SEEDING TIME AND INTERSEEDED COVER CROP SPECIES INFLUENCE SUGARBEET YIELD AND QUALITY

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

Sailesh Sigdel

In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Department:
Soil Science

September 2020

Fargo, North Dakota

North Dakota State University
Graduate School

Title

Seeding Time and Interseeded Cover Crop Species Influence Sugarbeet Yield and Quality

By

Sailesh Sigdel

The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

SUPERVISORY COMMITTEE:

Dr. Amitava Chatterjee
Chair

Dr. Abbey Wick

Dr. Caley Gasch

Dr. Marisol Berti

Approved:

October 19, 2020 — Date

Dr. Frank Casey — Department Chair

ABSTRACT

Field experiments were conducted to evaluate cover crop interseeding time and species effect on sugarbeet production during 2018 and 2019 growing seasons. Cover crops were first interseeded in June and second interseeding was done in late June or early July. Four cover crops species, Austrian pea (*Pisum sativum* L.), winter rye (*Secale cereale* L.), winter camelina [*Camelina sativa* (L.) Crantz], and brown mustard (*Brassica juncea* L.), were examined. First interseeding resulted in significantly higher cover crop biomass than second interseeding. In 2018, the highest recoverable sugar yield was observed with pea (13.9 Mg ha^{-1}) and camelina (6.6 Mg ha^{-1}) first-interseeded, at Ada and Downer, MN, respectively. In 2019, camelina (11.2 Mg ha^{-1}) at Ada, MN, and pea (12.4 Mg ha^{-1}) at Prosper, ND both second-interseeded, had the highest recoverable sugar yield. Cover crops had no negative impacts on sugarbeet, but the selection of species and planting time are critical.

ACKNOWLEDGMENTS

Foremost, I would like to express my sincere gratitude to my advisor Dr. Amitava Chatterjee for the continuous support of my M.S. study and research. I would like to thank him for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me in all of the research and writing of this thesis. I could not have imagined having a better advisor and mentor for my M.S. study.

Besides my advisor, I would like to thank my graduate research committee members, Dr. Abbey Wick, Dr. Caley Gasch, and Dr. Marisol Berti, for their encouragement, insightful comments, and questions. I would also like to acknowledge The Sugarbeet Research and Education Board of Minnesota and North Dakota for funding these projects.

My sincere thanks go to Norm Cattanach, for his continuous support and guidance throughout my research and fieldwork. I am thankful to my fellow lab mates in the soil management lab, Mathew Kruger, Donald Veverka, and Diksha Goyal, for their assistance during this project. I am also thankful to all helping hands who supported me directly and indirectly throughout my research.

Last but not least, I would like to thank my family, my parents Dipak Sigdel and Bishnu Lamsal, for giving birth to me in the first place and supporting me spiritually throughout my life.

DEDICATION

I dedicate this thesis to my parents and my love for nursing me with affection and love and their dedicated partnership for success in my life.

TABLE OF CONTENTS

ABSTRACT iii

ACKNOWLEDGMENTS iv

DEDICATION v

LIST OF TABLES vii

LIST OF FIGURES viii

LIST OF APPENDIX TABLES ix

LIST OF APPENDIX FIGURES x

INTRODUCTION 1

LITERATURE REVIEW 5

MATERIAL AND METHODS 19

RESULTS AND DISCUSSION 24

CONCLUSION 48

REFERENCES 50

APPENDIX 68

LIST OF TABLES

Table Page

1. Soil series description of 2018-2019 experimental locations at Ada, Downer, MN and Prosper, ND.[†] 19

2. Seeding rates (pure live seed) of interseeded cover crops for 2018 and 2019 growing season..... 19

3. Field operation schedule and soil and plant sampling times for two sites at each growing season..... 21

4. Soil physical and chemical properties for Ada, Downer, MN and Prosper, ND 23

5. Main and interaction effects of cover crop species (C) and interseeding time (I) on aboveground cover crop biomass yield (kg ha^{-1}) at Ada, Downer, and Prosper for 2018 and 2019 growing season..... 28

6. Main and interaction effects of cover crop species (C) and interseeding time (I) on cover crop biomass N accumulation (kg N ha^{-1}) at Ada, Downer, and Prosper for 2018 and 2019 growing season..... 33

7. Main and interaction effects of cover crop species (C) and interseeding time (I) on sugarbeet yield (Mg ha^{-1}) and sugar concentration (g kg^{-1}) for four site-year..... 36

8. Effect of different interseeded cover crops on sugarbeet root yield (Mg ha^{-1}), sugar concentration (g kg^{-1}) for Downer and Ada during 2018 growing season..... 37

9. Effect of different interseeded cover crops on recoverable sugar yield (RS Mg ha^{-1}), gross economic return (\$ ha^{-1}), and net profit over control (\$ ha^{-1}) for Ada, MN and Downer, MN during 2018 growing season. 39

10. Effect of different interseeded cover crops on sugarbeet root yield (Mg ha^{-1}), sugar concentration (g kg^{-1}) for Ada and Prosper during 2019 growing season 41

11. Effect of different interseeded cover crops on recoverable sugar yield (RS Mg ha^{-1}), gross economic return (\$ ha^{-1}), and net profit over control (\$ ha^{-1}) for Ada, MN and Prosper, ND during 2019 growing season. 43

12. Effect of different interseeded cover crops on soil inorganic-N (kg N ha^{-1}) within 0-15 cm depth at sugarbeet harvest for four site-year..... 46

LIST OF FIGURES

Figure Page

1. Distribution of average sugarbeet root yield (Mg ha^{-1}) across 24 counties in Minnesota and seven counties in North Dakota during the 2013-2017 growing seasons 6

2. Daily rainfall and daily average air temperature at each experimental site in 2018 and 2019 growing season. 27

LIST OF APPENDIX TABLES

Table Page

A1. Monthly average air temperature, 30-year average air temperature, monthly total rainfall, and 30-year average total rainfall during growing season at each experimental sites taken from NDAWN weather station. 68

A2. Levene's Test for Homogeneity of Aboveground cover crop biomass yield (Mg ha^{-1}) Variance 69

A3. Levene's Test for Homogeneity of Sugarbeet Yield Variance 69

A4. Levene's Test for Homogeneity of Sugar Content Variance 69

A5. ANOVA for main and interaction effects of cover crop species (CC) and interseeding time (I) on aboveground cover crop biomass yield (kg ha^{-1}) at Ada and Downer, MN for 2018 69

A6. ANOVA for Main and interaction effects of cover crop species (CC) and interseeding time (I) on aboveground cover crop biomass yield (kg ha^{-1}) at Ada, MN and Prosper, ND for 2019 70

A7. ANOVA table for main and interaction effects of cover crop species (CC) and interseeding time (I) on sugarbeet root yield at Ada and Downer, MN for 2018 growing seasons. 70

A8. ANOVA table for main and interaction effects of cover crop species (CC) and interseeding time (I) on sugarbeet root yield at Ada, MN and Prosper, ND for 2019 growing seasons. 71

A9. Analysis of Variance (ANOVA) for cover crop interseeding treatment on sugarbeet root yield at Ada and Downer, MN, 2018. 71

A10. Analysis of Variance (ANOVA) for cover crop interseeding treatment on sugarbeet root yield at Ada, MN and Prosper, ND, 2019. 71

A11. Analysis of Variance (ANOVA) for cover crop interseeding treatment on sugarbeet root sugar concentration at Ada and Downer, MN, 2018. 72

A12. Analysis of Variance (ANOVA) for cover crop interseeding treatment on sugarbeet root sugar concentration at Ada, MN and Prosper, ND, 2019. 72

A13. Information regarding price, revenue from agricultural products and operation cost of 2018 and 2019 growing season for sugarbeet payment calculator. 72

LIST OF APPENDIX FIGURES

Figure Page

A1. Fallow sugarbeet field during non-growing season. 73

A2. Regrowth of rye cover crop biomass after winter (April, 2019)...................................... 74

INTRODUCTION

The Red River Valley (RRV) of North Dakota and Minnesota is a major sugarbeet production region in the United States. This region has nearly 57% of the nation's planted sugarbeet acreage, and produce more than 50% of the nation's sugarbeet tonnage (USDA-NASS, 2019). The sugarbeet industry in the RRV has experienced substantial economic growth over the past 20 years (USDA ERS, 2015). In the northern Great Plains, wind erosion causes significant soil loss from agricultural fields (Turner et al., 2017). Due to conventional tillage practices, soils have less residue cover after harvest in the fall, and the soil is exposed to wind and water erosion. In the spring, severe damage due to wind blast of soil particles can cause sugarbeet stand loss (Stevens et al., 2010; Ichiki et al., 2013). According to the USDA Natural Resources Conservation Service (2013), the average wind erosion rate is 11.7 and 10.5 Mg ha^{-1} of soil loss per hectare per year for Minnesota and North Dakota, respectively. In the United States Upper Midwest, reported soil losses due to wind exceed 11.2 Mg ha^{-1} $year^{-1}$ in some soils (Neilsen, 1997; Hansen et al., 2012). Furthermore, increased climate fluctuations with frequent drought and severe, localized rainstorm events in the region have accelerated the soil erosion (O'Neal et al., 2005; Nielsen, 2018). Thus, there is growing concern among the growers to improve soil health and the sustainability of sugarbeet production.

