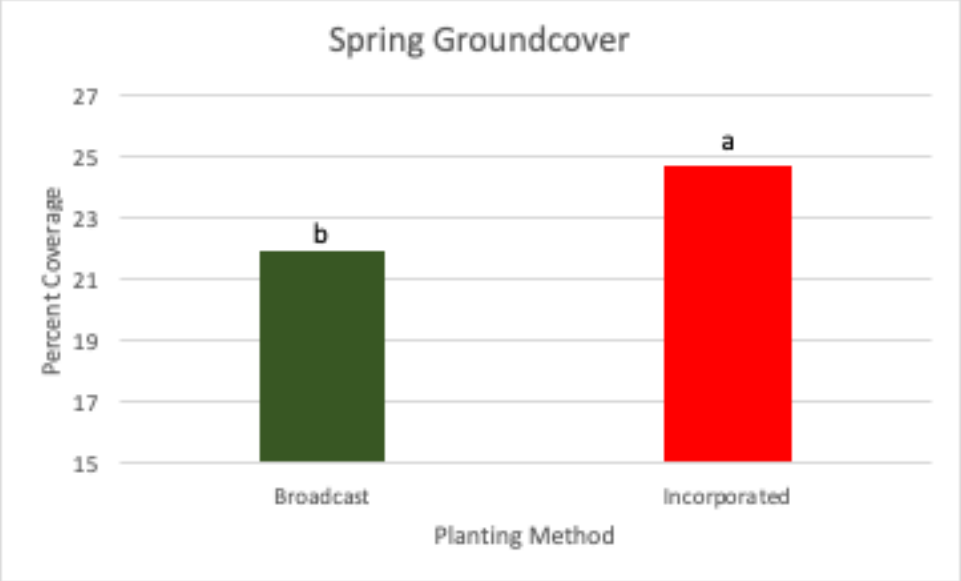

Figure 4-64: Planting method effects on percent spring ground coverage at UD Site-3-M-2018 for rye as estimated from photographs taken in spring 2018 by Canopeo.

4.8. Inter-site comparisons

It is not practical to make statistical comparisons between sites because of variability in treatments, local weather and soil conditions, but the results are summarized and compared as follows. DSU Site-2016 results support planting by mid-October and prior to October, if possible. Rye and rye-clover are recommended over wheat and barley at the early date and rye over all three at the standard date. Drilled is supported over broadcasting and lower seeding rates are largely justified to perform as well or better than higher rates. Results from Site UD 1-L-2016 support planting rye, barley, or rye / clover mixes at the early planting date, but not wheat. Lower seeding rates are largely supported to perform as well as higher rates. The results from site UD 2-C-2016 support medium seeding rates to produce the greatest fall cover and low rates

for spring cover (except for the CC_Rye mix). Low seeding rates are also supported for biomass production. Additionally, the rye / crimson clover mixes are supported for greater biomass over the monocultures. Site UD 3-M-2016's results showed that incorporating seeds over broadcasting is tentatively supported for greater fall cover. Site UD 1-G-2018's data suggests that if planting at an early date and trying to maximize ground coverage, planting a rye/clover mix is recommended. High seeding rates are not justified, with low rates outperforming in some circumstances, especially for the CC_Rye mix. Incorporating seeds over broadcasting is tentatively supported at the late date. Higher seeding rates were not justified at Site UD 2-C-2018 and medium rates were only justified for increasing spring coverage with the clover / rye mixes. Planting the mixes are supported at medium rates for increased spring cover and at any rate for higher biomass and N removal. Based on the results from Site UD 3-M-2018, incorporating seeds is supported over broadcasting for greater coverage.

The most consistently appearing effects on cover crop productivity were caused by planting dates and seeding rates. The general observation of earlier planting dates producing more groundcover was potentially the most dependable result of the study. Unfortunately, as noted in the previous section, many sites did not have multiple planting dates. Only two sites had three planting dates and only one more site had two dates. For the sites that did have multiple plantings, the actual planting dates, although falling within the same required time windows, were not as analogous as would be ideal. Although, both planted in 2015, DSU Site-2016's three dates were Sep 30, Oct 13, and Oct 30 and UD Site 1-L-2016's three dates were Sep 9, Oct 1, and Oct 20. DSU's fall coverage was approximately 73.3%, 49.7%, and 26.8%, respectively. UD's fall coverage was 47.3%, 20.2%, and 15.8%, respectively. Although, DSU's plots had more overall coverage even with later dates, both sites saw clear declines with sequential

planting. However, for both fall and spring coverage, UD's plots had a minimal decline for some interactions between the standard and late dates. Also notable is that between the early and late dates, the DSU site had a gap of 30 days and saw a 63.5% decline in fall coverage, while UD's site had a gap of 41 days with a 66.5% decline. UD's Site 1-G-2018 only had the two planting dates of September 11 and October 18, 2017. Although treatment interactions convoluted the data, when crops were analyzed individually, all five species mixes had greater spring coverage at the early date, averaging 26.7% compared to 9.4% at the late date. Potential extrapolations from this data would be that DSU's site would have had even greater coverage if dates were shifted earlier to UD's schedule and that UD's coverage would decrease if shifted to DSU's dates. Regardless, the data clearly demonstrates the benefit of planting earlier for ground coverage. The DSU site also supports earlier planting dates for increased biomass and N removal, but the data is not as clear at the other sites.

Potentially more influential and less predictable was that many results showed a minimal effect from seeding rate. Although planting date results are important, many farmers have external restraints on when they can plant, such as weather and cash crop conditions. Contrarily, seeding rate adjustments could easily be made by farmers and subsidy coordinators if research results justified changes. There were specific treatment interactions with rates that proved to be exceptions, but much of the results from different sites showed that the highest seeding rates were not significantly different, implying that farmers would be wasting money on seed in those situations. Out of the seven sites, none supported high rates over medium rates for ground coverage, biomass, or N retention. Two sites (UD 3-M-2016 and UD 3-M-2018) showed no seeding rate effects (ground coverage was the only data taken from those two sites). Two sites (DSU-2016 and UD 1-G-2018) also had no consistent seeding rate effects on coverage, but in

some cases showed greater biomass at low seeding rates. Site UD 1-L-2016 largely had minimal seeding rate effects except that the medium rate had more fall coverage than the low rate. UD Site 2-C-2018 showed that the low rates were sufficient for biomass and that only the medium rate was needed for spring coverage. And lastly, UD Site 2-C-2016 showed medium rates were adequate for fall cover and that low rates produced as much spring cover and biomass as higher rates. Therefore, this data supports lowering seeding rate requirements to no more than the medium rates for groundcover and that low rates produced as much as and in some cases more biomass than medium and higher rates.

Seeding method data also providing statistically significant results in this study. However, comparing DSU and UD plots is not ideal because different treatments were used. DSU plots compared drilled seeds with broadcasted seeds at equal seeding rate levels. UD plots compared incorporated seeds to broadcasted seeds with 30% increased seeding rates. However, the broadcasted/drilled evaluations did often appear similar to the broadcasted/incorporated plots. Although not uniformly disadvantageous, none of the sites' results support broadcasting in these situations. DSU's 2016 site showed clear advantages from drilling for increased biomass and N removal. Conversely, broadcasted plots produced similar fall groundcover except at the standard planting date, even without the 30% increase in seed. Similarly, UD Site 2-C-2018 had significantly greater spring coverage, biomass, and N removal in incorporated plots over broadcasted. UD Site 3-M-2016 had greater fall cover in incorporated plots, but not in spring cover. UD Site 3-M-2018 had greater spring cover in incorporated plots (fall cover was not recorded). The remaining three sites showed limited treatments and interactions that supported incorporation, but no results supported broadcasting. UD Site 1-L-2016 had higher spring coverage for incorporated plots at medium seeding rates. UD Site 2-C-2016 only supported

incorporating seeds for rye fall coverage. UD Site 1-G-2018 had results that generally supported incorporating over broadcasting, but only for the late planting date. Therefore, the data from this project clearly does not show any undesirable effects from drilling or incorporating on groundcover, biomass, or N retention and, in fact does provide some evidence of benefits in many situations. However, these results are not entirely conclusive and should be weighed with other potential factors including equipment, time, soil disturbance, and seed costs.

The effects of cover crop species on groundcover, biomass, and N retention also had some consistencies between sites. DSU's site had wheat producing less groundcover and wheat and barley having less biomass and N removal. At the standard date, rye produced the highest biomass and N removal. UD Site 1-L-2016 had lower wheat fall coverage, biomass, and N removal at the early planting date, when compared to other crops. UD Site 2-C-2016 had greater biomass for the mixes over all three monocultures. The mixes also performed better for spring cover at UD Site 1-G-2018, with barley producing the least. Barley and wheat removed the least N and the CC_Rye mix produced the most biomass at the low rate. High rate mixes at UD Site 2-C-2018 had the greatest spring cover. Barley and wheat had the lowest biomass and N removal. UD Sites 3-M-2016 and 3-M-2018 had no crop effects. Although not completely consistent for all treatments and effects, the data from five of the seven sites support not planting barley or wheat and in certain circumstances, a rye / clover mix can perform better than rye as well.

CHAPTER V: DISCUSSION AND RECOMMENDATIONS

5.1. Discussion

An initial interpretation of the research findings is that the results are clearly varied. Between sites, years, crops, and treatments, it is difficult to make broad generalizations that can lead to completely confident recommendations. When comparing results from one site to another, few treatment interactions proved to be overwhelmingly consistent. Even when analyzing the effects of a single individual treatment at one site on one dependent variable, the results could be favorable in one circumstance, but not in another very similar scenario. Even for generalizations, such as an increased or decreased seeding rate at one planting date were not always clear. Each site, and even treatment plot, has their own specific soil, planting and weather conditions making results inconsistent, but with each additional year and site of research, persisting similarities and observations can be identified and lead toward better recommendations for farmers and subsidy managers based on likely outcomes. This, in and of itself, is a conclusion that justifies the need for continued and reoccurring research. Based on the data, there were some clear treatment results that stood out among and between sites, of which discussions and recommendations can be made.

One of the most interesting results of this study is that not only were the highest rates of cover crops nearly uniformly unnecessary, but in some cases, the lowest rates actually produced more biomass than the high rates, especially at early planting dates. Similar to these results, but with a different cover crop species, an Alabama study evaluated the effects of planting dates and seeding rates on sunn hemp biomass and concluded that early dates at the lower end of recommended seeding rates were top performers (Balkom et al., 2011). In this Delaware study, the lowest seeding rates in some cases did not produce as much ground cover, but were

eventually able to equal or surpass the high seeding rates in total biomass. A potential explanation of this is tillering. Tillers are new grass side shoots that grow upward from a parent plant and crops that are known to tiller well in certain conditions can be seeded at lower rates (OSU, 2018). Potentially, the cover crops that were seeded at lower rates produced conditions that favored tillering. Some grain studies, including those with oats and wheat, have found that higher seeding rates can produce more stems, but lower height, yield, and/or number of tillers (Peltonen-Sainio and Järvinen, 1995; Carr et al., 2003). In other words, the lower seeding rate plots could produce more biomass through an increase in tillering. Another study in Maryland found that for a mixture, a lower rate of rye (47 kg/ha) with a medium rate of vetch (21 kg/ha) produced greater corn yields than higher rates of those cover crops (Clark et al., 1994). In my study, the medium rates may prove to be a happy medium that allows cover crops to efficiently utilize available nutrients after germination to maximize groundcover, but also still be able to tiller and produce high biomass levels. Further research is needed to determine if medium rates are justified over low or vice versa.

The general planting date results from this study largely appear predictable: the earlier planted, the better they will perform. However, this is not always the case. A Pennsylvania three-year study found highest biomass productions (measured in June) for mid-September-planted cover crops to be about 9,500 kg/ha for rye, 9,300 kg/ha for wheat and 6,300 kg/ha for barley vs. early-October plantings that produced 11,000 kg/ha rye, 9,400 kg/ha wheat, and 9,000 kg/ha barley (Duiker, 2014). Conversely, Mirsky et al. (2017) found different top performing seeding rates for different locations, but across all sites, earlier planting dates, generally produced greater biomass. Mirsky et al. (2012) also found that rye biomass could increase 2,000 kg/ha by planting in late-August instead of mid-October. Trials in upstate New York showed that triticale planted

prior to September 20 had greater biomass and N uptake than later plantings indicating that early plantings could effectively be used to scavenge residual N from previous crops (Lyons et al., 2017). Other studies have found that earlier planted winter cover crops can have more weed intrusion and weed biomass, therefore outcompeting the cover crops. This was found to be the case from hundreds of weed and cover crop biomass collections in the Mid-Atlantic (primarily Pennsylvania) in both tilled and no-till systems (Baraibar et al., 2018). In tilled systems, it is logical that when cover crops are seeded, the freshly tilled soil also reveals dormant weed seeds, which can thrive at the higher temperatures and longer days associated with the early planting date. However, no till systems produce a different scenario, seemingly making it harder for weed incursion to occur. A down side of this Delaware study is that the ground coverage data collected could not differentiate weed green cover from cover crop. As mentioned previously, regardless of planting date or treatment, the DSU plots had little to no weed pressure (based on light box photographs) compared to UD plots, which had noticeable weed pressure. Because all sites were no-tilled and dormant in-ground seeds were not exposed, it is reasonable that the only seed pressure came from the immediate area adjacent the sites. At the DSU site, the plots were surrounded by no-till winter wheat in corn residue, mowed grass, and a small drainage creek. The UD sites may have been exposed to more incoming weed seed throughout the planting dates from more variable environmental conditions.