Cover crops have the potential to reduce the impacts of soil erosion, improve nutrient use efficiency by reducing nutrient loss, fixing nitrogen, and improving soil quality (Hartwig and Ammon, 2002; Chatterjee and Clay, 2016; Adhikari et al., 2017; Kaye and Quemada, 2017; Daryanto et al., 2018). To provide ecosystem services and maintain ground coverage, cover crops are sown either after the harvest of the crop or concurrent with the crop (Mayer et al., 2005). The adoption of cover crops has become popular in the northern Great Plains to reduce soil erosion (Berti et al., 2017). Interseeding cover crops before harvest increases the likelihood of cover crop establishment and growth (Wilson et al., 2013; Belfry and Van Eerd, 2016). Interseeding cover crops can accumulate more biomass than fall-seeded cover crops and thus have more potential to reduce soil losses (Masiunas, 1998; Hively and Cox, 2001; Blanco-Canqui et al., 2015). However, the success of cover crop stand establishment depends on the growing season and cultivar characteristics.

The most commonly grown cover crops fall into three main botanical families: grasses (*Poaceae*), legumes (*Fabaceae*), and plants in the *Brassicaceae* family, henceforth brassicas, with different benefits and management considerations for each family. It is crucial to select a cover crop that provides benefits without a negative effect on the cash crop yield. Brassicas can scavenge nutrients (Rossato et al., 2001; Clark, 2007; Ruark et al., 2018; Gruver et al., 2019) and suppress weed (Iqbal et al., 2020), whereas grasses such as oat (*Avena sativa* L.) and rye (*Secale cereale* L.) are known for soil building and scavenging soil nutrients (Snapp et al., 2005; Krueger et al., 2011; Appelgate et al., 2017). Legume cover crops are most often selected for biological N_2 fixation, which may reduce N inputs required for the subsequent crop (Liang et al., 2014). Given the available cover crop options, growers should assess their needs and long-term goals before selecting a cover crop management strategy. Only annual ryegrass (*Lolium multiflorum* L.) has been extensively studied in various rotations with sugarbeet (Koch, 1998; Kreykenbohm et al., 1999; Kramberger et al., 2008). Brassicas and legume species have not been explored under sugarbeet systems (Thomsen, 2005). Therefore, it is critical to compare cereals, brassicas, and legumes on sugarbeet root yield, sugar content, and economic profitability.

The successful establishment of interseeded cover crops depends on both the timing and species. The time of the plow-in or the termination time and the seeding time of cover crops can influence main crop yield and N content (Clark et al., 1997; Sainju and Singh, 2001; Kuo and Jellum, 2002; Kramberger et al., 2008), likely due to N immobilization, resource competition, soil water depletion, or allelopathy (Kramberger et al., 2014; Pantoja et al., 2015; Martinez-Feria et al., 2016). Planting time of cover crops play a major role in determining the performance of the following crop. Some cover crop species require an early planting time for fall growth, whereas winter annual species focus on spring growth the following season can be planted later in the fall. The choice of the cover crop may largely depend on the planting time and the desired benefit and cost. For example, rye is chosen for its large quantities of biomass production and the ability to establish well with later planting time. Conversely, peas may be chosen if an earlier planting time is available, and nutrient fixation/retention is the desired result (Cousin, 1997; Duiker, 2004; Chen et al. 2006). Therefore, suitable cover crop species and appropriate interseeding time need to be assessed to identify viable cover cropping strategies that provide environmental benefits while maintaining productivity in the sugarbeet production system in the upper Midwest.

Therefore, this study's goal was to determine the effect of interseeding on cover crop biomass and sugarbeet yield and quality. It was hypothesized that the interseeding of cover crops would improve sugarbeet yield and quality. Field trials were conducted at two sites for the 2018 and 2019 growing seasons. Two interseeding time, first vs. second, and four cover crop species: (i) winter rye (*Secale cereale* L.), ii) winter camelina [(*Camelina sativa* L.) Crantz], iii) winter Austrian pea (*Pisum sativum* L.), and iv) brown mustard (*Brassica juncea* L.), were compared. Influence of planting time and cover crop species were examined based on (i) cover crop-biomass production and nitrogen (N) removal, (ii) sugarbeet yield, (iii) sugar content,

(iv) recoverable sugar, (v) economic profitability, and (vi) soil N availability after planting and before harvest.

LITERATURE REVIEW

Row-crop producers around the United States are considering management practices to improve soil health, environmental quality, and economic profitability; and cover crops are one of the sustainable practices receiving considerable attention from growers (SARE CTIC, 2020). Growers select cover crop management practices according to appropriate species for their area and crop rotation, appropriate planting timing, and to avoid competition with the row crop (Ghimire et al., 2018). This study was designed to answer these questions relative to the use of different cover crops in sugarbeet under the Red River Valley conditions. A summary of current research studies relating to (i) sugarbeet production in the United States, (ii) benefits of cover crop adoptions, and (iii) practices to facilitate the cover crop adoption has been discussed.

Sugarbeet Production in the Red River Valley

Sugarbeet, as a crop, is the major contributor to the nation's sugar production (USDA-ERS, 2019). Sugarbeet is a high-yield producer of sucrose, accounting for more than 30% of the world, and 50% of the U.S. refined sugar production (USDA, 2019). Sugarbeet is commonly grown in 11 states that spread across the Great Lakes, upper Midwest, the Great Plains, and far West regions of the country (NASS, 2019). Dominating sugarbeet growing states include Minnesota, Idaho, North Dakota, Michigan, Montana, Nebraska, Ohio, Wyoming, Colorado, California, Oregon, and Washington (NASS, 2019).

The RRV of MN and ND supply nearly 55 % (249,691 ha) of the U.S. sugarbeet planted area (NASS, 2019) (Figure 1). The sugarbeet industry in the RRV has experienced substantial economic growth over the past 20 years (USDA ERS, 2015).

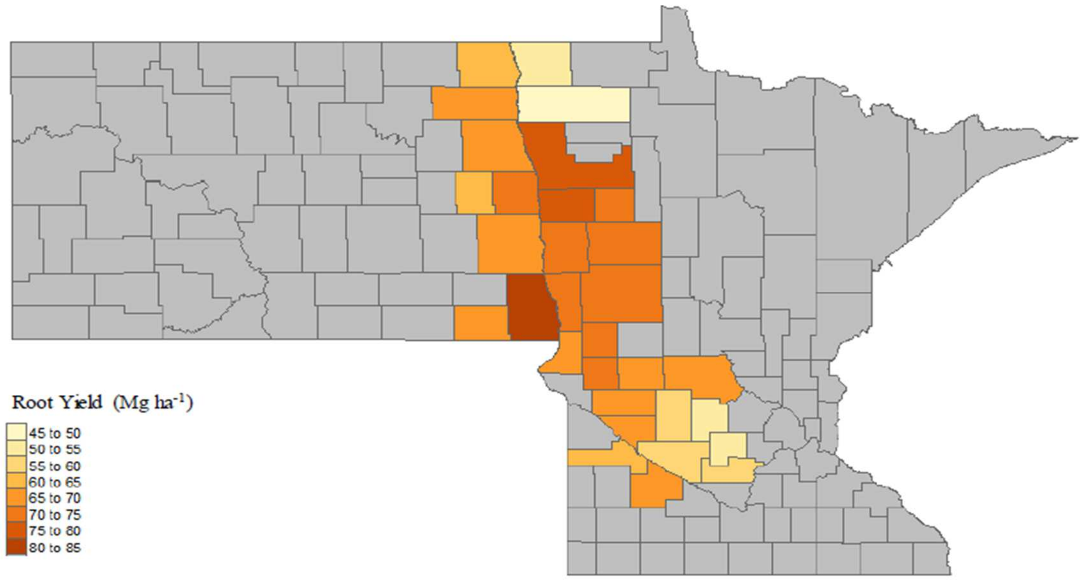

Figure 1. Distribution of average sugarbeet root yield (Mg ha^{-1}) across 24 counties in Minnesota and seven counties in North Dakota during the 2013-2017 growing seasons.