Results from this study showed that the rye – clover mixes often performed similarly to rye alone and better than wheat and barley monocultures. Thapa et al. (2018) found a similar result with vetch-rye mixes that were found to produce as much or more biomass as monocultures of vetch or rye and accumulate as much N as vetch, alone. Although not studied in this Delaware project, the poor late date results show the need for evaluating if species perform

similarly when inter-seeded. One interseeding project evaluated drilling legumes and annual rye-grass into corn in the Mid-Atlantic and found that the rye-grass-legume mixtures produced more biomass than legumes or rye-grass alone (Curran et al., 2018). Although, Curran et al. (2018) concluded that interseeding at early dates could hurt corn yields, Belfry et al. (2016) found that interseeding a variety of cover crop monocultures and mixes into corn could produce enough groundcover to protect soil post corn harvest and not affect the corn yield. Another factor to consider when evaluating Delaware project results is that individual species can perform differently when planted in mixes than as monocultures and that planting dates can affect growth ratios. Murrell et al. (2017) found that earlier planting dates for mixes produced more diverse growth and that later plantings tended to let a single species, such as rye dominate in spring. Also, Murrell et al. (2017) showed that grasses produced more biomass in mixes than when planted as a monoculture, brassicas produced more biomass as monocultures and legumes performed more variably. It may have been valuable in this Delaware project to evaluate if rye's individual biomass was affected based on its inclusion in the different mix rates with clover.

Several studies have shown that rye can outperform other species, as it did in this study over the other two monocultures. A Maryland study found that following corn harvest, rye recovered more N from fertilizer than vetch, crimson clover, or ryegrass, and did so early in spring because of its greater growth in cool weather (Shipley et al., 1992). Studies such as Ditsch et al. (1993) have also demonstrated rye's ability to recover residual N from fertilizer applications in corn. Mirsky et al. (2012) reported that although rye is often a top performer, it is not typical for rye biomass to exceed 6,000 kg/ha. However, with optimized seeding rate and planting dates, rye biomass has reached 12,000 kg/ha. In my study, rye did exceed 10,000 kg/ha at the DSU site when planted at the early and standard dates, indicating near ideal treatments.

One Iowa study using self-seeded cover crops had quite different results with wheat producing greater fall groundcover and biomass than rye (McDonald et al., 2008). This is another area of research unexplored in this Delaware project, perhaps indicating that results could have been different if self-seeded. However, McDonald et al. (2008) had top performing treatments that produced similar fall cover as this Delaware project, but considerably less spring biomass.

Results showed that drilled plots often outperformed broadcasted plots and incorporated plots occasionally outperformed broadcasted plots. However, species by method interactions were rare. Although we did not compare the three methods directly, in the Midwest, Noland et al. (2018) compared the biomass of a variety of cover crop species that were drilled, broadcasted, and incorporated with a light disk into corn. Noland et al. (2018) showed that drilled seeds produced more fall biomass than broadcasted for all but one species, and that drilled and incorporated vetch and red clover produced more spring biomass than broadcasted.

Results from any agricultural research project are highly dependent on weather conditions including with cover crops. Tables 5-1 and 5-2 show the monthly temperatures and rainfall at weather stations that are located in the same towns as the research sites from the Delaware Environmental Observing System (DEOS, 2019). Weather differences between sites have the potential to explain discrepancies between germination, establishment and biomass. Temperatures during the 2015-16 season were similar between sites of that year. Temperatures during the 2017-18 season were also similar between sites of that year. Monthly rainfall between sites was more varied than temperature, but with only a few centimeters of difference in any month. However, comparing between the two years, the 2017-18 average almost 2˚C cooler. Most notably, December 2017 was approximately 8˚C cooler than 2015. That month in 2017 also had almost 13 cm less rainfall than in 2015. The rainfall averages for the season were also

several cm below 2015. Even with the difference in temperature and rainfall between the years, it is difficult to compare sites or attribute any results to specific weather conditions. Table 5-3 shows the results across all treatments at each site. However, not all parameters were measured and not all treatments were the same. Furthermore, only site 2-C in 2015-16 and site 2-C in 2017-18 were located at the same place. Comparing these results, the 2015-16 sites show greater spring coverage, but lower biomass. Several studies have associated weather conditions with cover crop success, typically milder temperatures or heavier fall rains (Thapa et al., 2018; Vann et al., 2019; Mirsky et al., 2017). However, a potential explanation of Delaware results is that the higher temperature promoted more ground cover growth, but the higher rainfalls limited biomass production. If weather patterns like what Delaware experienced become more common, it may be useful to identify species that potentially could better withstand wetter or shorter cover crop growing windows. One example of identifying species for different localized conditions is a Kansas planting date trial that evaluated native cover crop species that could germinate and perform better in the drier conditions in that area (Schartz et al. 1999).

Table 5-1: Average temperature from weather stations near research sites (DEOS, 2019).

			Average Temperature (Degrees C)					
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Avg
DSU Site 2015-16	21.56	13.22	10.72	9.94	0.94	3.61	9.78	9.97
UD Site 1-L '15-'16	21.50	13.50	10.83	10.61	1.56	4.17	10.06	10.32
UD Site 2-C '15-'16	21.78	13.61	11.06	10.72	1.67	4.22	10.11	10.45
UD Site 3-M '15-'16	22.61	15.06	12.28	10.94	2.33	4.17	9.78	11.02
UD Site 1-G '17-'18	20.56	16.50	8.89	2.39	0.78	7.11	4.56	8.68
UD Site 2-C '17-'18	20.56	16.50	8.89	2.39	0.78	7.11	4.56	8.68
UD Site 3-M '17-'18	20.94	17.28	9.72	3.06	0.56	6.67	4.72	8.99

Table 5-2: Average precipitation from weather stations near research sites (DEOS, 2019).

			Average Rainfall (cm)					
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Tot.
DSU Site 2015-16	7.19	11.07	6.25	12.85	3.66	9.78	6.50	57.30
UD Site 1-L '15-'16	11.02	10.67	9.27	14.91	7.19	13.03	4.45	70.54
UD Site 2-C '15-'16	8.56	11.56	8.94	12.75	8.71	11.63	4.85	67.01
UD Site 3-M '15-'16	12.19	16.28	9.35	13.16	7.59	11.23	6.88	76.68
UD Site 1-G '17-'18	5.72	9.55	6.05	2.51	6.55	10.72	8.79	49.89
UD Site 2-C '17-'18	5.72	9.55	6.05	2.51	6.55	10.72	8.79	49.89
UD Site 3-M '17-'18	7.52	11.94	6.63	2.69	8.46	5.82	12.17	55.22

Table 5-3: Average results from all treatments.

	Averages for all treatments			
	Fall Cover	Spring Cover	Biomass	N Removal
DSU Site Smyrna 2015-16	49.94	N/A	6255.18	129.00
UD Site 1-L Laurel 2015-16	27.78	23.95	2264.42	38.65
UD Site 2-C Georgetown 2015-16	34.09	44.55	2286.84	N/A
UD Site 3-M Millsboro 2015-16	25.33	20.45	N/A	N/A
UD Site 1-G Georgetown 2017-18	N/A	18.37	3093.96	63.81
UD Site 2-C Georgetown 2017-18	N/A	27.61	3632.04	75.43
UD Site 3-M Millsboro 2017-18	N/A	23.32	N/A	N/A
Unit	%	%	kg/ha	kg/ha

One result that is clear from table 5-3 above and also from treatment results is that DSU's site in Smyrna had greater productivity in fall cover, biomass, and N removal. Although there are too many uncontrolled variables to statistically quantify treatment effects, speculation can be made as to why this site performed at higher levels. One point to reiterate is that the DSU site drilled seeds and broadcasted at equal rates, while UD plots incorporated and broadcasted at 30% higher rates. For comparison sake, drilled results can be removed from this discussion, but will be discussed later in this section. Broadcasted plots are often seeded at a 30% higher rate, assuming this would increase performance. However, even without that increase, the DSU

broadcast plots still produced 48.96% fall cover, 5425 kg/ha of biomass, and 111.4 kg/ha of N removal. Although these results are less than the drilled DSU plots, they are still greater than nearly every treatment at the other sites. There are many potential explanations for the differences between this site and UD's Sussex sites, but they are all speculative. One possible factor is the residual soil N following cash crop harvest, which was not universally tested among plots. The DSU site, had a shorter-season corn variety, potentially using less N. Also, N applications during the cash crop growing season were not standardized between sites, meaning that some sites could have had more N applied and/or at a later date, therefore increasing residual soil N when cover crops were planted. However, this would not change intra-site comparisons and treatment effects that have been previously described. Another potential factor is that weed pressure at the different sites appeared to be very dissimilar. Although not measured, DSU's site had little to no observed weed pressure and UD's on-farm sites had very significant observed weed pressure, even in the fall. Additionally, sites in Sussex county tend to be sandier than the Smyrna site, allowing greater organic matter losses, and theoretically worse cover crop performance (Burke et al., 1989). This could potentially be even more impactful for the on-farm trials, for which long-term management was not controlled prior to the study.

Additionally, kill dates could affect biomass results. Although all sites did final data collection in late March to early April, UD's on farm sites tended to be earlier in order to give on-farm fields back to the farmers. It is possible that some results may have become more equitable with more growing days allowing weaker performing plots to create more biomass. Duiker et al. (2014) found that wheat planted in early October in PA could increase from approximately 6,700 kg/ha of biomass in early May to 9,000 kg/ha in early June and wheat could increase from less than 4,500 to 9,000 kg/ha during the same period. Mirsky et al. (2011) found

that rye increased 2,000 kg/ha for each 10 days of termination delay from May 1 to June 1. The Delaware study averaged between 2,200 and 6,700 kg/ha of biomass measured in late March to early April, so it is likely that significant growth would have occurred if termination was delayed. Later termination and biomass sample collection timing would likely have resulted in significantly higher biomass results that could potentially also increase cover crop benefits, such as weed suppression. Wagner-Riddle et al. (1994) showed that delaying rye termination by one week consistently increased biomass, which is critical for weed suppression. However, Wagner-Riddle et al. (1994) also found that the later killing had the negative effect of decreasing soil water content one year, but, interestingly increased the water content another year. Future studies may benefit from collecting early biomass samples from research centers to compare to collaborator farm results, but delaying termination on the research farms to collect later soil and biomass data.

5.2. Farmer and Subsidy Recommendations

Based on the results of this project, specific cover crop management practices for greater groundcover, biomass, and/or N removal, recommendations can be made to farmers and subsidy program coordinators. First, the seeding rate labeled as high in this study was determined to have no benefit over medium rates and potentially produce less biomass than low rates when planted prior to October 1. Therefore, monoculture seeding rate recommendations are to not exceed 94, 101, and 101 kg/ha for rye, barley, and wheat, respectively. For rye/crimson clover mixes, rate recommendations are not to exceed 45 kg/ha of rye and 17 kg/ha of crimson clover. Furthermore, it appears that 11.2 kg/ha of crimson clover is sufficient in most cases when planting a rye/cover mix. Future research could potentially justify using even lower rates for all species/mixes.

Although results were not completely consistent, barley and wheat were most often the worst producers in groundcover, biomass, and/or N removal. The rye/clover mixes did occasionally outperform rye monocultures, as well, but the mixes often saw a decline with later dates that was more precipitous than rye alone. In general, rye at any date or rye/clover mixes at earlier dates are recommended for greater groundcover, biomass, and N removal. It should be noted that other cover crop species would be beneficial for other functions that were not studied in this project.

Ideal seeding methods depend on the resources and situations of individual farmers. Equipment costs/availability, soil disturbance, seed costs, and objectives should be part of the calculations when choosing or recommending seeding methods. With that being said, strictly for producing greater biomass and N removal, drilling cover crop seeds is recommended over broadcasting at equal rates. However, results from this study showed similar fall groundcover even without the increased broadcasting rate. Incorporating seeds is also tentatively recommended over broadcasting at a 30% increased rate, particularly at later dates and for increasing groundcover.

Lastly, earlier planting dates are recommended over standard, which are recommended over late. This is particularly apt for producing greater groundcover, but some results also showed greater biomass and N removal. The latest planting dates did perform poorly, regardless of crop, rate or method. Unfortunately, many farmers will still not be able to plant before these dates, so further solutions should be sought.