Strong wind can severely damage sugarbeet plants in many ways (Ohnami, 2009; Stevens et al., 2010; Ichiki et al., 2013). Until the sugarbeet has reached full canopy, it offers minimum soil protection (Dregseth et al., 2003). After the fall tillage, a majority of the fields are left unprotected for six to nine months of the year (October-May/June). According to data published by the USDA Natural Resources Conservation Service (2013), the erosion levels have decreased in the past three decades, but it is still occurring at detrimental rates. Still, the most severe areas of erosion are well above the general estimates of 11.2 Mg ha^{-1} year^{-1}. Furthermore, increased climate fluctuation with frequent drought and severe, localized rainstorm events in the region has accelerated the effect (O'Neal et al., 2005; Stevens et al., 2009; Nielsen, 2018). In row-crop systems, including a cover crop can offer a more extended period of soil protection, take up water and nutrients, and reduce the risk of nutrient losses from the soil.

Cover Crops

Cover crops are a tool that growers can use to minimize soil movement off the agricultural field. Cover crops can be grown with or after a cash crop (Bich et al., 2014). In contrast to cash crops, cover crops are traditionally incorporated into crop rotations during off-seasons and used for environmental benefits rather than profitability. They can provide a plethora of ecosystem services like control soil erosion, improve nutrient use efficiency by reducing nutrient loss, fixing N_2, and improving soil quality (Hartwig and Ammon, 2002; Adhikari et al., 2017; Chatterjee and Clay, 2016) within agronomic systems. Cover crops may reduce the effect of climate change through mitigation of warming and reduction of vulnerability to erosion, drought, extreme rain events, and other landscape effects caused by climate warming (Kaye and Quemada, 2017). According to the National Agricultural Statistical Services (NASS, 2017), 6.2 million ha of total cropland was planted with cover crops in the United States. Recently, significant interest in adopting cover crops among growers to improve soil health and sustain crop productivity has been reported (Baranksi, 2018; Ruis et al., 2018). Cover crops have become an important inclusion to the farming system in the upper Midwest because of its potential to reduce erosion and improve soil and water quality (Peterson et al., 2019; Andersen et al., 2020). In ND, Myers (2019) reported an increase of 89.1% in cover crop adoption from 2012 to 2017. However, the benefits provided by cover crops are dependent on several factors such as species involved (Wortman and Dawson, 2015; Chatterjee and Clay, 2017; Sigdel and Chatterjee, 2020), time of establishment (Bich, 2013; Wayman et al., 2015; Bovoughan and Read, 2018), seeding rates (SARE, 2007), growing condition, crop rotation (Coudel et al., 2018), and previous herbicide application (Bich, 2013).

Benefits of Cover Crops to Crop Production and the Environment

Buildup of soil organic matter (SOM)

Soil OM plays a pivotal role in nutrient-cycling, soil health, biological activity, and water availability (Lal, 2014; McDaniel et al., 2014; Blanco-Canqui et al., 2015). Cover crops increase or maintain SOM levels relative to no cover crop management by supplying greater carbon (C) inputs in the form of plant biomass (Sainju et al., 2000; 2005). The impact of cover crops on SOM is related mostly to the quantity and quality of biomass returned to the soil, the decomposition rate of decay of the plant material, and length of time under cover crops, original SOM level, soil type, tillage systems, and climactic factors (Kuo et al., 1997; Blanco-Canqui et al., 2015).

Increased C sequestration in soil with cover crops and N fertilization compared with no cover crops and N fertilization has been reported by several researchers (Sainju. et al., 2000; Jian et al., 2020). Higher levels of C input returned from cover crops increased soil organic C at 0–10 and 10–30 cm depths (Sainju et al., 2002). Cereal cover crops increase or maintain SOM levels relative to legume cover crops and no cover crop management by supplying higher C inputs in the form of plant biomass (Ding et al., 2006; Blanco-Canqui et al., 2015). Legumes as a cover crop can increase or maintain SOM if the biomass is higher (Kuo et al., 1997; Liang et al., 2014). Continuous corn (*Zea mays* L.)-hairy vetch (*Vicia villosa* L.) cropping system in Kentucky increased total soil C and N compared with management without hairy vetch because of higher residue inputs (Fortuna et al., 2008). A similar study found that legume cover crop influenced an increase in SOC, compared with a no legume fertilizer-based system because of higher C input from plant biomass inputs (Bakht et al., 2009). Long-term studies in Italy have also shown higher SOC in the top 10-cm of soil five years after cover crop integration, and in the top 30-cm after 15 years (Mazzoncini et al., 2011). Soil organic C was observed to be approximately 9% higher in plots with a high-N legume cover crop (clover (*Trifolium spp.*) and hairy vetch) compared with a no-cover crop control.

Similarly, Moore et al. (2014) observed higher SOM, particulate organic matter, and potentially mineralizable N in the surface soil (5 cm) compared with a no cover crop control after 9-years of a cover crop incorporation in a silage corn-soybean [*Glycine max* (L.) Merr.] rotation in Iowa. Specifically, SOM was 15% higher in the top 5-cm and 5% higher in the 5-10 cm depth when the rye was planted after soybean and corn silage. In the long term, such increased SOM through cover crop growth and decomposition contributes to improved aggregate stability through belowground growth and by the addition of organic C and binding agents (Blanco-Canqui et al., 2015). The significance of increased SOC, and therefore SOM, include the potential for enhanced soil structural characteristics, improved soil water status, and increased soil biological activity (Kaspar and Singer, 2011; McDaniel et al., 2014; Blanco-Canqui et al., 2015). Therefore, including cover crops into cash crops can increase nutrient cycling and increase or maintain the SOM level.

Reducing soil erosion

Standing cover crop and crop residues left on the soil surfaces help decrease wind and water erosion by (i) intercepting raindrops, (ii) reducing aggregate disruption and surface sealing and (iii) slowing water movement to increase the amount of time water has to infiltrate into the soil (Frye et al., 1988; Hartwig and Ammon, 2002). Similarly, rill erosion caused by shear force may also be reduced by using cover crops directly by increasing the hydraulic resistance of the surface, slowing flow velocity, and indirectly by increasing the infiltration rate of the soil (Kaspar and Singer, 2011). The usefulness of cover crops in protecting the soil from wind is mostly recognized in semi-arid environments, where living roots provide anchoring and shoots provide physical protection, which reduces erosion and leads to improved air quality (Blanco-Canqui et al., 2015). Several studies reported cover cropping reduced annual soil loss from conventional till systems (Mutchler and McDowell, 1990; Siller et al., 2016; Jahanzad et al., 2017; Etemadi et al., 2018). Cover crops adoption can reduce soil loss of up to 40-96% (Langdale et al., 1991; Blanco-Canqui et al., 2015). In Ontario, Canada, Wall et al. (1991) reported a reduction in soil loss between 40 and 78% under intercropping silage corn with red clover (*Trifolium pratense* L.) (planted perpendicular to corn rows).

Erosion and compaction are two concerns threatening global soil resources, which cover crops have a demonstrated capability to mitigate. Incorporating species with a large taproot such as forage radish (*Raphanus sativus* L.) has been shown to increase the critical water content at which compaction occurs. It helps alleviate compacted soil by physically creating pores, decreasing bulk density, and increasing porosity (Kaspar and Singer, 2011; Blanco-Canqui et al., 2015). Similar to other cropping systems, the cover crop in sugarbeet production system could provide multiple ecosystem benefits as well as provide the soil cover thus minimizing soil erosion (Siller et al., 2016; Jahanzad et al., 2017; Etemadi et al., 2018).Thus, establishing a stand of cover crops by interseeding into cash crops would allow for soil protection in place immediately after the main crop is harvested.

Improved N management

Nitrogen assimilation by cover crops can protect water quality and retain N; otherwise, labile N in the agricultural field is available for future mineralization and crop use (Noland et al., 2018). Its adoption can (i) reduce N loss through immobilization and/or (ii) add N thorough biological N_2 fixation (Sarrantonio and Gallandt, 2003; Sainju et al., 2005; Chatterjee and Clay, 2017). A significant amount of residual soil N can be captured by cover crops and reduce leaching by recycling N for subsequent crop uptake (Kaye and Quemada, 2018; Daryanto et al., 2018; Thapa et al., 2018; Sigdel and Chatterjee, 2020). Cover crops are also considered to be a sustainable strategy for building N reserves (Blanco-Canqui et al., 2015; Jilling et al., 2020). Leguminous cover crops can add up to 86 kg N ha^{-1} to the soil through fixation (Vaughan and Evanlyo, 1998; Jensen et al., 2010), while non-leguminous and grasses produce high biomass and are good at scavenging NO_3-N before leaching. Cherr et al. (2006) suggest that N supply from cover crop residues to cash crops grown in rotation provides a 'keystone' service that makes cover crop use attractive to growers. Biological N_2 fixation by legume cover crops can supply significant N to crops grown in rotation and replace off-farm N fertility inputs (Tonitto et al., 2006; Gselman and Kramberger, 2008), making it a sustainable and renewable source of N. A study conducted in Switzerland evaluated 19 different legume cover crop species at two sites, and found atmospheric-derived N ranged from 2-172 kg N ha^{-1}, depending on biomass, biological N_2 fixation efficiency, and environment (Büchi et al., 2015). Whereas, non-leguminous winter cover crops can take up significant amounts of residual soil NO_3^- to reduce leaching to waterways and improve N cycling (Sainju and Singh, 2008; Moller and Reents, 2009; Thorup-Kristensen and Dresboll, 2010). Brandi-Dohrn et al. (1997) compared winter nitrate leaching losses under winter rye and winter fallows over three years in fields planted in a sweet corn-broccoli (*Brassica oleracea* var. *italica* L.) rotation; they found that using winter rye reduced NO_3-leaching between 16-34 kg N ha^{-1}.