5.3. Future Research Recommendations Related to This Project

Results from this study showed that at one site, broadcasted plots without a 30% increase produced similar groundcover as drilled plots. Also, incorporated plots did perform better than

broadcasted plots with the 30% seeding rate increase, but this was not a uniform outcome across all treatment interactions. Furthermore, results showed that regardless of planting method, the seeding rate was not always directly correlated to cover crop productivity. Therefore, it is recommended that future research be done to do comprehensive analysis if this generally accepted 30% increase in broadcasted seeds is a cost-effective use of farmer expenses. Additional seeding rate studies should focus on further investigating lower seeding rates, especially for mixes, including rye and crimson clover but also other mixes that can include brassicas. Three-way mixes that include a grass, legume, and brassica are common recommendations made to farmers, but local research has not focused on ideal management specifications of these mixes.

Fall soil N at shallow and deep depths should be tested prior to cover crop planting to inform management. Research related to N levels should be encouraged. In soils with little to no remaining N, cover crops may not be as critical for nutrient management, but also may not be able to maximize other functional benefits, such as improved soil health and potentially reduced future fertilizer needs. Further research could improve the integration of cover crop and nutrient management planning to potentially increase agricultural and environmental benefits.

Although cover crops are often promoted as a ubiquitous source of benefits for farmers and environmental stewards, many studies show the complexities around integrating cover crop management into farming systems. Benefits are not uniformly achieved and there can even be negative outcomes, as well, such as with pests or difficulty in termination. Another example of potential issues is the available N for cash crops when they are planted following cover crops. Some cover crops can retain significant amounts of N after termination so that it is not plant available when needed by cash crops. Other cover crops can create conditions that cause the

removed N to mineralize too quickly for long-term cash crop utilization. Further research in Delaware could better advise farmers about efficient nutrient and fertilizer management based on cover crop characteristics and performance. Additionally, research and outreach in Delaware should focus on the species and management practices that can maximize the specific functions that Delaware farmers desire. Holistic, collaborative, and interdisciplinary research approaches with farmers' involvement should be sought to maximize cover crop functionality in various farming systems.

One of the clearest results from this study is that earlier planted cover crops were more productive. Although, this does not appear to be uniformly true in other studies, this no-till system of cover crops following corn harvest appears to be ideal for early planting. However, as already mentioned, farmers have firm external restrictions on when they can plant. Many farmers not only cannot meet subsidy deadlines, they are unable to plant in time to get cover crop benefits or even establishment. This is even more of a concern in fields following soybean harvests, which, based on weather conditions, can be well into December. Research to address this issue is essential for widespread and reliable cover crop use. This could potentially be done by identifying cover crop species that can be planted later and still produce functional benefits. More likely, solutions can be found by continuing research to find innovative ways of planting cover crop in fields prior to cash crop harvesting. This is currently being investigated, such as with the Penn State Inter-seeder, and "Highboy" air-seeder, but results have been inconsistent in the Mid-Atlantic region and many challenges remain. Getting more successful cover crops into the ground earlier may be the most effective method to improve agricultural and environmental benefits. On the other end of the growing season, research should continue into evaluating the best ways of planting cash crops after cover crops. Solutions can minimize bare soil and

disturbance, such as with planting green, but many challenges are still present before conclusive recommendations can be made.

Lastly, research with similar treatments and methodology as was done in this project should be replicated in order to strengthen or refine results and continually make improvements to recommendations in the future.

REFERENCES

Abdin, O. A., Coulman, B. E., Cloutier, D. C., Faris, M. A., & Smith, D. L. (1997). Establishment, development and yield of forage legumes and grasses as cover crops in grain corn in Eastern Canada. *Journal of agronomy and crop science*, *179*(1), 19-27.

Arai, Y., Livi, K. J. T., & Sparks, D. L. (2005). Phosphate reactivity in long-term poultry litter-amended southern Delaware sandy soils. Soil Science Society of America Journal, 69(3), 616-629.

Arthurs, J., Resource Conservationist, Delaware NRCS. (2018, October 27). Interview.

Balkcom, K. S., Massey, J. M., Mosjidis, J. A., Price, A. J., & Enloe, S. F. (2011). Planting date and seeding rate effects on sunn hemp biomass and nitrogen production for a winter cover crop. *International Journal of Agronomy*, *2011*.

Baraibar, B., Mortensen, D. A., Hunter, M. C., Barbercheck, M. E., Kaye, J. P., Finney, D. M., & White, C. M. (2018). Growing degree days and cover crop type explain weed biomass in winter cover crops. Agronomy for Sustainable Development, 38(6), 65.

Belfry, K. D., & Van Eerd, L. L. (2016). Establishment and impact of cover crops intersown into corn. *Crop Science*, *56*(3), 1245-1256.

Bergtold, J. S., Ramsey, S., Maddy, L., & Williams, J. R. (2017). A review of economic considerations for cover crops as a conservation practice. Renewable Agriculture and Food Systems, 1-15.

Burke, I. C., Yonker, C. M., Parton, W. J., Cole, C. V., Schimel, D. S., & Flach, K. (1989). Texture, climate, and cultivation effects on soil organic matter content in US grassland soils. Soil science society of America journal, 53(3), 800-805.

Campbell, C.A. et al. (1993). Spring wheat yield trends as influenced by fertilizer and legumes. J. Prod. Ag. 6:564-568.

Claassen, R., Bowman, M., McFadden, J., Smith, D., & Wallander, S. (2018). Tillage Intensity and Conservation Cropping in the United States. U.S. Department of Agriculture, Economic Research Service. Economic Information Bulletin Number 197.

Clark, A. (2007). Managing cover crops profitably—3rd ed. Sustainable Agriculture Research and Education (SARE). College Park, MD.

Clark, A. J., Decker, A. M., & Meisinger, J. J. (1994). Seeding rate and kill date effects on hairy vetch-cereal rye cover crop mixtures for corn production. Agronomy Journal, 86(6), 1065-1070.

Carr, P. M., Horsley, R. D., & Poland, W. W. (2003). Tillage and seeding rate effects on wheat cultivars. Crop science, 43(1), 210-218.

Curran, W. S., Hoover, R. J., Mirsky, S. B., Roth, G. W., Ryan, M. R., Ackroyd, V. J., ... & Pelzer, C. J. (2018). Evaluation of cover crops drill interseeded into corn across the Mid-Atlantic region. *Agronomy Journal*.

Dabney, S. M. (1998). Cover crop impacts on watershed hydrology. Journal of Soil and Water Conservation, 53(3), 207-213.

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

Den Hollander, N. G., Bastiaans, L., & Kropff, M. J. (2007). Clover as a cover crop for weed suppression in an intercropping design: I. Characteristics of several clover species. *European Journal of Agronomy*, *26*(2), 92-103

Delaware Natural Resources and Environmental Control (DNREC). Chesapeake Bay. (n.d.). Retrieved October 08, 2017, from http://delawarewatersheds.org/chesapeake-bay/

Delaware Natural Resources and Environmental Control (DNREC). Division of Soil and Water Conservation; Total Maximum Daily Loads (TMDL). (n.d.). Retrieved August 8, 2017, from http://www.dnrec.delaware.gov/swc/wa/Pages/WatershedAssessmentTMDLs.aspx

Delaware Code, Title 3, Chap. 22. Agriculture Regulatory Provisions. Nutrient Management. Subchapter III. State Nutrient Management Program. § 2247 (a), (b). Retrieved February 16, 2019 from: http://delcode.delaware.gov/title3/c022/sc03/index.shtml.

Delaware Environmental Observing System (DEOS). Historical Monthly Station Summary Retrieval. Retrieved March 5, 2019 from: http://www.deos.udel.edu/data/monthly_retrieval.php.

Derpsch, R., Franzluebbers, A. J., Duiker, S. W., Reicosky, D. C., Koeller, K., Friedrich, T., ... & Weiss, K. (2014). Why do we need to standardize no-tillage research? Soil and Tillage Research, 137, 16-22.

Derpsch, R., Friedrich, T., Kassam, A., & Li, H. (2010). Current status of adoption of no-till farming in the world and some of its main benefits. International Journal of Agricultural and Biological Engineering, 3(1), 1-25.

Ditsch, D. C., Alley, M. M., Kelley, K. R., & Lei, Y. Z. (1993). Effectiveness of winter rye for accumulating residual fertilizer N following corn. *Journal of Soil and Water Conservation*, *48*(2), 125-132.

Duiker, S. W. (2014). Establishment and termination dates affect fall-established cover crops. Agronomy Journal, 106(2), 670-678.

Erbach, D. C. (1982). Tillage for continuous corn and corn-soybean rotation. Transactions of the ASAE, 25(4), 906-0911.

Fox, M. & Monteith, T. (2015). Delaware's Transect Survey. We're Looking for Residue, have you seen any? Retrieved from: https://www.chesapeakebay.net/channel_files/21229/delawares_cropland_transect_survey_agwg.pdf

Francis, C. A., & Clegg, M. D. (1990). Crop rotations in sustainable production systems. Sustainable agricultural systems, 107-122.

Gaskin, J. W., Hancock, D., Uttam, S., Chatam, K. (2015). Cover Crop Biomass Sampling. University of Georgia Extension.

González-Esquiva, J. M., García-Mateos, G., Hernández-Hernández, J. L., Ruiz-Canales, A., Escarabajal-Henerajos, D., & Molina-Martínez, J. M. (2017). Web application for analysis of digital photography in the estimation of irrigation requirements for lettuce crops. *Agricultural water management*, *183*, 136-145.

Hively, W. D., Lang, M., McCarty, G. W., Keppler, J., Sadeghi, A., & McConnell, L. L. (2009). Using satellite remote sensing to estimate winter cover crop nutrient uptake efficiency. Journal of soil and water conservation, 64(5), 303-313.

Hellevang, Kenneth J. (1995). Grain Moisture Content Effects and Management. North Dakota State University Extension Service.

Jordan, J. L., Morgan, S. L., & Elnagheeb, A. H. (1994). An Economic Analysis of Cover Crop Use in Georgia to Protect Groundwater Quality. Research bulletin (University of Georgia. College of Agriculture. Experiment Stations) (USA).

Kepfer, S., State Resource Conservationist, Delaware NRCS. (2014, August, 14). Phone Interview.

Ketterings, Q. M., Swink, S. N., Duiker, S. W., Czymmek, K. J., Beegle, D. B., & Cox, W. J. (2015). Integrating cover crops for nitrogen management in corn systems on northeastern US dairies. *Agronomy Journal*, *107*(4), 1365-1376.

Lauer, J., Porter, P., & Oplinger, E. (1997). The corn and soybean rotation effect. Field Crops, 28, 426-514.

Liu, J., Bergkvist, G., & Ulén, B. (2015). Biomass production and phosphorus retention by catch crops on clayey soils in southern and central Sweden. *Field Crops Research*, *171*, 130-137.

Lyons, S. E., Ketterings, Q. M., Godwin, G., Cherney, J. H., Czymmek, K. J., & Kilcer, T. (2017). Early fall planting increases growth and nitrogen uptake of winter cereals. *Agronomy Journal*, *109*(3), 795-801.

Ma, S., Swinton, S. M., Lupi, F., & Jolejole, C. B. (2010). Why farmers opt not to enroll in payment-for-environmental-services programs (No. 320-2016-10468).

Marshall, E. P. (2012). Incentives, costs, and implications of wide-spread cover crop adoption in the United States (No. 323-2016-11680).

McDonald, P. B., Singer, J. W., & Wiedenhoeft, M. H. (2008). Establishment and Growth of Self-Seeded Winter Cereal Cover Crops in a Soybean–Corn Rotation. *Agronomy journal*, *100*(2), 432-439.

Mirsky, S. B., Ackroyd, V. J., Cordeau, S., Curran, W. S., Hashemi, M., Reberg-Horton, S. C., ... & Spargo, J. T. (2017). Hairy vetch biomass across the Eastern United States: Effects of latitude, seeding rate and date, and termination timing. *Agronomy Journal*, *109*(4), 1510-1519.

Mirsky, S. B., Curran, W. S., Mortenseny, D. M., Ryany, M. R., & Shumway, D. L. (2011). Timing of cover-crop management effects on weed suppression in no-till planted soybean using a roller-crimper. *Weed Science*, *59*(3), 380-389.

Mirsky, S. B., Ryan, M. R., Curran, W. S., Teasdale, J. R., Maul, J., Spargo, J. T., . . . Camargo, G. G. (2012). Conservation tillage issues: Cover crop-based organic rotational no-till grain production in the mid-atlantic region, USA. Renewable Agriculture and Food Systems, 27(1), 31-40.

Monteith, T. S., Environmental Scientist III, Sussex County Watershed Coordinator, Watershed Assessment and Management Section, DNREC Division of Watershed Stewardship (2019, February, 19). Email Interview.

Murrell, E. G., Schipanski, M. E., Finney, D. M., Hunter, M. C., Burgess, M., LaChance, J. C., ... & Kaye, J. P. (2017). Achieving diverse cover crop mixtures: effects of planting date and seeding rate. *Agronomy Journal*, *109*(1), 259-271.