Over the winter, cover crops cover the ground, which helps prevent erosion, and depending on species could provide multiple ecosystem benefits. However, cover crop benefits and adoption in crop rotations may be limited by the short planting window after the cash crop is harvested, limited winter-hardy cover crop species, additional input costs, lack of attractive, and lack of measurable short-term economic benefits of growing cover crops (Singer, 2008; Myers and Watt, 2015; Basche and Roesch-McNally, 2017). To overcome such issue, cover crops can be interseeded into standing main crops, allowing sufficient time to establish before winter (Wilson et al., 2013; Belfry and Van Eerd, 2016; Mohammed et al., 2019).

Interseeding of Cover Crops

Interseeding or sowing a cover crop into a standing primary cash crop is a way to get a jump on the conventional post-harvest cover crop season. Interseeding is advantageous because a profitable main crop can be grown with a cover crop for residue return and N_2 fixation in the same year. Thus, a higher proportion of soil also remains covered both spatially and temporally (Vanek et al., 2005). This can lead to an increase in cover crop biomass production, and presumably, better soil erosion control and SOM enhancement (Qi and Helmers, 2009; Steele et al., 2012; Belfry and Van Eerd, 2016). The prior establishment also increases cover crop choices compared with waiting to sow a cover crop until after a full-season main crop harvest (Grubinger, 2014). The planting timing must be considered to interseed cover crops (Noland et al., 2018). Interseeding must be delayed enough to minimize competition with the primary crop, but early enough so the cover crop can survive competition with the main crop and then withstand the harvest traffic (Grubinger, 2014). The best timing depends on the main crop type-cover crop combination and location (Ross et al. 2008; Baribusta et al., 2008; Berti et al., 2017; Peterson et al., 2019; Andersen et al., 2020).

Interseeding of cover crops can overcome short planting window constraints and allow cover crop establishment and growth before freezing occurs. Given that interseeded cover crops will have more time to grow in favorable conditions, they are thought to provide more ground coverage and weed suppression (Peterson et al., 2019). Studies have shown that interseeded cover crops produce more biomass and ground coverage (Hively and Cox, 2001). Thus, cover crop interseeded with sugarbeet is expected to establish quicker thus protecting sugarbeet and soil from wind damage (Yonts et al., 2002).

Interseeding effect on main crop yield

Interseeding time and method of planting determine the success of cover crops (Alford et al., 2003; Singer et al., 2006; Noland et al., 2018). Competition for light is often a primary limiting factor in the establishment and survival of interseeded cover crops (Humphreys et al., 2003). For instance, in corn, the percentage of incoming photosynthetically active radiation (PAR) absorbed by the corn canopy increases rapidly from ~20-90% between the 5-12 leaf stages (Gallo et al., 1985), necessitating precise timing for successful cover crop interseeding. Cover crops can be interseeded with the planting of the main crop to planting just before the main crop senescence. Cover crops interseeded before the closure of the main crop canopy must be planted early enough to establish roots while optimum solar radiation is reaching the soil surface, still late enough to avoid direct competition with the main crop for water, nutrients, and solar radiation (Abdin et al., 1997; Grubinger, 2014; Noland et al., 2018). Planting too early can result in competition between the interseeded cover crops and main crops, thus reducing main crop yields (Berti et al., 2017). Hairy vetch interseeded at 21 days instead of 14 days after planting increased corn yield in Japan (Uchino et al., 2009). Belfry and Van Eerd, (2016) found results of no yield reduction when interseeding 17 different cover crop species along with different mixes into corn stages V4-V6. There are several neutral to mixed responses of interseeded cover crops on main crops due to differential growing conditions and species grown (Mohammadi and Ghobadi, 2010; Belfry and Van erd, 2016). Therefore, species grown, environmental factors, management decisions such as tillage practices (Sarrantonio and Scott, 1988), and timing can affect N availability and economic yield of the main crop.

Impact of interseeded cover crops in following rotational crop

Interestingly cover crops affect the primary crop yield, and it is also important to consider that rotational crop yield does not get diminished. Studies have found mixed responses in the main crop yield following interseeded cover crops (Scott et al., 1987; Hively and Cox, 2001). Hively and Cox (2001) reported 21% and 15% higher corn yield following white clover (*Trifolium repens* L.) and red clover interseeding respectively, compared with no cover crop; however, there was a neutral response on crop yield with annual ryegrass and red fescue (*Festuca rubra* L.). Similarly, no reduction was observed on corn yield, when 11 different cover crop species were interseeded (Scott et al., 1987). These results show the benefit of interseeding cover crops can carry over into the next main crop or, at a minimum, may not hurt the following crop (Andersen et al., 2020).

However, other studies have reported reductions in the yield of following the rotational crop (Kumar and Goh, 2002; Sigdel and Chatterjee, 2020) due to diseases, weed competition, soil nitrogen (N) immobilization, reduced light intensity, phytotoxicity or difficulty in stand establishment (Papendick and Miller, 1977; Cook and Veseth, 1991; Kumar and Goh, 2000). Sigdel and Chatterjee (2020) found that rye resulted in lower wheat yield than without cover crop. Johnson et al. (1998) also found similar yield reduction with rye. They attribute the lower return to reduced corn height in those plots, which may be because of lower soil temperature, allelopathy, or low nutrient availability. Some studies also reported yield drag due to root disease transfer through cover crop use (Poromarto and Nelson, 2010). Selection of the effective cover crops in root disease susceptible regions is very important (Acharya et al., 2018). Thus, the full benefit of cover crop to the following crop is species-dependent and usually associated the synchrony between cover crop N mineralization and N demand of the following crop as well as an accurate estimation of supplemental fertilizer N requirements of the following crop.

Factors Affecting Success of Cover Crop Interseeding

Interseeding time

Studies (Abdin et al., 1997; Belfry and Van Eerd, 2016) showed that early interseeded cover crops get enough time to produce more biomass than late interseeded. However, planting too early can cause unacceptable levels of competition between the cover crop and the main crop. A study conducted at multiple locations in Ontario, Canada, found cover crops interseeded when seed corn was V4-V6 accumulated 33% more biomass than the treatments sown when the corn was V10-V12 (Belfry and Van Eerd, 2016). Another study in Eastern Canada saw an increase in ground cover in earlier-seeded cover crops (Abdin et al., 1997). According to the study, twelve forage species interseeded 10 and 20 days after corn emergence at two different locations provided 41% more ground cover than the later seeded ones. Similarly, Blanco-Canqui et al., (2017) stated that soil cover in corn increased from 24% cover with no cover crop to 65% cover in plots interseeded with winter rye.

According to the study conducted by Johnson et al. (1998) in the upper Midwest region of the US, seeding oat before soybean leaf drop during mid of August was beneficial rather than seeding oats too early like end of July. This study observed oat seeded 26 days before soybean leaf drop had more oat shoot biomass than earlier and later seeding times. This suggests that seeding time was successful because it was sown before the soybeans dropped their leaves, and then that leaves provided the soil with cover to help hold in moisture and aid in oat growth. Other studies have found no increase in biomass production in earlier planted cover crops (Mohammadi, 2010; Berti and Samarappuli, 2018; Peterson et al., 2019). Another study in western Iran found hairy vetch biomass at corn maturity was the same whether hairy vetch was planted the same day as the corn or ten days after the corn emerged (Mohammadi, 2010). The extra time did not correspond to more biomass production. Another multi-location study in Quebec, Canada found, one location showed earlier seeding could lead to more ground cover. In contrast, the other site had no significant difference between the two planting times on the ground cover or biomass production (Abdin et al., 1997). These studies show that while planting earlier may result in increased biomass or ground cover, it is not always consistent. There may be differences between cover crops species and environment differences that need to be considered.

Selection of cover crop species

The selection of the cover crop species plays a vital role in determining cover crop success (Abdin et al., 1998; Noland et al., 2018). Some cover crop species like rye have shown to produce more biomass when interseeded (Komatsuzaki and Wagger, 2015; SARE, 2016; Crowley et al., 2018). The overall rotation will also impact if a grass versus a legume or brassica should be planted. Legume species, such as clovers, are commonly planted because they can add nitrogen to the soil, which may benefit the following crop. Legumes have been shown to produce the most biomass in many studies (Scott et al., 1987; Abdin et al., 1997; Baributsa et al., 2008; Belfry and Van Eerd, 2016; Peterson et al., 2019; Andersen et al., 2020), which can help suppress weeds. In one study, crimson clover (*Trifolium incarnatum* L.) generally produced the most biomass, followed by a mixture of red clover and annual ryegrass (Abdin et al., 1997). Another study by Scott et al. (1987) observed that yellow sweetclover (*Melilotus officinalis* L.), ryegrass, alfalfa (*Medicago sativa* L.), and rye were among the most successful species when the corn was planted 0.15-0.30 m tall. A study in Michigan found that hairy vetch produced more biomass than red clover (Baributsa et al., 2008). Another study found oilseed radish and a mixture of oilseed radish + forage pea produced the most biomass of the species and mixtures they interseeded in seed corn at the V6-V8 stage (Belfry and Van Eerd, 2016).

While clover species are good biomass producers, they may not be ideal in all situations, such as before another legume species or in areas with excess nitrogen which limits nodule formation (Streeter and Wong, 1988; Ferguson et al., 2018). Therefore, grass species have been compared to see which can cover the most ground and produce the most biomass in an interseeded setting. A study showed no significant differences between rye, oat, and a mixture of rye and oat (Johnson et al., 1998). In that study, oat produced more fall biomass than rye or the mix in one year, but the average of the three years showed no differences between treatments. They also observed no differences in the spring biomass or the residue left from the treatments. While rye did not do better than oat in that study, in another study, rye did produce more biomass than hairy vetch and berseem clover (*Trifolium alexandrinum* L.) (Fakhari et al., 2015). Ryegrass, both annual and perennial, have been found to provide the most ground cover compared with other cover crop species (Scott et al., 1987; Hively and Cox, 2001).

Perennial ryegrass provided the most fall ground cover when planted when the corn was 0.15-0.30 m tall or at mid-silk (R2) compared with all other treatments planted at the earlier planting time (Scott et al., 1987). Perennial ryegrass covered 84% of the ground in the fall when planted early and 85% of the ground when planted at mid-silk. Another study found annual ryegrass and alfalfa had the most fall biomass and ground cover in one year when broadcasted into soybeans before harvest (Hively and Cox, 2001). Whether a legume or a grass species would fit best in the overall rotations, there are cover crop species that can produce biomass and cover the ground when interseeded.

Similarly, brassica cover crops are known for rapid fall growth and their ability to scavenge nutrients (Clark, 2007). Dean and Weil (2009) found N uptake by brassica cover crop like radish can be greater than or equal to cereal rye. They are also known for their ability to break up compaction and serve as a trap crop for harmful crop pests (Iqbal et al., 2020). Due to its deep tap root and rapid growth, they can uptake N from deep within the soil profile, bringing it closer to the soil surface and within the biomass (Wick et al., 2017). Due to the potential of brassica species to release N back into the environment, it is being used in cover crop mixes (Dean and Weil, 2009).

From the above discussion, it is evident that interseeding has variable responses depending on management decision, crop rotation, and climate. A study in conducted in Montana suggested that growing sugarbeet with living mulch can be successfully implemented without any or minimal negative impact on sugarbeet productivity to other cropping system (Afshar et al., 2018). We did not find an interseeding study under the sugarbeet production system for the northern Great Plains region. Similar to other cropping system, interseeding cover crop in sugarbeet production system could provide multiple ecosystem benefits. However, the cover crop management practices can directly affect sugarbeet production. Further investigation is required to better understand how cover crop management practices such as species selection and interseeding time affect the sugarbeet yield and quality.

MATERIAL AND METHODS

Plot Establishment

Field trials were conducted at two locations during 2018 and 2019 growing seasons (Table 1). The experiment was laid out in a randomized complete block design (RCBD) with a factorial arrangement of four different cover crops species and two interseeding times and check (no cover crop) treatments. Four cover crops species were winter rye (*Secale cereale* L.) cv. ND Dylan, winter camelina [*Camelina sativa* (L.) Crantz] cv. Joelle, winter Austrian pea (*Pisum sativum* L.), brown mustard (*Brassica juncea* L.) cv. Kodiak, Mighty Mustard ™ (Table 2). Cover crops were interseeded at two different times (Table 3). Nine treatments were replicated four times within a site. Individual treatment plots measured 3.35-m wide and 9.14-m long.

Table 1. Soil series description of 2018-2019 experimental locations at Ada, Downer, MN and Prosper, ND.†

Year	Location	Geo-points	Series	Taxonomy
2018	Ada	47.327˚N,96.394˚W	Ullen	Sandy, mixed, frigid Aeric Calciaquolls
2018	Downer	46.864˚N, 96.518˚W	Wyndmere	Coarse-loamy, mixed, superactive, frigid Aeric Calciaquolls
2019	Ada	47.309˚N, 96.390˚W	Glyndon	Coarse-silty, mixed, superactive, frigid Aeric Calciaquoll
2019	Prosper	47.005˚N, 97.115˚W	Kindred-Bearden	Fine-silty, mixed, superactive, frigid Typic Endoaquolls

† Soil series data obtained from Web Soil Survey (Soil Survey Staff, 2016).

Table 2. Seeding rates (pure live seed) of interseeded cover crops for 2018 and 2019 growing season.

Cover crop	Cultivar	Seeding rate (kg ha^{-1})
Austrian pea	Austrian	22.4
Winter camelina	Joelle	6.72
Brown mustard	Kodiak	11.2
Rye	ND Dylan	22.4

Sugarbeet Planting

Each plot contained six sugarbeet rows spaced 55.9-cm apart. Crystal 093, a glyphosate tolerant sugarbeet cultivar, was planted at the rate of 148,200 plants per ha^{-1}. Sugarbeet seed was planted to a 5-cm depth with a six row John Deere row crop planter (John Deere, Moline, IL).

Cover crop Interseeding

For both growing seasons, cover crops were interseeded at two different time i.e. early (first interseeding) and late (second interseeding) (Table 3). Cover crop seeds were seeded at recommended seeding rate (pure live seed) (Table 2) using a V-shaped hoe with two blades 15-cm apart to make a parallel furrow to simulate planting with a commercial inter-seeder. The furrows were 2-to 2.5-cm deep and centered in each of the sugarbeet rows. Cover crop seeds were distributed evenly into the furrows by hand. The furrows were then covered with soil. Same interseeding technique was used for both the early and late cover crop interseeding times.

Weed, Disease, and Pest Management

For the weed control, glyphosate (n-phosphono methyl glycine) at the rate of 0.74 kg a.i. ha^{-1} (formulation 25 mL L^{-1}) and ammonium sulfate (Class Act, Winfield Solutions, LLC Shoreview, MN) at 10 mL L^{-1} were sprayed on the third week of May to the second week of July each year (Table 3). Similarly, to control cercospora leaf spot (*Cercospora beticola*) in sugarbeet, three fungicides, thiophanate methyl and pyraclostrobin were applied on the first and second week of August at the rate of 512 mL L^{-1}, 555 mL L^{-1}, and 730 mL L^{-1}, respectively for both years (Table 3).

Table 3. Field operation schedule and soil and plant sampling times for two sites at each growing season.

Field Operations	2018		2019	
	Ada	Downer	Ada	Prosper
Sugarbeet planting	7-May	3-May	13-May	16-May-
Interseeding				
First interseeding	45 DAP	55 DAP	31 DAP	32 DAP
Second interseeding	65 DAP	74 DAP	42 DAP	47 DAP
Herbicide application	28-May	28-May	10-Jun	10-Jun
	14-Jun	14-Jun	18-Jun	18-Jun
	-	-	22-Jul	22-Jul
Hand weeding	-	-	-	24-Jul
Fungicide application	2-Aug	2-Aug	6-Aug	6-Aug
	-	-	22-Aug	22-Aug
Sugarbeet harvest	26-Sep	17-Sep	16-Sep	9-Oct
Data Collection				
Soil inorganic N (0-15cm)	30-Aug	29-Aug	15-Jun	17-Jun
	26-Sep	17-Sep	8-Jul	22-Jul
	16-Oct	16-Oct	9-Aug	9-Aug
	-	-	16-Sep	9-Oct
Cover crop biomass	25-Sep	15-Sep	4-Sep	4-Sep
Sugarbeet root yield	26-Sep	17-Sep	16-Sep	9-Oct
Spring cover crop biomass	24-Apr	24-Apr		

* DAP, days after planting sugarbeet.