Natural Resources Conservation Service. (2016, September). Retrieved October 08, 2017, from https://www.nrcs.usda.gov/wps/portal/nrcs/main/de/water/watersheds/

Natural Resources Conservation Service. Conservation Practice Code 340. (2011). Retrieved February 11, 2018 from: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1046845.pdf

Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Retrieved October 28, 2018 from: https://websoilsurvey.sc.egov.usda.gov/.

Nelson, Jennifer. State Association Executive Director. Delaware Association for Conservation Districts. (2019, March 24.) Email Interview.

Noland, R. L., Wells, M. S., Sheaffer, C. C., Baker, J. M., Martinson, K. L., & Coulter, J. A. (2018). Establishment and function of cover crops interseeded into corn. *Crop Science*, *58*(2), 863-873.

Øgaard, A. F. (2015). Freezing and thawing effects on phosphorus release from grass and cover crop species. Acta Agriculturae Scandinavica, Section B—Soil & Plant Science, 65(6), 529-536.

Oregon State University (OSU, 2018). Tillering. Retrieved from https://forages.oregonstate.edu/regrowth/how-does-grass-grow/developmental-phases/vegetative-phase/tillering

Patrignani, A., & Ochsner, T. E. (2015). Canopeo: A powerful new tool for measuring fractional green canopy cover. Agronomy Journal, 107(6), 2312-2320.

Peltonen-Sainio, P., & Järvinen, P. (1995). Seeding rate effects on tillering, grain yield, and yield components of oat at high latitude. Field Crops Research, 40(1), 49-56.

Pietilainen, O. P. (1991). Dissolved reactive and total phosphorus load from agricultural and forested basins to surface waters in Finland. Aqua Fennica, 21, 127-136.

Rabotyagov, S. S., Kling, C. L., Gassman, P. W., Rabalais, N. N., & Turner, R. E. (2014). The economics of dead zones: Causes, impacts, policy challenges, and a model of the Gulf of Mexico hypoxic zone. Review of Environmental Economics and Policy, 8(1), 58-79.

Reeves, D. W. (2017). Cover crops and rotations. In Crops residue management (pp. 125-172). CRC Press.

Reicosky, D. C., & Forcella, F. (1998). Cover crop and soil quality interactions in agroecosystems. *Journal of Soil and Water Conservation*, *53*(3), 224-229.

Rosecrance, R. C., McCarty, G. W., Shelton, D. R., & Teasdale, J. R. (2000). Denitrification and N mineralization from hairy vetch (Vicia villosa Roth) and rye (Secale cereale L.) cover crop monocultures and bicultures. Plant and Soil, 227(1-2), 283-290.

Sarrantonio, Marianne. (1996). Northeast Cover Crop Handbook. Rodale Institute.

Schartz, R. J., & Janke, R. R. (1999). Evaluation of native legumes for use as cover crops. *Journal of Sustainable Agriculture*, *15*(2-3), 45-59.

Schomberg, H. H., & Endale, D. M. (2005). Cover crop effects on nitrogen mineralization and availability in conservation tillage cotton. *Biology and Fertility of Soils*, *41*(1), 73-74.

Shipley, P., Messinger, J. J., & Decker, A. M. (1992). Conserving residual corn fertilizer nitrogen with winter cover crops. *Agronomy Journal*, *84*(5), 869-876.

Sims, J. T., Edwards, A. C., Schoumans, O. F., & Simard, R. R. (2000). Integrating soil phosphorus testing into environmentally based agricultural management practices. Journal of Environmental Quality, 29(1), 60-71.

Singer, J. W., Nusser, S. M., & Alf, C. J. (2007). Are cover crops being used in the US corn belt? Journal of Soil and Water Conservation, 62(5), 353-358.

Snapp, S. S., S. M. Swinton, R. Labarta, D. Mutch, J. R. Black, R. Leep, J. Nyiraneza, and K. O'Neil. (2005). Evaluating Cover Crops for Benefits, Costs and Performance within Cropping System Niches. Agron. J. 97:322-332. doi:10.2134/agronj2005.0322

Sharpley, A., Foy, B., & Withers, P. (2000). Practical and innovative measures for the control of agricultural phosphorus losses to water: an overview. Journal of Environmental Quality, 29(1), 1-9.

Staver, K. W., & Brinsfield, R. B. (1998). Using cereal grain winter cover crops to reduce groundwater nitrate contamination in the mid-Atlantic coastal plain. Journal of Soil and Water Conservation, 53(3), 230-240.

Sturgis, B. (2017, April 10). Environmental Scientist IV, DNREC Division of Watershed Stewardship. Email Interview.

Thapa, R., Poffenbarger, H., Tully, K. L., Ackroyd, V. J., Kramer, M., & Mirsky, S. B. (2018). Biomass Production and Nitrogen Accumulation by Hairy Vetch–Cereal Rye Mixtures: A Meta-Analysis. *Agronomy Journal*, *110*(4), 1197-1208.

Thomas, A. (2016, July 14). UD researchers look at programs to incentivize cover crop adoption among growers. Retrieved from: https://www.udel.edu/udaily/2016/july/incentivizing-cover-crop-adoption/.

United States. Clean Water Act, sec. 303(d), 33 U.S.C. § 1313(d).

United States Department of Agriculture (USDA), Economic Research Service, National Agricultural Statistics Service (NASS) (2012). Census of Agriculture.

United States Department of Agriculture (USDA), National Agricultural Statistics Service (NASS) (2017). State Agriculture Overview, Delaware. Retrieved February 10, 2019, from: https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=DELAWARE.

United States Department of Agriculture, National Agricultural Statistics Service (NASS), Delaware Department of Agriculture (DDA). Delaware Agricultural Statistics Bulletin (2015-2016).

United States Department of Agriculture, Natural Resources Conservation Service (2014). National Handbook of Conservation Practices. http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/references/?cid=nrcs143_026849

University of Delaware (UD), Phosphorous in Poultry Litter: Guidelines from the University of Delaware. (n.d.). Retrieved December 12, 2017, from http://extension.udel.edu/factsheets/phosphorous-in-poultry-litter-new-guidelines- from-the-university-of-delaware/

Vann, R. A., Reberg-Horton, S. C., Castillo, M. S., McGee, R. J., & Mirsky, S. B. (2019). Winter Pea, Crimson Clover, and Hairy Vetch Planted in Mixture with Small Grains in the Southeast United States. *Agronomy Journal*, *111*(2), 805-815.

Villamil, M. B., Bollero, G. A., Darmody, R. G., Simmons, F. W., & Bullock, D. G. (2006). No-till corn/soybean systems including winter cover crops. Soil Science Society of America Journal, 70(6), 1936-1944.

Wagner-Riddle, C., Gillespie, T. J., & Swanton, C. J. (1994). Rye cover crop management impact on soil water content, soil temperature and soybean growth. *Canadian journal of plant science*, *74*(3), 485-495.

White, C. M., DuPont, S. T., Hautau, M., Hartman, D., Finney, D. M., Bradley, B., ... & Kaye, J. P. (2017). Managing the tradeoff between nitrogen supply and retention with cover crop mixtures. Agriculture, ecosystems & environment, 237, 121-133.

Yeo, I. Y., Lee, S., Sadeghi, A. M., Beeson, P. C., Hively, W. D., McCarty, G. W., & Lang, M. W. (2014). Assessing winter cover crop nutrient uptake efficiency using a water quality simulation model. *Hydrology and Earth System Sciences*, *18*(12), 5239-5253.

APPENDIX

Table A-1: DSU Site-2016. SAS Output with the effects of planting date and planting method interactions on percent fall ground coverage shown from photographs taken in December 2015 and analyzed with Canopeo.

DSU Cover Crops

Effect=Method*date Method=Tukey(P<.05) Set=1

Obs	crop	Method	date	Estimate	Standard Error	Letter Group
1		Broadcas	Early	74.4764	2.2602	A
2		Broadcas	Late	28.2650	2.2602	D
3		Broadcas	Standard	44.1381	2.2602	C
4		Drilled	Early	72.2231	2.2602	A
5		Drilled	Late	25.3106	2.2602	D
6		Drilled	Standard	55.2175	2.2602	B

Table A-2: DSU Site-2016. SAS Output with the effects of planting date on percent ground coverage shown from photographs taken in December 2015 and analyzed with Canopeo.

Effect=time Method=Tukey-Kramer(P<.05) Set=2

Obs	crop	Method	time	Estimate	Standard Error	Letter Group
5			Early	73.3497	1.6683	A
6			Late	26.7878	1.6683	C
7			Standard	49.6778	1.6683	B

Table A-3: DSU Site-2016. SAS Output with the effects of planting date and planting method interactions on percent ground coverage shown from photographs taken in December 2015 and analyzed with Canopeo.

Effect=crop Method=Tukey(P<.05) Set=2

Obs	crop	Method	date	Estimate	Standard Error	Letter Group
7	Barley			50.2131	1.8454	A
8	Rye			55.1457	1.8454	A
9	Rye_Cl			51.0987	1.8454	A
10	Wheat			43.2961	1.8454	B

Table A-4: DSU Site-2016. SAS Output for the effects of planting method on dried aboveground biomass, collected in April, 2016 (ton/ac).

Effect=Method Method=Tukey-Kramer(P<.05) Set=1

Obs	crop	Method	rate	time	Estimate	Standard Error	Letter Group
1		Broadcas			2.4221	0.2194	B
2		Drilled			3.1611	0.2194	A

Table A-5: DSU Site-2016. SAS Output for the effects of seeding rate and planting date interactions on dried aboveground biomass, collected in April, 2016 (ton/ac).

Effect=rate*time Method=Tukey-Kramer(P<.05) Set=2

Obs	crop	Method	rate	time	Estimate	Standard Error	Letter Group
3			High	Early	3.2983	0.3021	B
4			High	Late	1.9200	0.3021	CD
5			High	Standard	2.8096	0.3021	BC
6			Low	Early	4.3646	0.3021	A
7			Low	Late	1.2087	0.3021	D
8			Low	Standard	2.9704	0.3021	B
9			Medium	Early	3.7254	0.3021	AB
10			Medium	Late	1.2804	0.3021	D
11			Medium	Standard	3.5471	0.3021	AB

Table A-6: DSU Site-2016. SAS Output for the effects of crop species and planting date interactions on dried aboveground biomass, collected in April, 2016 (ton/ac).

Effect=crop*time Method=Tukey-Kramer(P<.05) Set=3

Obs	crop	Method	rate	time	Estimate	Standard Error	Letter Group
12	Barley			Early	3.1761	0.3313	C
13	Barley			Late	1.2922	0.3313	F
14	Barley			Standard	2.6667	0.3313	CDE
15	Rye			Early	4.7189	0.3313	A
16	Rye			Late	2.1333	0.3313	CDEF
17	Rye			Standard	4.7550	0.3313	A
18	Rye/Clov			Early	4.4933	0.3313	AB
19	Rye/Clov			Late	1.3983	0.3313	EF
20	Rye/Clov			Standard	3.3544	0.3313	BC
21	Wheat			Early	2.7961	0.3313	CD
22	Wheat			Late	1.0550	0.3313	F
23	Wheat			Standard	1.6600	0.3313	DEF

Table A-7: DSU Site-2016. SAS Output for the effects of planting method on N removal from plant samples collected in April, 2016 (lbs/ac).

Effect=Method Method=Tukey-Kramer(P<.05) Set=3

Obs	crop	Method	rate	time	Estimate	Standard Error	Letter Group
22		Broadcas			99.3719	13.0016	B
23		Drilled			130.78	12.9861	A

Table A-8: DSU Site-2016. The effects of seeding rate and planting date interactions on N removal from plant samples collected in April, 2016 (lbs/ac).

Effect=rate*time Method=Tukey-Kramer(P<.05) Set=2

Obs	crop	Method	rate	time	Estimate	Standard Error	Letter Group
13			High	Early	127.42	17.4840	BC
14			High	Late	75.6808	17.4840	CD
15			High	Standard	108.19	17.4840	BCD
16			Low	Early	189.50	17.4840	A
17			Low	Late	49.7704	17.4840	D
18			Low	Standard	134.81	17.4840	AB
19			Medium	Early	148.12	17.4840	AB
20			Medium	Late	49.8765	17.7153	D
21			Medium	Standard	152.32	17.4840	AB

Table A-9: DSU Site-2016. SAS Output for the effects of crop species and planting date interactions on N removal from plant samples collected in April, 2016 (lbs/ac).

Effect=crop*time Method=Tukey-Kramer(P<.05) Set=1

Obs	crop	Method	rate	time	Estimate	Standard Error	Letter Group
1	Barley			Early	106.87	19.0899	BC
2	Barley			Late	48.2389	19.0899	C
3	Barley			Standard	90.8122	19.0899	C
4	Rye			Early	208.04	19.0899	A
5	Rye			Late	84.3172	19.0899	C
6	Rye			Standard	212.53	19.0899	A
7	Rye/Clov			Early	210.05	19.0899	A
8	Rye/Clov			Late	60.4667	19.0899	C
9	Rye/Clov			Standard	163.92	19.0899	AB
10	Wheat			Early	95.1028	19.0899	BC
11	Wheat			Late	40.7476	19.4654	C
12	Wheat			Standard	59.8283	19.0899	C

Table A-10: DSU Site-2016. The effects of crop species, seeding rate, planting method and planting date interactions on Total Soil N from 0-6 in. samples collected in April, 2016 (lbs/ac).