Data Collection

Cover crop biomass

Above ground cover crop biomass was measured before sugarbeet harvest (Table 3). Biomass was collected from a 0.61 ×0.61 m^2 quadrat per plot. Cover crop biomass was clipped at the soil surface and dried at 60˚C until a consistent weight was achieved and then weighed to obtain dry weight.

Sugarbeet root yield and quality

For sugarbeet yield, the center two rows of each plot were mechanically harvested during the third week of September (Table 3), discarding the roots at each end of the harvest row to eliminate any alley effects. A sub-sample of 15-20 sugarbeet roots were analyzed to determine sugar concentration and recoverable sugar at American Crystal Sugar Quality Tare Lab, East Grand Forks, MN.

Soil sampling and analyses

Initial soil samples were collected from each site before fertilizer application for the analysis of basic soil physical and chemical properties. Standard methods were used to determine bulk density (Blake and Hartge, 1986), nitrate-N (Mulvaney, 1996), Olsen-P (Frank et al., 1998) and available K using air-dried soil (Warncke and Brown, 1998) were determined. The selected soil physical and chemical properties of experimental sites are presented in Table 4. Soil inorganic N concentrations to a 0-15 cm depth were determined on soil samples collected at the time of harvest. For soil ammonia (NH_4^+) and nitrate (NO_3^-) concentration determination, soil samples were kept frozen until analysis. A 6.5 g of field moist soil sample was extracted with 2 M KCl using Whatman no. 42 filter paper and analyzed for NH_4^+ and NO_3^- using a Timberline Ammonia Analyzer ® (Timberline Instruments, Boulder, CO, USA). Gravimetric soil moisture content was determined by oven drying a field moist subsample at 105 °C and gravimetric water content was used in calculating soil NH_4^+ and NO_3^- concentration on an oven dry soil basis.

Economic Analysis

Economic return was calculated using the following equation,

$$\text{Return } (\$\text{ ha}^{-1}) = \text{Yield } (\text{Mg ha}^{-1}) \times (\text{sugar \%} - \text{sugar loss to molasses \%}) \times \text{Price } (\$\text{ Mg}^{-1}) + \text{Agricultural products } (\$\text{ Mg}^{-1}) - \text{Operation cost } (\$\text{ Mg}^{-1})$$

Information regarding price, revenue from agricultural products and operation cost of the respective growing season was collected from personal communication with American Crystal Sugar Inc. personnel (T. Grove, personal communication).

Table 4. Soil physical and chemical properties for Ada, Downer, MN and Prosper, ND.

Characteristics	Ada	Downer	Ada	Prosper
Year	2018	2018	2019	2019
Textural class	Sandy clay loam	Sandy loam	Sandy clay Loam	Silty clay loam
pH	8.4	8.1	7.6	6.7
NO_3-N 0-15 cm (kg N ha^{-1})	9.9	10.0	16.1	17.9
Olsen P (mg kg^{-1})	5.0	5.0	20.0	40
K (mg kg^{-1})	67	74	172	280
Organic Matter (g kg^{-1})	24	26	31	33

Statistical Analysis

Data were analyzed statistically first with nine treatments (four cover crop species × two interseeding time and control) and also as a factorial excluding control with four replicates. The effect of cover crop interseeding on yield was analyzed using RCBD. The procedure general linear model (GLM) of the Statistical Analysis System 9.4 (SAS Inc., Cary, NC) was used for analysis of variance of all data. Each location per year combination was defined as an environment and was considered random effect, while cover crops and interseeding timing were considered fixed effects. Locations in each year were analyzed separately and tested for homogeneity of variance (Appendix Table 2, 3, and 4). Location per year were not combined because environments were not homogenous. Probabilities equal to or less than 0.05 were considered significant for main effects and interactions. The least significant difference (LSD) test was used to separate differences between treatment means if analysis of variance indicated the presence of such differences.

RESULTS AND DISCUSSION

Since the location per year was not homogenous and the trial outcomes were highly dependent on weather conditions, we quantified cover crop interseeding effect across all sites and treatments. This chapter is divided into four sections, (i) weather during growing season (May-September), (ii) cover crop biomass yield and N removal, (iii) sugarbeet yield and quality, and (iv) residual soil nitrate. The results and discussion for each section are divided by each sub-section which contains results and discussion for growing season 2018 and 2019.

Weather During Growing Season (May-September)

Since field trials outcomes are highly dependent on weather and environmental conditions, here we present weather data for field locations. Average daily air temperature and daily rainfall during the 2018-2019 growing season are presented in Figure 2. In 2018, sugarbeet was planted at the beginning of May and harvested in mid- to late-September. In 2019, wet field conditions delayed sugarbeet planting until mid-May, and sugarbeet was harvested in late September to early October (Table 3).

Growing season, 2018

In 2018, the growing season for Downer, MN, started out warmer and drier than 30-year average in May (+3˚C) and June (+2˚C) but was colder than 30-year average throughout the rest of the growing season (Appendix Table 1). Sugarbeet planting and its emergence occurred during a dry period. For the first week after planting, the Downer site did not receive any rainfall, followed by only 2.5-mm of rainfall during the second week (NDAWN). Cover crops were planted at 55 DAP (27 June) and 74 DAP (16 July) for the first and second interseeding time, respectively. Both first- and second-interseeded cover crops received 52.1 and 51.6 mm of rainfall, respectively, within one week of cover crop planting (NDAWN). Wilson (2013) observed that receiving rain within one week after seeding facilitates cover crop establishment. Downer received a total of 434 mm of precipitation throughout the growing season (May-September) in 2018 (Appendix Table 1).

Ada, MN, also started out warmer and drier than 30-year average in May (+3˚C) and June (+2 ˚C). Precipitation was below 30-year average for the majority of the growing season (Appendix Table I). Sugarbeet received 62.8 mm of rainfall within a month of planting, which aided beet establishment. Cover crops were planted at 45 DAP (21 June) and 65 DAP (11 July) for the first and second interseeding time, respectively, for Ada. Cover crops interseeded in June only received 0.8-mm of rainfall within a week of cover crop planting, whereas the second-planted cover crops received 22.3 mm of rainfall within one week of interseeding. Failure to receive substantial rain soon after cover crop interseeding reduced cover crop establishment at Ada. Several studies also showed that precipitation prior to or following cover crop interseeding is an important factor in cover crop establishment (Wilson, 2013; Nielson et al., 2015; Blanco-Canqui et al., 2017). Ada received a total of 344 mm of rainfall throughout the growing season, which was 81.1 mm below 30-year average (Appendix Table 1).

Growing season, 2019

In 2019, planting was delayed for almost two weeks compared with the normal growing season due to wet soil conditions during the initial weeks of May (USDA-Weekly Weather and Crop Bulletin, 2019). There was a substantial amount of soil moisture due to the late melting of snow. Rainfall was below 30-year average in May (-19.8 mm) and June (-45.4 mm), and above 30-year average from July (+10 mm) throughout the growing season at Ada (Appendix Table 1). The sugarbeet received 27.9 mm of rain within a week following planting. Cover crops were planted at 31 DAP (13 June) and 41 DAP (24 June) for the first- and second-interseeding time, for Ada. First-interseeded cover crops received 10.7-mm of rainfall within a week of cover crop planting, whereas second-interseeded cover crops received 18.8-mm of rainfall within one week of interseeding. Cover crops received 298-mm of total rainfall throughout the growing period. Ada received a total of 434-mm of rainfall throughout the growing season, which was 8.1-mm above 30-year average in the 2019 growing season (Appendix Table 1).

For Prosper, ND, the growing season (May-October) started out cooler in the month of May followed by warmer than 30-year average in June (+1˚C) and July (+1°C). Except for May (-17.5 mm), the rest of the growing season at Prosper had above-average precipitation. July and September received the most significant amount of rainfall, 156 mm (+68 mm), and 148 mm (+82 mm), respectively (Figure 2). First-interseeded cover crops received 605-mm of total rainfall, whereas second-interseeded cover crops received 483.2-mm of rainfall throughout the season. Prosper in 2019 received a total of 665-mm of precipitation throughout the growing season (May – Oct), which was 206-mm above average. Prosper had multiple days throughout the growing season, where the soil was wet and with stagnant water. Excessive rainfall towards the end of the season reduced the growth of the late-interseeded cover crops. The late-interseeded cover crops were most affected by excessive rainfall due to their small seedling size (Maddonni et al., 2001; Thelen, 2006; Belfry and Van Eerd, 2016; Berti et al., 2017).

While soil moisture was not measured in this experiment, observational evaluations of the study throughout the two growing seasons would suggests that timely rain during the growing was an important factor affecting cover crop establishment and accumulation.