Effect=crop*rate*Metho*time Method=Tukey(P<0.1) Set=1

Obs	crop	rate	Method	time	Estimate	Standard Error	Alpha	Lower	Upper	Letter Group
1	Barley	High	Broadcas	Early	0.2340	0.01682	0.1	0.2062	0.2618	A
2	Barley	High	Broadcas	Late	0.2117	0.01682	0.1	0.1838	0.2395	AB
3	Barley	High	Broadcas	Standard	0.2287	0.01682	0.1	0.2008	0.2565	A
4	Barley	High	Drilled	Early	0.2283	0.01682	0.1	0.2005	0.2562	A
5	Barley	High	Drilled	Late	0.2040	0.01682	0.1	0.1762	0.2318	AB
6	Barley	High	Drilled	Standard	0.2060	0.01682	0.1	0.1782	0.2338	AB
7	Barley	Low	Broadcas	Early	0.2213	0.01682	0.1	0.1935	0.2492	A
8	Barley	Low	Broadcas	Late	0.2023	0.01682	0.1	0.1745	0.2302	AB
9	Barley	Low	Broadcas	Standard	0.2407	0.01682	0.1	0.2128	0.2685	A
10	Barley	Low	Drilled	Early	0.2133	0.01682	0.1	0.1855	0.2412	AB
11	Barley	Low	Drilled	Late	0.2050	0.01682	0.1	0.1772	0.2328	AB
12	Barley	Low	Drilled	Standard	0.1907	0.01682	0.1	0.1628	0.2185	AB
13	Barley	Medium	Broadcas	Early	0.2513	0.01682	0.1	0.2235	0.2792	A
14	Barley	Medium	Broadcas	Late	0.2117	0.01682	0.1	0.1838	0.2395	AB
15	Barley	Medium	Broadcas	Standard	0.2193	0.01682	0.1	0.1915	0.2472	A
16	Barley	Medium	Drilled	Early	0.2217	0.01682	0.1	0.1938	0.2495	A
17	Barley	Medium	Drilled	Late	0.2080	0.01682	0.1	0.1802	0.2358	AB
18	Barley	Medium	Drilled	Standard	0.2370	0.01682	0.1	0.2092	0.2648	A
19	Rye	High	Broadcas	Early	0.2480	0.01682	0.1	0.2202	0.2758	A
20	Rye	High	Broadcas	Late	0.2080	0.01682	0.1	0.1802	0.2358	AB
21	Rye	High	Broadcas	Standard	0.2147	0.01682	0.1	0.1868	0.2425	AB
22	Rye	High	Drilled	Early	0.1187	0.01682	0.1	0.09083	0.1465	B
23	Rye	High	Drilled	Late	0.2170	0.01682	0.1	0.1892	0.2448	A
24	Rye	High	Drilled	Standard	0.2303	0.01682	0.1	0.2025	0.2582	A
25	Rye	Low	Broadcas	Early	0.1970	0.01682	0.1	0.1692	0.2248	AB
26	Rye	Low	Broadcas	Late	0.2240	0.01682	0.1	0.1962	0.2518	A
27	Rye	Low	Broadcas	Standard	0.2270	0.01682	0.1	0.1992	0.2548	A
28	Rye	Low	Drilled	Early	0.1987	0.01682	0.1	0.1708	0.2265	AB
29	Rye	Low	Drilled	Late	0.2100	0.01682	0.1	0.1822	0.2378	AB
30	Rye	Low	Drilled	Standard	0.2263	0.01682	0.1	0.1985	0.2542	A
31	Rye	Medium	Broadcas	Early	0.2330	0.01682	0.1	0.2052	0.2608	A
32	Rye	Medium	Broadcas	Late	0.2323	0.01682	0.1	0.2045	0.2602	A
33	Rye	Medium	Broadcas	Standard	0.2543	0.01682	0.1	0.2265	0.2822	A
34	Rye	Medium	Drilled	Early	0.2323	0.01682	0.1	0.2045	0.2602	A
35	Rye	Medium	Drilled	Late	0.2180	0.01682	0.1	0.1902	0.2458	A
36	Rye	Medium	Drilled	Standard	0.2333	0.01682	0.1	0.2055	0.2612	A

37	Rye/Clov	High	Broadcas	Early	0.2167	0.01682	0.1	0.1888	0.2445	A
38	Rye/Clov	High	Broadcas	Late	0.2037	0.01682	0.1	0.1758	0.2315	AB
39	Rye/Clov	High	Broadcas	Standard	0.2147	0.01682	0.1	0.1868	0.2425	AB
40	Rye/Clov	High	Drilled	Early	0.2053	0.01682	0.1	0.1775	0.2332	AB
41	Rye/Clov	High	Drilled	Late	0.2213	0.01682	0.1	0.1935	0.2492	A
42	Rye/Clov	High	Drilled	Standard	0.2257	0.01682	0.1	0.1978	0.2535	A
43	Rye/Clov	Low	Broadcas	Early	0.2397	0.01682	0.1	0.2118	0.2675	A
44	Rye/Clov	Low	Broadcas	Late	0.2413	0.01682	0.1	0.2135	0.2692	A
45	Rye/Clov	Low	Broadcas	Standard	0.2220	0.01682	0.1	0.1942	0.2498	A
46	Rye/Clov	Low	Drilled	Early	0.2380	0.01682	0.1	0.2102	0.2658	A
47	Rye/Clov	Low	Drilled	Late	0.2067	0.01682	0.1	0.1788	0.2345	AB
48	Rye/Clov	Low	Drilled	Standard	0.2203	0.01682	0.1	0.1925	0.2482	A
49	Rye/Clov	Medium	Broadcas	Early	0.2270	0.01682	0.1	0.1992	0.2548	A
50	Rye/Clov	Medium	Broadcas	Late	0.2237	0.01682	0.1	0.1958	0.2515	A
51	Rye/Clov	Medium	Broadcas	Standard	0.2097	0.01682	0.1	0.1818	0.2375	AB
52	Rye/Clov	Medium	Drilled	Early	0.2210	0.01682	0.1	0.1932	0.2488	A
53	Rye/Clov	Medium	Drilled	Late	0.2107	0.01682	0.1	0.1828	0.2385	AB
54	Rye/Clov	Medium	Drilled	Standard	0.1977	0.01682	0.1	0.1698	0.2255	AB
55	Wheat	High	Broadcas	Early	0.2387	0.01682	0.1	0.2108	0.2665	A
56	Wheat	High	Broadcas	Late	0.2267	0.01682	0.1	0.1988	0.2545	A
57	Wheat	High	Broadcas	Standard	0.2407	0.01682	0.1	0.2128	0.2685	A
58	Wheat	High	Drilled	Early	0.2433	0.01682	0.1	0.2155	0.2712	A
59	Wheat	High	Drilled	Late	0.2460	0.01682	0.1	0.2182	0.2738	A
60	Wheat	High	Drilled	Standard	0.2153	0.01682	0.1	0.1875	0.2432	A
61	Wheat	Low	Broadcas	Early	0.2137	0.01682	0.1	0.1858	0.2415	AB
62	Wheat	Low	Broadcas	Late	0.2073	0.01682	0.1	0.1795	0.2352	AB
63	Wheat	Low	Broadcas	Standard	0.2420	0.01682	0.1	0.2142	0.2698	A
64	Wheat	Low	Drilled	Early	0.2347	0.01682	0.1	0.2068	0.2625	A
65	Wheat	Low	Drilled	Late	0.1997	0.01682	0.1	0.1718	0.2275	AB
66	Wheat	Low	Drilled	Standard	0.2087	0.01682	0.1	0.1808	0.2365	AB
67	Wheat	Medium	Broadcas	Early	0.2310	0.01682	0.1	0.2032	0.2588	A
68	Wheat	Medium	Broadcas	Late	0.2057	0.01682	0.1	0.1778	0.2335	AB
69	Wheat	Medium	Broadcas	Standard	0.1737	0.01682	0.1	0.1458	0.2015	AB
70	Wheat	Medium	Drilled	Early	0.2087	0.01682	0.1	0.1808	0.2365	AB
71	Wheat	Medium	Drilled	Late	0.2300	0.01682	0.1	0.2022	0.2578	A
72	Wheat	Medium	Drilled	Standard	0.2587	0.01682	0.1	0.2308	0.2865	A

Table A-11 DSU Site-2016. The effects of planting method on Total Soil N from 6-12 in. samples collected in April, 2016 (lbs/ac).

Effect=Method Method=Tukey-Kramer(P<.1) Set=1

Obs	Method	Estimate	Standard Error	Alpha	Lower	Upper	Letter Group
1	Broadcas	0.1349	0.003800	0.1	0.1257	0.1442	A
2	Drilled	0.1257	0.003813	0.1	0.1165	0.1349	B

Table A-12: UD Site-1-L-2016. SAS Output for the effects of cover crop species planted on September 9, 2015 on dried aboveground biomass, collected in spring, 2016 (ton/ac).

Effect=crop Method=Tukey-Kramer(P<.05) Set=1

Obs	time	crop	Estimate	Standard Error	Letter Group
11	1-Oct	Barley	1.3775	0.1152	AB
12	1-Oct	CC_Rye	1.5877	0.1177	A
13	1-Oct	Rye	1.3600	0.1152	AB
14	1-Oct	Rye_CC	1.1788	0.1152	AB
15	1-Oct	Wheat	1.1396	0.1152	B

Table A-13: UD Site-1-L-2016. SAS Output for the effects of cover crop species planted on October 1, 2015 on dried aboveground biomass, collected in spring, 2016 (ton/ac).

Obs	time	crop	Estimate	Standard Error	Letter Group
1	15-Oct	Barley	0.8400	0.1652	A
2	15-Oct	CC_Rye	0.6533	0.1652	A
3	15-Oct	Rye	1.0517	0.1652	A
4	15-Oct	Rye_CC	0.8550	0.1652	A
5	15-Oct	Wheat	1.2033	0.1652	A

Table A-14: UD Site-1-L-2016. SAS Output for the effects of cover crop species planted on October 20, 2015 on dried aboveground biomass, collected in spring, 2016 (ton/ac).

Effect=crop Method=Tukey(P<.05) Set=3

Obs	time	crop	Estimate	Standard Error	Letter Group
6	31-Oct	Barley	0.9700	0.1614	A
7	31-Oct	CC_Rye	0.6817	0.1614	A
8	31-Oct	Rye	0.6517	0.1614	A
9	31-Oct	Rye_CC	0.7000	0.1614	A
10	31-Oct	Wheat	0.8183	0.1614	A

Table A-15: UD Site-1-L-2016. SAS Output for the effects of cover crop species planted on September 9, 2015 (early planting date) on N removal in samples collected in spring, 2016 (lbs/ac).

Effect=crop Method=Tukey-Kramer(P<.05) Set=1

Obs	time	crop	Estimate	Standard Error	Letter Group
11	1-Oct	Barley	54.6388	4.4531	AB
12	1-Oct	CC_Rye	64.9227	4.5517	A
13	1-Oct	Rye	52.7225	4.4531	AB
14	1-Oct	Rye_CC	46.0583	4.4531	B
15	1-Oct	Wheat	39.4321	4.4531	B

Table A-16: UD Site-1-L-2016. SAS Output for the effects of cover crop species planted on October 1, 2015 (standard planting date) on N removal in samples collected in spring, 2016 (lbs/ac).

Effect=crop Method=Tukey(P<.05) Set=2

Obs	time	crop	Estimate	Standard Error	Letter Group
1	15-Oct	Barley	26.4833	4.1926	A
2	15-Oct	CC_Rye	22.4667	4.1926	A
3	15-Oct	Rye	28.6450	4.1926	A
4	15-Oct	Rye_CC	28.9917	4.1926	A
5	15-Oct	Wheat	34.3550	4.1926	A

Table A-17: UD Site-1-L-2016. SAS Output for the effects of cover crop species planted on October 20, 2015 (late planting date) on dried aboveground biomass, collected in spring, 2016 (lbs/ac).

Effect=crop Method=Tukey(P<.05) Set=3

Obs	time	crop	Estimate	Standard Error	Letter Group
6	31-Oct	Barley	29.8383	4.0473	A
7	31-Oct	CC_Rye	20.2050	4.0473	A
8	31-Oct	Rye	21.0917	4.0473	A
9	31-Oct	Rye_CC	21.8317	4.0473	A
10	31-Oct	Wheat	25.4700	4.0473	A

Table A-18: UD Site-1-L-2016. SAS Output for the effects of cover crop species on Total Soil N from 0-6 in. samples collected in spring, 2016 (lbs/ac).

Effect=crop Method=Tukey-Kramer(P<0.1) Set=1

Obs	crop	Estimate	Standard Error	Alpha	Lower	Upper	Letter Group
1	Barley	0.1810	0.01461	0.1	0.1538	0.2083	B
2	CC_Rye	0.2011	0.01461	0.1	0.1738	0.2283	AB
3	Rye	0.2087	0.01461	0.1	0.1815	0.2359	A
4	Rye_CC	0.2056	0.01461	0.1	0.1783	0.2328	AB
5	Wheat	0.1938	0.01461	0.1	0.1665	0.2210	AB

Table A-19: UD Site-1-L-2016. SAS Output for the effects of cover crop species on total Soil N from 6-12 in. samples collected in spring, 2016 (lbs/ac).

Effect=crop Method=Tukey(P<.1) Set=1

Obs	crop	rate	time	Estimate	Standard Error	Alpha	Lower	Upper	Letter Group
1	Barley			0.1401	0.007580	0.1	0.1275	0.1526	A
2	CC_Rye			0.1147	0.007580	0.1	0.1022	0.1272	A
3	Rye			0.1204	0.007580	0.1	0.1078	0.1329	A
4	Rye_CC			0.1160	0.007580	0.1	0.1035	0.1285	A
5	Wheat			0.1324	0.007580	0.1	0.1199	0.1450	A

Table A-20: UD Site-1-L-2016. SAS Output for the effects of seeding rate and planting date interactions on Total Soil N from 6-12 in. samples collected in spring, 2016. 'Time' shown indicate early (9-Sep), standard (1-Oct), and late (20-Oct) planting dates (lbs/ac).

Effect=rate*time Method=Tukey(P<.1) Set=2

Obs	crop	rate	time	Estimate	Standard Error	Alpha	Lower	Upper	Letter Group
6		H	1-Oct	0.1131	0.01017	0.1	0.09628	0.1299	A
7		H	15-Oct	0.1252	0.01017	0.1	0.1083	0.1420	A
8		H	31-Oct	0.1435	0.01017	0.1	0.1266	0.1603	A
9		L	1-Oct	0.1206	0.01017	0.1	0.1037	0.1374	A
10		L	15-Oct	0.1358	0.01017	0.1	0.1189	0.1526	A
11		L	31-Oct	0.1053	0.01017	0.1	0.08848	0.1221	A
12		M	1-Oct	0.1275	0.01017	0.1	0.1106	0.1443	A
13		M	15-Oct	0.1273	0.01017	0.1	0.1105	0.1442	A
14		M	31-Oct	0.1243	0.01017	0.1	0.1075	0.1411	A

Table A-21: UD Site-2-C-2016. SAS output for the effects of seeding rates on percent fall ground coverage shown from photographs taken in December 2015 and analyzed with Canopeo.

Effect=rate Method=Tukey-Kramer(P<.05) Set=1

Obs	crop	Method	rate	Estimate	Standard Error	Letter Group
1			H	39.6743	3.3772	A
2			L	27.8568	3.3772	B
3			M	34.7335	3.3772	A

Table A-22: UD Site-2-C-2016. SAS output for the effects of crop species and planting method interactions on percent fall ground coverage shown from photographs taken in December 2015 and analyzed with Canopeo.

Effect=crop*Method Method=Tukey-Kramer(P<.05) Set=2

Obs	crop	Method	rate	Estimate	Standard Error	Letter Group
4	Barley	Broad		28.5708	4.4083	BCD
5	Barley	Incorp		28.2142	4.4083	BCD
6	CC_Rye	Broad		36.8333	4.4083	ABCD
7	CC_Rye	Incorp		44.9442	4.4083	A
8	Rye	Broad		26.2550	4.4083	CD
9	Rye	Incorp		45.0058	4.4083	A
10	Rye_CC	Broad		40.9050	4.4083	ABC
11	Rye_CC	Incorp		42.9083	4.4083	AB
12	Wheat	Broad		22.0625	4.4083	D
13	Wheat	Incorp		25.1825	4.4083	D

Table A-23: UD Site-2-C-2016. SAS output for the effects of planting method on percent spring ground coverage shown from photographs taken in spring 2016 and analyzed with Canopeo.

Effect=Method Method=Tukey-Kramer(P<.05) Set=1

Obs	crop	Method	rate	Estimate	Standard Error	Letter Group
1		Broad		42.3638	3.6884	A
2		Incorp		46.7440	3.6884	A

Table A-24: UD Site-2-C-2016. SAS output for the effects of crop species and seeding rate interactions on percent spring ground coverage shown from photographs taken in spring 2016 and analyzed with Canopeo.

Effect=crop*rate Method=Tukey-Kramer(P<.05) Set=2

Obs	crop	Method	rate	Estimate	Standard Error	Letter Group
3	Barley		H	32.1300	5.6291	D
4	Barley		L	19.8938	5.6291	D
5	Barley		M	26.6050	5.6291	D
6	CC_Rye		H	78.4413	5.6291	A
7	CC_Rye		L	55.2713	5.6291	BC
8	CC_Rye		M	67.6000	5.6291	AB
9	Rye		H	30.0400	5.6291	D
10	Rye		L	22.8888	5.6291	D
11	Rye		M	36.3275	5.6291	CD
12	Rye_CC		H	59.7363	5.6291	AB
13	Rye_CC		L	68.9875	5.6291	AB
14	Rye_CC		M	75.7525	5.6291	AB
15	Wheat		H	35.9575	5.6291	CD
16	Wheat		L	31.0925	5.6291	D
17	Wheat		M	27.5850	5.6291	D

Table A-25: UD Site-2-C-2016. The effects of cover crop species planted on October 8, 2015 (standard date) on dried aboveground biomass, collected in spring, 2016 (ton/ac).

Effect=crop Method=Tukey-Kramer(P<.05) Set=1

Obs	time	crop	Estimate	Standard Error	Letter Group
1	8-Oct	Barley	0.8889	0.1525	B
2	8-Oct	CC_Rye	1.2346	0.1505	A
3	8-Oct	Rye	0.9204	0.1505	B
4	8-Oct	Rye_CC	1.3425	0.1505	A
5	8-Oct	Wheat	0.7017	0.1505	B

Table A-26: UD Site-3-M-2016. SAS output for the effects of cover crop species on percent fall ground coverage shown from photographs taken in December 2015 and analyzed with Canopeo.

Effect=crop Method=Tukey-Kramer(P<.05) Set=1

Obs	crop	Method	Estimate	Standard Error	Letter Group
1	Barley		20.9321	4.3387	A
2	CC_Rye		28.8378	3.2779	A
3	Rye		32.0714	3.8640	A
4	Rye_CC		23.2662	3.3394	A
5	Wheat		21.5561	3.1355	A

Table A-27: UD Site-3-M-2016. SAS output for the effects of cover crop species on percent spring ground coverage shown from photographs taken in spring 2016 and analyzed with Canopeo.

Effect=crop Method=Tukey-Kramer(P<.05) Set=1

Obs	crop	Estimate	Standard Error	Letter Group
1	Barley	18.2907	3.9662	A
2	CC_Rye	20.8352	2.7171	A
3	Rye	19.6528	3.3872	A
4	Rye_CC	20.2557	2.7977	A
5	Wheat	23.1922	2.5247	A

Table A-28: UD Site-3-M-2016. SAS output for the effects of planting methods on percent fall ground coverage shown from photographs taken in December 2015 and analyzed with Canopeo.

Effect=Method Method=Tukey-Kramer(P<.05) Set=2

Obs	crop	Method	Estimate	Standard Error	Letter Group
6		Broad	22.4110	2.5418	B
7		Incorp	28.2544	2.9084	A

Table A-29: UD Site-1-G-2018. (On next pages.) SAS output for the effects of cover crop species, method, rate, and time interactions on percent spring ground coverage shown from photographs taken in spring 2018 and analyzed with Canopeo.

Effect=crop*Metho*rate*time Method=Tukey-Kramer(P<.05) Set=1

Obs	crop	Method	rate	time	Estimate	Standard Error	Letter Group
1	Barley	Broad	H	30-Sep	14.6525	2.1180	EFGHIJKLMNO
2	Barley	Broad	H	31-Oct	3.2762	2.1180	O
3	Barley	Broad	L	30-Sep	12.7087	2.1180	GHIJKLMNO
4	Barley	Broad	L	31-Oct	6.8025	2.1180	NO
5	Barley	Broad	M	30-Sep	13.8412	2.1180	EFGHIJKLMNO
6	Barley	Broad	M	31-Oct	3.9687	2.1180	O
7	Barley	Incorp	H	30-Sep	13.3975	2.1180	FGHIJKLMNO
8	Barley	Incorp	H	31-Oct	11.0262	2.1180	IJKLMNO
9	Barley	Incorp	L	30-Sep	17.3250	2.1180	EFGHIJKLMN
10	Barley	Incorp	L	31-Oct	6.1262	2.1180	NO
11	Barley	Incorp	M	30-Sep	12.8300	2.1180	GHIJKLMNO
12	Barley	Incorp	M	31-Oct	8.2912	2.1180	JKLMNO
13	CC_Rye	Broad	H	30-Sep	36.6925	2.1180	ABC
14	CC_Rye	Broad	H	31-Oct	7.9537	2.1180	KLMNO
15	CC_Rye	Broad	L	30-Sep	36.8112	2.1180	ABC
16	CC_Rye	Broad	L	31-Oct	3.8662	2.1180	O
17	CC_Rye	Broad	M	30-Sep	39.6050	2.1180	A
18	CC_Rye	Broad	M	31-Oct	7.7562	2.1180	LMNO
19	CC_Rye	Incorp	H	30-Sep	37.7887	2.1180	A
20	CC_Rye	Incorp	H	31-Oct	14.9025	2.1180	EFGHIJKLMNO
21	CC_Rye	Incorp	L	30-Sep	34.9650	2.1180	ABCD
22	CC_Rye	Incorp	L	31-Oct	8.2125	2.1180	JKLMNO
23	CC_Rye	Incorp	M	30-Sep	40.0013	2.1180	A
24	CC_Rye	Incorp	M	31-Oct	15.9925	2.1180	EFGHIJKLMN
25	Rye	Broad	H	30-Sep	20.1675	2.1180	EFGHIJ
26	Rye	Broad	H	31-Oct	8.6287	2.1180	JKLMNO
27	Rye	Broad	L	30-Sep	24.5638	2.1180	DEFG
28	Rye	Broad	L	31-Oct	9.5925	2.1180	IJKLMNO
29	Rye	Broad	M	30-Sep	25.1688	2.1180	CDEF
30	Rye	Broad	M	31-Oct	14.1612	2.1180	EFGHIJKLMNO
31	Rye	Incorp	H	30-Sep	23.2038	2.1180	DEFGH
32	Rye	Incorp	H	31-Oct	7.1125	2.1180	MNO
33	Rye	Incorp	L	30-Sep	21.0112	2.1180	EFGHI
34	Rye	Incorp	L	31-Oct	11.9825	2.1180	HIJKLMNO
35	Rye	Incorp	M	30-Sep	19.7313	2.1180	EFGHIJKL
36	Rye	Incorp	M	31-Oct	14.3250	2.1180	EFGHIJKLMNO

Obs	crop	Method	rate	time	Estimate	Standard Error	Letter Group
37	Rye_CC	Broad	H	30-Sep	37.2313	2.1180	AB
38	Rye_CC	Broad	H	31-Oct	5.4175	2.1180	NO
39	Rye_CC	Broad	L	30-Sep	36.6800	2.1180	ABC
40	Rye_CC	Broad	L	31-Oct	5.6088	2.1180	NO
41	Rye_CC	Broad	M	30-Sep	37.7688	2.1180	A
42	Rye_CC	Broad	M	31-Oct	8.5837	2.1180	JKLMNO
43	Rye_CC	Incorp	H	30-Sep	38.0362	2.1180	A
44	Rye_CC	Incorp	H	31-Oct	19.0300	2.1180	EFGHIJKLM
45	Rye_CC	Incorp	L	30-Sep	38.2137	2.1180	A
46	Rye_CC	Incorp	L	31-Oct	10.0837	2.1180	IJKLMNO
47	Rye_CC	Incorp	M	30-Sep	39.3450	2.1180	A
48	Rye_CC	Incorp	M	31-Oct	13.8437	2.1180	EFGHIJKLMNO
49	Wheat	Broad	H	30-Sep	18.8413	2.1180	EFGHIJKLM
50	Wheat	Broad	H	31-Oct	5.3725	2.1180	NO
51	Wheat	Broad	L	30-Sep	24.0563	2.1180	DEFG
52	Wheat	Broad	L	31-Oct	6.2375	2.1180	NO
53	Wheat	Broad	M	30-Sep	19.8500	2.1180	EFGHIJK
54	Wheat	Broad	M	31-Oct	9.4050	2.1180	IJKLMNO
55	Wheat	Incorp	H	30-Sep	25.3013	2.1180	BCDEF
56	Wheat	Incorp	H	31-Oct	16.6587	2.1180	EFGHIJKLMN
57	Wheat	Incorp	L	30-Sep	25.6563	2.1180	BCDE
58	Wheat	Incorp	L	31-Oct	11.6562	2.1180	HIJKLMNO
59	Wheat	Incorp	M	30-Sep	23.6388	2.1180	DEFGH
60	Wheat	Incorp	M	31-Oct	5.9550	2.1180	NO

Table A-30: UD Site-1-G-2018. The effects of cover crop species planted on September 11, 2017 on percent spring ground coverage shown from photographs taken in spring 2018 and analyzed with Canopeo.