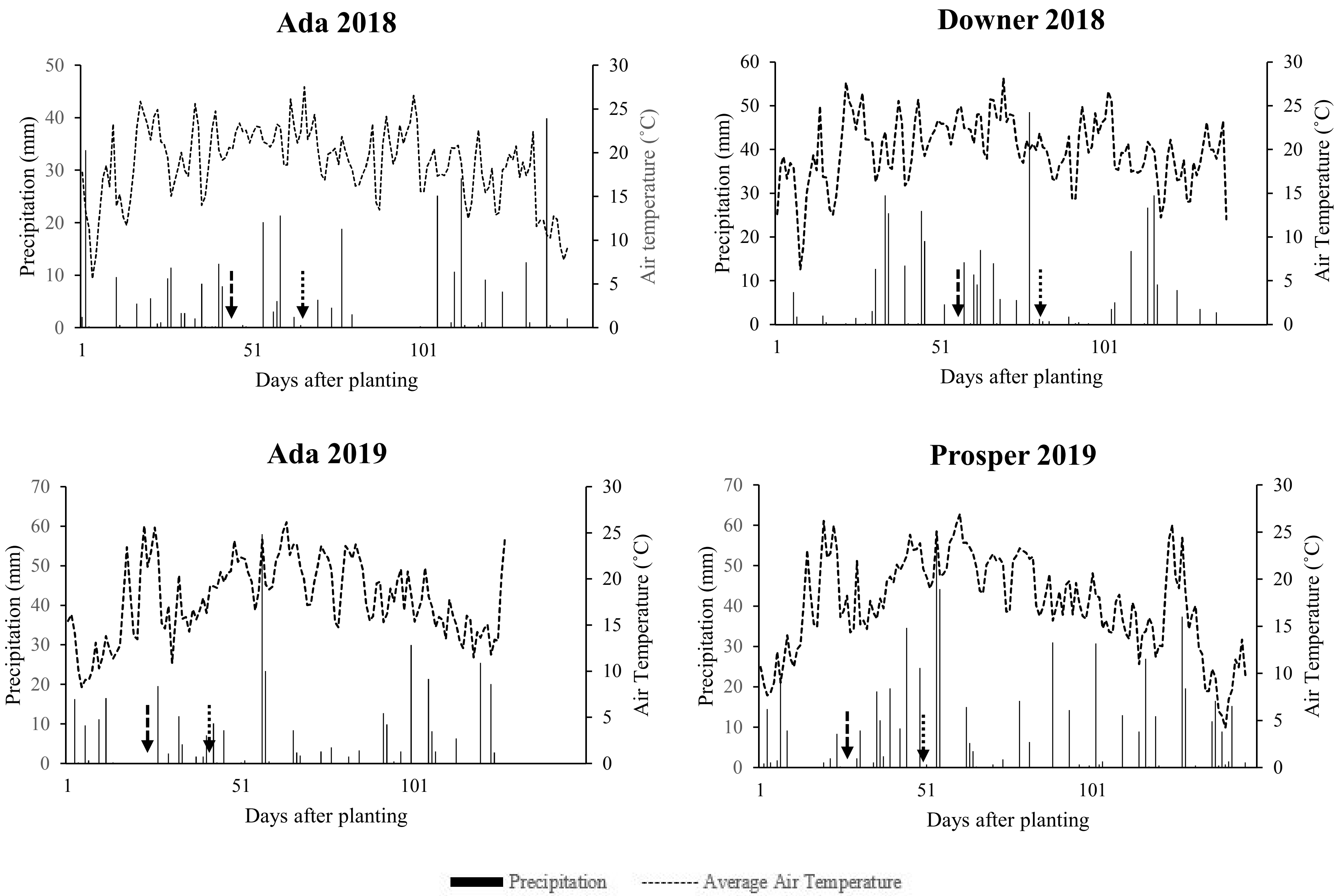

Figure 2. Daily rainfall and daily average air temperature at each experimental site in 2018 and 2019 growing season. The first interseeding is represented with ⇣ , and the second interseeding is represented with ⇣ .

Aboveground Cover Crop Biomass Yield

Since cover crop biomass production is assumed to be proportional to its benefits (Kuo et al., 1997; Finney et al., 2016; Chapagain et a., 2020), we quantified cover crop biomass across all sites and treatments. Cover crop biomass production in response to interseeding time and selection of species is presented in Table 5. Interseeding time had a significant (P<0.05) effect on biomass production at Downer only in 2018 and both sites in 2019. Cover crop species showed a significant (P<0.05) influence on biomass yield at Downer in 2018 and Ada in 2019. Interaction between interseeding time and cover crop species had a significant (P<0.05) influence on cover crop biomass yield for both sites in 2018.

Table 5. Main and interaction effects of cover crop species (C) and interseeding time (I) on aboveground cover crop biomass yield (kg ha^{-1}) at Ada, Downer, and Prosper for 2018 and 2019 growing season.

Effect	Cover crop biomass yield			
	2018		2019	
	Ada	Downer	Ada	Prosper
	---------------------- (kg ha^{-1}) -------------------------			
Interseeding time (I)				
First interseeding	154 (134‡)	1650 a† (821)	2010 a (651)	1180 a (774)
Second interseeding	81 (109)	534 b (271)	548 b (115)	118 b (128)
P<F	*0.056*	*<0.001*	*<0.001*	*<0.001*
Cover crop species (C)				
Austrian pea	76 (76)	741 c (635)	1510 a (986)	671 (831)
Camelina	139 (136)	832 bc (286)	680 b (660)	506 (634)
Brown mustard	127 (138)	1540 a (1245)	1220 ab (1023)	943 (1028)
Rye	128 (153)	1270 ab (722)	1700 a (828)	493 (570)
P<F	*0.602*	*0.001*	*0.001*	*0.39*
Interaction (I × C)				
Int. 1× Pea	119 abc (85)	1210 bc (556)	2350 (624)	1260 (821)
Int. 1 × Camelina	77 bc (62)	1020 bcd (205)	1280 (227)	905 (712)
Int. 1× Brown mustard	190 ab (181)	2540 a (910)	2130 (456)	1630 (1086)
Int. 1× Rye	229 a (164)	1840 ab (542)	2270 (701)	958 (427)
Int. 2 × Pea	34 c (38)	270 d (164)	680 (205)	81 (78)
Int. 2 × Camelina	202 a (169)	630 cd (217)	80 (90)	108 (116)
Int. 2 × Brown mustard	65 c (42)	540 cd (271)	310 (111)	258 (156)
Int. 2× Rye	28 c (32)	700 cd (223)	1110 (449)	31 (15)
P<F	*0.023*	*0.003*	*0.331*	*0.757*

† Different letters indicate significant difference of means at 95% significance level, according to $LSD_{0.05}$.
‡ indicates standard deviation of the mean values.
§ First interseeding Int. 1, second Int. 2.

Growing season- 2018

<u>Ada</u>

At this site, cover crops biomass production ranged from 76 to 139 kg ha^{-1} across species (Table 5). In 2018, the main effects, interseeding time and cover crop species had no influence, but their interaction had a significant ($P<0.05$) impact on cover crop biomass production (Table 5). The average cover crop biomass production was lower at Ada compared with Downer. Low biomass yield in Ada may be explained by water deficit after interseeding (Figure 2). This is in agreement with Sandler et al., (2015) findings, where lack of rain in the days following establishment led to decreased biomass yield. Averaged across interseeding time, the cover crops interseeded first produced two-fold higher biomass than the cover crops interseeded later. Research also shows that cover crops interseeded early tend to produce more biomass, as they get more exposure to resources, light, air, and space for early growth in between the rows (Thelen, 2006; Curran et al., 2018). The interseeding time by cover crop species interaction significantly ($P<0.05$) impacted cover crop biomass at this site (Table 5).The highest and lowest biomass was in rye on the first seeding time (229 kg ha^{-1}) and second seeding time (28 kg ha^{-1}), respectively in Ada, in the 2018 growing season. Higher biomass of the first interseeded rye can attributed to its potential for rapid growth and for accumulating large amounts of biomass in more exposure to resources in between sugarbeet rows (Wilson et al., 2013; Martin et al., 1976; Komatsuzaki and Wagger, 2015; SARE, 2016; Crowley et al., 2018). In contrast, due to the dense canopy coverage from the sugarbeet canopy, the growth was limited for the rye interseeded in July. Here it is important to mention that vigorous growth rate after germination of the second-interseeded camelina might have resulted in a higher biomass yield (202 kg ha^{-1}) compared with other species interseeded later.