Effect=crop Method=Tukey-Kramer(P<.05) Set=1

Obs	time	crop	Estimate	Standard Error	Letter Group
1	30-Sep	Barley	14.1258	1.0835	C
2	30-Sep	CC_Rye	37.6440	1.0835	A
3	30-Sep	Rye	22.3077	1.0835	B
4	30-Sep	Rye_CC	37.8792	1.0835	A
5	30-Sep	Wheat	22.8906	1.0835	B

Table A-31: UD Site-1-G-2018. SAS output for log-transformed data showing the effects of crop species, method, and rate interactions on spring ground coverage for cover crops planted on October 18, 2017 from photographs taken in spring 2018 and analyzed with Canopeo.

Effect=crop*Method*rate Method=Tukey-Kramer(P<.05) Set=1

Obs	time	crop	Method	rate	Estimate	Standard Error	Letter Group
1	31-Oct	Barley	Broad	H	1.3889	0.1681	G
2	31-Oct	Barley	Broad	L	1.9239	0.1681	BCDEFG
3	31-Oct	Barley	Broad	M	1.4808	0.1681	FG
4	31-Oct	Barley	Incorp	H	2.3467	0.1681	ABCDEF
5	31-Oct	Barley	Incorp	L	1.9283	0.1681	BCDEFG
6	31-Oct	Barley	Incorp	M	2.1696	0.1681	ABCDEFG
7	31-Oct	CC_Rye	Broad	H	2.1678	0.1681	ABCDEFG
8	31-Oct	CC_Rye	Broad	L	1.5581	0.1681	FG
9	31-Oct	CC_Rye	Broad	M	2.0536	0.1681	BCDEFG
10	31-Oct	CC_Rye	Incorp	H	2.6929	0.1681	ABCD
11	31-Oct	CC_Rye	Incorp	L	2.1357	0.1681	ABCDEFG
12	31-Oct	CC_Rye	Incorp	M	2.7972	0.1681	AB
13	31-Oct	Rye	Broad	H	2.2425	0.1681	ABCDEFG
14	31-Oct	Rye	Broad	L	1.9272	0.1681	BCDEFG
15	31-Oct	Rye	Broad	M	2.4623	0.1681	ABCDE
16	31-Oct	Rye	Incorp	H	2.0495	0.1681	BCDEFG
17	31-Oct	Rye	Incorp	L	2.4997	0.1681	ABCDE
18	31-Oct	Rye	Incorp	M	2.7066	0.1681	ABC
19	31-Oct	Rye_CC	Broad	H	1.7974	0.1681	EFG
20	31-Oct	Rye_CC	Broad	L	1.8094	0.1681	DEFG
21	31-Oct	Rye_CC	Broad	M	2.1532	0.1681	ABCDEFG
22	31-Oct	Rye_CC	Incorp	H	2.9656	0.1681	A
23	31-Oct	Rye_CC	Incorp	L	2.3471	0.1681	ABCDEF
24	31-Oct	Rye_CC	Incorp	M	2.6569	0.1681	ABCDE
25	31-Oct	Wheat	Broad	H	1.7915	0.1681	EFG
26	31-Oct	Wheat	Broad	L	1.8948	0.1681	CDEFG
27	31-Oct	Wheat	Broad	M	2.1328	0.1681	ABCDEFG
28	31-Oct	Wheat	Incorp	H	2.7222	0.1681	ABC
29	31-Oct	Wheat	Incorp	L	2.3405	0.1681	ABCDEF
30	31-Oct	Wheat	Incorp	M	1.8971	0.1681	CDEFG

Table A-32. UD Site-1-G-2018. SAS outputs for the effect of planting date on spring coverage for individual crops/mixes. '30-Sep' is the early date planted on September 11, 2017 and '31-Oct' is the late date planted on October 18, 2017.

Obs	crop	Method	rate	time	Estimate	Standard Error	Letter Group
1	Barley			30-Sep	14.1258	0.6243	A
2	Barley			31-Oct	6.5819	0.6243	B

Obs	crop	Method	rate	time	Estimate	Standard Error	Letter Group
28	CC_Rye			30-Sep	37.6440	0.8649	A
29	CC_Rye			31-Oct	9.7806	0.8649	B

Obs	crop	Method	rate	time	Estimate	Standard Error	Letter Group
55	Rye			30-Sep	22.3077	1.2594	A
56	Rye			31-Oct	10.9671	1.2594	B

Obs	crop	Method	rate	time	Estimate	Standard Error	Letter Group
82	Rye_CC			30-Sep	37.8792	1.0074	A
83	Rye_CC			31-Oct	10.4279	1.0074	B

Obs	crop	Method	rate	time	Estimate	Standard Error	Letter Group
109	Wheat			30-Sep	22.8906	1.1078	A
110	Wheat			31-Oct	9.2142	1.1078	B

able A-33: UD Site-1-G-2018. SAS outputs for the effects of method and rate interactions on spring groundcover for barley.

Obs	crop	Method	rate	time	Estimate	Standard Error	Letter Group
10	Barley	Broad	H		8.9644	0.9715	A
11	Barley	Broad	L		9.7556	0.9715	A
12	Barley	Broad	M		8.9050	0.9715	A
13	Barley	Incorp	H		12.2119	0.9715	A
14	Barley	Incorp	L		11.7256	0.9715	A
15	Barley	Incorp	M		10.5606	0.9715	A

Table A-34: UD Site-1-G-2018. SAS outputs for the effects of method and rate interactions on spring groundcover for Rye.

Effect=Method*rate Method=Tukey-Kramer(P<.05) Set=14

Obs	crop	Method	rate	time	Estimate	Standard Error	Letter Group
64	Rye	Broad	H		14.3981	1.9237	A
65	Rye	Broad	L		17.0781	1.9237	A
66	Rye	Broad	M		19.6650	1.9237	A
67	Rye	Incorp	H		15.1581	1.9237	A
68	Rye	Incorp	L		16.4969	1.9237	A
69	Rye	Incorp	M		17.0281	1.9237	A

Table A-35: UD Site-1-G-2018. SAS output for the effects of crop and timing interactions on percent spring ground coverage for cover crops planted with **high seeding rates**. Data is from photographs taken in spring 2018 and analyzed with Canopeo. 30-Sep is early date planted on September 11, 2017 and 31-Oct is late date planted on October 18, 2017.

Effect=crop*time Method=Tukey-Kramer(P<.05) Set=1

Obs	rate	crop	Method	time	Estimate	Standard Error	Letter Group
1	H	Barley		30-Sep	14.0250	1.5076	C
2	H	Barley		31-Oct	7.1513	1.5076	D
3	H	CC_Rye		30-Sep	37.2406	1.5076	A
4	H	CC_Rye		31-Oct	11.4281	1.5076	CD
5	H	Rye		30-Sep	21.6856	1.5076	B
6	H	Rye		31-Oct	7.8706	1.5076	CD
7	H	Rye_CC		30-Sep	37.6338	1.5076	A
8	H	Rye_CC		31-Oct	12.2238	1.5076	CD
9	H	Wheat		30-Sep	22.0713	1.5076	B
10	H	Wheat		31-Oct	11.0156	1.5076	CD

Table A-36: UD Site-1-G-2018. SAS output for the effects of crop and timing interactions on percent spring ground coverage for cover crops planted with **medium seeding rates**. Data is from photographs taken in spring 2018 and analyzed with Canopeo. 30-Sep is early date planted on September 11, 2017 and 31-Oct is late date planted on October 18, 2017.

Effect=crop*time Method=Tukey-Kramer(P<.05) Set=5

Obs	rate	crop	Method	time	Estimate	Standard Error	Letter Group
61	M	Barley		30-Sep	13.3356	1.5310	C
62	M	Barley		31-Oct	6.1300	1.5310	D
63	M	CC_Rye		30-Sep	39.8031	1.5310	A
64	M	CC_Rye		31-Oct	11.8744	1.5310	CD
65	M	Rye		30-Sep	22.4500	1.5310	B
66	M	Rye		31-Oct	14.2431	1.5310	C
67	M	Rye_CC		30-Sep	38.5569	1.5310	A
68	M	Rye_CC		31-Oct	11.2137	1.5310	CD
69	M	Wheat		30-Sep	21.7444	1.5310	B
70	M	Wheat		31-Oct	7.6800	1.5310	CD

Table A-37: UD Site-1-G-2018. SAS output for the effects of crop and timing interactions on percent spring ground coverage for cover crops planted with **low seeding rates**. Data is from photographs taken in spring 2018 and analyzed with Canopeo. 30-Sep is early date planted on September 11, 2017 and 31-Oct is late date planted on October 18, 2017.

Effect=crop*time Method=Tukey-Kramer(P<.05) Set=3

Obs	rate	crop	Method	time	Estimate	Standard Error	Letter Group
31	L	Barley		30-Sep	15.0169	1.5175	C
32	L	Barley		31-Oct	6.4644	1.5175	D
33	L	CC_Rye		30-Sep	35.8881	1.5175	A
34	L	CC_Rye		31-Oct	6.0394	1.5175	D
35	L	Rye		30-Sep	22.7875	1.5175	B
36	L	Rye		31-Oct	10.7875	1.5175	CD
37	L	Rye_CC		30-Sep	37.4469	1.5175	A
38	L	Rye_CC		31-Oct	7.8463	1.5175	D
39	L	Wheat		30-Sep	24.8562	1.5175	B
40	L	Wheat		31-Oct	8.9469	1.5175	CD

Table A-38: UD Site-1-G-2018. SAS output for the effects of crop, method, and timing interactions on percent spring ground coverage for cover crops planted with **high seeding rates**. Data is from photographs taken in spring 2018 and analyzed with Canopeo. 30-Sep is early date planted on September 11, 2017 and 31-Oct is late date planted on October 18, 2017.

Effect=crop*Method*time Method=Tukey-Kramer(P<.05) Set=2

Obs	rate	crop	Method	time	Estimate	Standard Error	Letter Group
11	H	Barley	Broad	30-Sep	14.6525	2.0498	CDEF
12	H	Barley	Broad	31-Oct	3.2763	2.0498	G
13	H	Barley	Incorp	30-Sep	13.3975	2.0498	CDEF
14	H	Barley	Incorp	31-Oct	11.0263	2.0498	DEFG
15	H	CC_Rye	Broad	30-Sep	36.6925	2.0498	A
16	H	CC_Rye	Broad	31-Oct	7.9538	2.0498	EFG
17	H	CC_Rye	Incorp	30-Sep	37.7888	2.0498	A
18	H	CC_Rye	Incorp	31-Oct	14.9025	2.0498	CDEF
19	H	Rye	Broad	30-Sep	20.1675	2.0498	BCD
20	H	Rye	Broad	31-Oct	8.6288	2.0498	EFG
21	H	Rye	Incorp	30-Sep	23.2038	2.0498	BC
22	H	Rye	Incorp	31-Oct	7.1125	2.0498	EFG
23	H	Rye_CC	Broad	30-Sep	37.2313	2.0498	A
24	H	Rye_CC	Broad	31-Oct	5.4175	2.0498	FG
25	H	Rye_CC	Incorp	30-Sep	38.0363	2.0498	A
26	H	Rye_CC	Incorp	31-Oct	19.0300	2.0498	BCD
27	H	Wheat	Broad	30-Sep	18.8412	2.0498	BCD
28	H	Wheat	Broad	31-Oct	5.3725	2.0498	FG
29	H	Wheat	Incorp	30-Sep	25.3013	2.0498	B
30	H	Wheat	Incorp	31-Oct	16.6588	2.0498	BCDE

Table A-39: UD Site-1-G-2018. SAS output for the effects of planting method and seeding rate interactions on dried aboveground biomass from samples collected in spring, 2018 (ton/ac).

Effect=Method*rate Method=Tukey-Kramer(P<.05) Set=1

Obs	crop	Method	rate	Estimate	Standard Error	Letter Group
1		Broad	H	1.1386	0.1127	B
2		Broad	L	1.3424	0.1128	AB
3		Broad	M	1.4800	0.1134	AB
4		Incorp	H	1.4101	0.1103	AB
5		Incorp	L	1.6333	0.1186	A
6		Incorp	M	1.2604	0.1125	AB

Table A-40: UD Site-1-G-2018. SAS output for the effects of crop species and seeding rate interactions on dried aboveground biomass from samples collected in spring, 2018 (ton/ac).

Effect=crop*rate Method=Tukey-Kramer(P<.05) Set=2

Obs	crop	Method	rate	Estimate	Standard Error	Letter Group
7	Barley		H	1.0113	0.1493	B
8	Barley		L	1.0700	0.1493	B
9	Barley		M	1.0738	0.1493	B
10	CC_Rye		H	1.2350	0.1493	B
11	CC_Rye		L	2.1759	0.1851	A
12	CC_Rye		M	1.6163	0.1851	AB
13	Rye		H	1.3404	0.1691	B
14	Rye		L	1.2121	0.1691	B
15	Rye		M	1.5725	0.1493	AB
16	Rye_CC		H	1.5180	0.1585	AB
17	Rye_CC		L	1.6118	0.1703	AB
18	Rye_CC		M	1.5444	0.1585	AB
19	Wheat		H	1.2671	0.1691	B
20	Wheat		L	1.3694	0.1585	B
21	Wheat		M	1.0440	0.1704	B

Table A-41: UD Site-1-G-2018. SAS output for the effects of crop species on N removal from samples collected in spring, 2018 (lbs.ac).

Effect=crop Method=Tukey-Kramer(P<.05) Set=1

Obs	crop	Method	rate	Estimate	Standard Error	Letter Group
1	Barley			41.3483	5.1285	C
2	CC_Rye			76.8547	5.6453	A
3	Rye			54.6577	5.4431	BC
4	Rye_CC			70.3431	5.4518	AB
5	Wheat			41.4098	5.5340	C

Table A-42: UD Site-1-G-2018. SAS Output for the effects of planting method and seeding rate interactions on N removal from samples collected in spring, 2018 (lbs/ac).

Effect=Method*rate Method=Tukey-Kramer(P<.05) Set=2

Obs	crop	Method	rate	Estimate	Standard Error	Letter Group
6		Broad	H	47.4107	5.7358	A
7		Broad	L	55.8648	5.7347	A
8		Broad	M	66.4939	5.7371	A
9		Incorp	H	56.3220	5.6190	A
10		Incorp	L	65.7905	6.0066	A
11		Incorp	M	49.6544	5.7244	A

Table A-43: UD Site-1-G-2018. SAS output for the effects of cover crop species on Total Soil N from 0-6 in. samples collected in Spring, 2018 (lbs/ac).

Effect=crop Method=Tukey-Kramer(P<.1) Set=1

Obs	crop	rate	Method	Estimate	Standard Error	Alpha	Lower	Upper	Letter Group
1	Barley			0.1307	0.01823	0.1	0.1004	0.1611	A
2	CC_Rye			0.1401	0.01831	0.1	0.1096	0.1705	A
3	Rye			0.1468	0.01823	0.1	0.1165	0.1771	A
4	Rye_CC			0.1330	0.01823	0.1	0.1026	0.1633	A
5	Wheat			0.1277	0.01823	0.1	0.09742	0.1581	A

Table A-44: UD Site-1-G-2018. SAS output for the effects of seeding rates on Total Soil N from 0-6 in. samples collected in Spring, 2018 (lbs/ac).

Effect=rate Method=Tukey-Kramer(P<.1) Set=2

Obs	crop	rate	Method	Estimate	Standard Error	Alpha	Lower	Upper	Letter Group
6		H		0.1375	0.01662	0.1	0.1098	0.1652	A
7		L		0.1376	0.01662	0.1	0.1099	0.1653	A
8		M		0.1318	0.01663	0.1	0.1041	0.1595	A

Table A-45: UD Site-1-G-2018. SAS output for the effects of planting method on Total Soil N from 0-6 in. samples collected in Spring, 2018 (lbs/ac).

Effect=Method Method=Tukey-Kramer(P<.1) Set=3

Obs	crop	rate	Method	Estimate	Standard Error	Alpha	Lower	Upper	Letter Group
9			Broad	0.1394	0.01575	0.1	0.1131	0.1657	A
10			Incorp	0.1320	0.01574	0.1	0.1057	0.1582	A

Table A-46: UD Site-1-G-2018. SAS output for the effects of cover crop species on Total Soil N from 6-12 in. samples collected in Spring, 2018 (lbs/ac).

Effect=crop Method=Tukey(P<.1) Set=1

Obs	crop	rate	Method	Estimate	Standard Error	Alpha	Lower	Upper	Letter Group
1	Barley			0.1033	0.009988	0.1	0.08668	0.1198	A
2	CC_Rye			0.1275	0.009988	0.1	0.1110	0.1441	A
3	Rye			0.1037	0.009988	0.1	0.08718	0.1203	A
4	Rye_CC			0.1166	0.009988	0.1	0.1001	0.1332	A
5	Wheat			0.1131	0.009988	0.1	0.09652	0.1296	A

Table A-47: UD Site-1-G-2018. SAS output for the effects of seeding rates on Total Soil N from 6-12 in. samples collected in Spring, 2018 (lbs/ac).

Effect=rate Method=Tukey(P<.1) Set=2

Obs	crop	rate	Method	Estimate	Standard Error	Alpha	Lower	Upper	Letter Group
6		H		0.1055	0.007737	0.1	0.09269	0.1184	A
7		L		0.1182	0.007737	0.1	0.1053	0.1310	A
8		M		0.1149	0.007737	0.1	0.1020	0.1277	A

Table A-48: UD Site-1-G-2018. SAS output for the effects of planting method on Total Soil N from 6-12 in. samples collected in Spring, 2018 (lbs/ac).

Effect=Method Method=Tukey(P<.1) Set=3

Obs	crop	rate	Method	Estimate	Standard Error	Alpha	Lower	Upper	Letter Group
9			Broad	0.1141	0.006317	0.1	0.1037	0.1246	A
10			Incorp	0.1116	0.006317	0.1	0.1011	0.1220	A

Table A-49: UD Site-2-C-2018. SAS output for the effects of planting method on spring coverage from photographs taken in spring 2018 and analyzed with Canopeo.

Effect=Method Method=Tukey-Kramer(P<.05) Set=1

Obs	crop	Method	rate	Estimate	Standard Error	Letter Group
1		Broad		22.9172	1.0752	B
2		Incorp		32.3031	1.0785	A

Table A-50: UD Site-2-C-2018. SAS Output for the effects of crop species and seeding rate interactions on spring coverage from photographs taken in spring 2018 and analyzed with Canopeo.

Effect=crop*rate Method=Tukey-Kramer(P<.05) Set=2

Obs	crop	Method	rate	Estimate	Standard Error	Letter Group
3	Barley		H	12.8806	2.4946	E
4	Barley		L	15.9238	2.4946	DE
5	Barley		M	14.9019	2.4946	DE
6	CC_Rye		H	40.3481	2.4946	AB
7	CC_Rye		L	25.5377	2.5738	CD
8	CC_Rye		M	45.6944	2.4946	A
9	Rye		H	23.4388	2.4946	CDE
10	Rye		L	29.1119	2.4946	BC
11	Rye		M	27.9194	2.4946	C
12	Rye_CC		H	41.1425	2.4946	A
13	Rye_CC		L	28.3756	2.4946	C
14	Rye_CC		M	42.3713	2.4946	A
15	Wheat		H	22.5563	2.4946	CDE
16	Wheat		L	21.1481	2.4946	CDE
17	Wheat		M	22.8019	2.4946	CDE

Table A-51: UD Site-2-C-2018. SAS output for the effects of cover crop species planted on September 9, 2017 on dried aboveground biomass, collected in spring, 2018 (ton/ac).

Effect=crop Method=Tukey-Kramer(P<.05) Set=1

Obs	crop	Method	Estimate	Standard Error	Letter Group
1	Barley		1.2550	0.1286	B
2	CC_Rye		1.7479	0.1286	A
3	Rye		1.7513	0.1286	A
4	Rye_CC		2.0254	0.1286	A
5	Wheat		1.3042	0.1286	B

Table A-52: UD Site-2-C-2018. SAS output for the effects of planting method for crops planted on September 9, 2017 on dried aboveground biomass, collected in spring, 2018 (ton/ac)

Effect=Method Method=Tukey-Kramer(P<.05) Set=2

Obs	crop	Method	Estimate	Standard Error	Letter Group
6		Broad	1.4983	0.1020	B
7		Incorp	1.7352	0.1020	A

Table A-53: UD Site-2-C-2018. SAS output for the effects of cover crop species planted on September 9, 2017 on N removal from samples collected in spring, 2018 (lbs/ac).

Effect=crop Method=Tukey-Kramer(P<.05) Set=1

Obs	crop	Method	Estimate	Standard Error	Letter Group
1	Barley		39.8696	5.8169	C
2	CC_Rye		95.0387	5.8169	A
3	Rye		63.6804	5.8169	B
4	Rye_CC		103.03	5.8169	A
5	Wheat		34.8412	5.8169	C

Table A-54: UD Site-2-C-2018. SAS output for planting method effects for crops planted on September 9, 2017 on N removal from samples collected in spring, 2018 (lbs/ac).

Effect=Method Method=Tukey-Kramer(P<.05) Set=2

Obs	crop	Method	Estimate	Standard Error	Letter Group
6		Broad	61.9512	4.4613	B
7		Incorp	72.6323	4.4613	A

Table A-55: UD Site-2-C-2018. SAS output for the effects of cover crop species on Total Soil N from 0-6 in. samples collected in Spring, 2018 (lbs/ac).

Effect=crop Method=Tukey(P<.1) Set=1

Obs	crop	rate	Method	Estimate	Standard Error	Alpha	Lower	Upper	Letter Group
1	Barley			0.1487	0.007349	0.1	0.1365	0.1609	A
2	CC_Rye			0.1508	0.007349	0.1	0.1386	0.1630	A
3	Rye			0.1500	0.007349	0.1	0.1378	0.1622	A
4	Rye_CC			0.1613	0.007349	0.1	0.1491	0.1735	A
5	Wheat			0.1519	0.007349	0.1	0.1397	0.1641	A

Table A-56: UD Site-2-C-2018. SAS output for the effects of planting method on Total Soil N from 0-6 in. samples collected in Spring, 2018 (lbs/ac).

Effect=Method Method=Tukey(P<.1) Set=2

Obs	crop	rate	Method	Estimate	Standard Error	Alpha	Lower	Upper	Letter Group
6			Broad	0.1498	0.004648	0.1	0.1421	0.1575	A
7			Incorp	0.1553	0.004648	0.1	0.1476	0.1630	A

Table A-57: UD Site-2-C-2018. SAS output for the effects of seeding rate on Total Soil N from 0-6 in. samples collected in Spring, 2018 (lbs/ac).

Effect=rate Method=Tukey(P<.1) Set=3

Obs	crop	rate	Method	Estimate	Standard Error	Alpha	Lower	Upper	Letter Group
8		H		0.1538	0.005693	0.1	0.1444	0.1633	A
9		L		0.1489	0.005693	0.1	0.1395	0.1583	A
10		M		0.1549	0.005693	0.1	0.1455	0.1644	A

Table A-58: UD Site-2-C-2018. SAS output for the effects of cover crop species on Total Soil N from 6-12 in. samples collected in Spring, 2018 (lbs/ac).

Effect=crop Method=Tukey-Kramer(P<.1) Set=1

Obs	crop	rate	Method	Estimate	Standard Error	Alpha	Lower	Upper	Letter Group
1	Barley			0.1179	0.01523	0.1	0.08387	0.1519	A
2	CC_Rye			0.1185	0.01523	0.1	0.08445	0.1525	A
3	Rye			0.1252	0.01523	0.1	0.09116	0.1592	A
4	Rye_CC			0.1276	0.01523	0.1	0.09358	0.1616	A
5	Wheat			0.1221	0.01523	0.1	0.08808	0.1561	A

Table A-59: UD Site-2-C-2018. SAS output for the effects of planting method on Total Soil N from 6-12 in. samples collected in Spring, 2018 (lbs/ac).

Effect=Method Method=Tukey-Kramer(P<.1) Set=2

Obs	crop	rate	Method	Estimate	Standard Error	Alpha	Lower	Upper	Letter Group
6			Broad	0.1220	0.01407	0.1	0.03442	0.2095	A
7			Incorp	0.1225	0.01407	0.1	0.03497	0.2101	A

Table A-60: UD Site-2-C-2018. SAS output for the effects of seeding rate on Total Soil N from 6-12 in. samples collected in Spring, 2018 (lbs/ac).

Effect=rate Method=Tukey-Kramer(P<.1) Set=3

Obs	crop	rate	Method	Estimate	Standard Error	Alpha	Lower	Upper	Letter Group
8		H		0.1212	0.01447	0.1	0.07251	0.1698	A
9		L		0.1183	0.01447	0.1	0.06964	0.1670	A
10		M		0.1272	0.01447	0.1	0.07859	0.1759	A

Table A-61: UD Site-3-M-2018. SAS output for the effects of planting method on spring coverage from photographs taken in spring 2018 and analyzed with Canopeo (lbs/ac).

Effect=Method Method=Tukey(P<.05) Set=1

Obs	Method	Estimate	Standard Error	Letter Group
1	Broad	21.9283	0.8008	B
2	Incorp	24.7161	0.8008	A