Downner

Cover crop biomass yield at this site ranged from 741 to 1540 kg ha^{-1} across the species (Table 5). Main effects, interseeding time, cover species and their interaction were significant (P<0.05) (Table 5). Cover crop biomass yield ranking was brown mustard>rye>camelina>Austrian pea. Brown mustard had the highest biomass (1540 kg ha^{-1}), and pea produced the lowest biomass (741 kg ha^{-1}). Brown mustard had significantly (P<0.05) higher biomass than camelina and winter pea but similar to rye. This result is similar to various studies that have found rye and mustard to be quick-growing (Wortman et al., 2012; Baraibar et al., 2018). Ruis et al. (2019) suggested that for drier regions, hard-seeded species such as brassica crops, combined with substantial rain can be beneficial for cover crop establishment, likely through the increase in water available for seed imbibition. Similar to Ada 2018, cover crops had higher biomass yield in the first interseeding time. This may have been due to precipitation prior to or following the first cover crop interseeding at Downer (Figure 2), which helped the cover crops produce more biomass than in the second interseeding date. The cover crops interseeded first produced an average of 1650 Mg ha^{-1} of aboveground biomass, which was three-fold higher than the average of cover crops interseeded later (Table 5). However, sugarbeet suppressed cover crop biomass growth for the cover crops interseeded in July. This is similar to Van Eerd (2016) findings, where cover crops interseeded at the V4-V6 growth stage had difficulty surviving through the growing season and did not produce enough biomass to benefit the cropping system. Berti et al. (2017) also confirmed that late-interseeded cover crops are suppressed under the crop's canopy.

Cover crop biomass yield was significantly (P<0.05) impacted by the interseeding time by cover crop species interaction at this site (Table 5). The brown mustard interseeded first resulted in a significantly higher cover crop biomass yield (2540 kg ha^{-1}) compared with other interseeded cover crops.

Growing season-2019

Prosper

Cover crop biomass yield at this site ranged from 493 to 943 kg ha^{-1} across species, as shown in Table 5. Low cover crop biomass yield in Prosper may be explained by excess water throughout the season, with a rain event totaling just over 665 mm of rainfall (Appendix 1). This large rain event caused saturated field conditions for a prolonged period. Only the effect of interseeding time was significant (P<0.05) (Table 5). Averaged across the interseeding time, the cover crops interseeded first produced ten times higher biomass (1180 kg ha^{-1}) compared with the cover crops interseeded later (118 kg ha^{-1}) (Table 5). The cover crops interseeded later were most affected by excessive rainfall due to their small seedling size and lack of sunlight due to canopy closure (Maddonni et al., 2001; Thelen, 2006; Belfry and Van Eerd, 2016; Berti et al., 2017). There was no significant interaction observed between species and interseeding time.

Ada

At this site, cover crop biomass yield ranged from 680 to 1700 kg ha^{-1} across species (Table 5). There was a significant (P<0.05) effect of interseeding time and species on cover crop biomass yield. Cover crop species and interseeding time determined the biomass accumulation. Cover crop biomass yield was greater in rye followed by Austrian pea brown mustard, and camelina. Interaction of cover crop species and interseeding time did not affect cover crops biomass yield. Average biomass yield from the first interseeding was 2010 kg ha^{-1}, whereas all cover crops averaged across produced 548 kg ha^{-1} for the second interseeding time. Among the species, rye (1700 kg ha^{-1}) and Austrian pea (1510 kg ha^{-1}) had significantly (P<0.05) higher biomass yield than camelina (680 kg ha^{-1}). These results for rye biomass are similar to other interseeding experiments including winter rye (Appelgate et al., 2017; Noland et al., 2018; Peterson et al., 2019). Winter camelina did not produce as high amount of biomass as pea and mustard, due to the fact that camelina requires vernalization to induce reproductive stage,which limits growth (Peterson et al., 2019).

Cover crop biomass N accumulation was measured in the above ground biomass in the fall. The analysis determined that the total plant N accumulation corresponded with the amount of cover crop biomass produced. Cover crop biomass N content for different interseeded cover crop species ranges between 2.23 to 44.1 kg N ha^{-1} for Austrian pea, 3.72 to 22.2 kg N ha^{-1} for camelina, 4.05 to 49.1 kg N ha^{-1} for mustard, and 2.58 to 33.9 kg N ha^{-1} for rye throughout the 2018 and 2019 growing season (Table 6). The wide range of N accumulation is a reflection on biomass produced. This is similar to Sutradhar et al. (2017) findings, where pea intersown into switchgrass had N accumulation of 42.1 kg N ha^{-1}. Studies by Applegate et al., (2017) and Noland et al., (2018) also observed N accumulation of 21.2 kg N ha^{-1} and 21.7 to 26 kg N ha^{-1} respectively for interseeded rye. These results indicate that the cover crops used in this experiment are efficient at taking up N and total N accumulation depended on cover crops biomass accumulation. Various studies also showed that the quantity of cover crop N accumulation is species-dependent and the N accumulated ranges differently (Decker et al., 1994; Vyn et al., 2000; Pieri, 2011; Berti et al., 2017).

The N accumulation of interseeded cover crops was significantly (P<0.05) affected by interseeding time except at Ada in the 2018 growing season. The total N accumulation was higher for early interseeded cover crop due to higher biomass accumulation than late interseeding. The biomass accumulation for early interseeding ranged from 4.03 to 53.9 kg N ha^{-}

[1], and 2.25 to 13.9 kg N ha^{-1} for late interseeding. The results indicate when cover crops are established early into the sugarbeet, an acquisition of large amounts of N is present in the biomass, reducing the potential offsite loss of free N in the soil.

Table 6. Main and interaction effects of cover crop species (C) and interseeding time (I) on cover crop biomass N accumulation (kg N ha^{-1}) at Ada, Downer, and Prosper for 2018 and 2019 growing season.

Effects	Cover crop biomass N accumulation			
	2018		2019	
	Ada	Downer	Ada	Prosper
	------------------------ (kg N ha^{-1})	---------------------------		
Interseeding time (I)				
First interseeding	4.03 (3.58‡)	45.1 a† (26.8)	54.0 a (19.6)	33.0 a (24.7)
Second interseeding	2.25 (2.93)	13.9 b (7.08)	13.6 b (9.80)	3.5 b (4.04)
P<F	*0.117*	*<0.001*	*<0.001*	*<0.001*
Cover crop species (C)				
Austrian Pea	2.23 (2.21)	21.5 b (18.4)	44.1 a (28.6)	19.5 (24.1)
Camelina	3.72 (3.63)	22.2 b (7.64)	18.2 b (17.6)	13.5 (17.0)
Brown mustard	4.05 (4.42)	49.1 a (39.6)	38.9 a (32.6)	30.0 (32.7)
Rye	2.57 (3.05)	25.4 b (14.4)	33.9 a (16.6)	9.9 (11.4)
P<F	*0.591*	*0.001*	*0.001*	*0.111*
Interaction (I × C) *P<F*	*0.079*	*0.004*	*0.014*	*0.414*

† Different letters indicate significant difference of means at 95% significance level, according to $LSD_{0.05}$.
‡ indicates standard deviation of the mean values.

Result shows that the cover crops biomass was higher for the first interseeding time in most locations. Prior to or following early cover crop interseeding, water availability helped the cover crops produce more biomass compared with the late-interseeded cover crops. In addition, the cover crops interseeded early had the advantage of producing more biomass because there was no sugarbeet competition and a longer growing season, compared with the later interseeded treatments. It is likely sugarbeet canopy suppressed cover crop growth by decreasing the amount of light available to the cover crops as it has been measured in other interseeded cover crop in corn and soybean (Wilson, 2012; Bich et al., 2014; Belfry and Van Eerd, 2016).

Overall, cover crop species and interseeding time determined the biomass accumulation. The amount of biomass produced mostly varied between two interseeding time as (i) longer growing periods provide more biomass production than a shorter one (Thelen, 2006; Curran et al., 2018), (ii) less competition for resources with cash crops, (iii) early interseeded cover crops receive more exposure to sunlight (Belfry and Van Eerd, 2016; Ruis et al., 2019). Inconsistency in biomass for different species might be due to differences in cover crop physiology and the suitability of different plants to specific environments. Several individual studies suggest that cover crop biomass growth and development can be highly variable, even with in the same region (Finney et al., 2016; Thomas et al., 2016, 2017). Variability in cover crops can also be attributed to site-specific factors including climate, cropping system, cover crop groups, interseeding time, seeding rate, growing season, planting method, soil moisture, and soil texture (Chatterjee and Clay, 2017). Further research is needed to determine why some cover crops did better in certain site-years, and if those conditions can be replicated to ensure success.

Sugarbeet Yield and Quality

Growing season-2018

The cover crop species and interseeding time did not influence the sugarbeet root yield at Ada in 2018 growing season (Table 7). However, this study found a significant interaction between cover crop species and interseeding time on sugarbeet root yield at Ada. No significant (P<0.05) difference in the sugarbeet root yield was seen between the cover crop species and planting time (Table 7). Geiszler and Ransom (2018) also found a similar lack of effect of cover crop on corn yield, for similar cover crop planting time. The lack of impact of cover crop species on yield is probably due to the limited competitive effect of the intercropped cover crop (Geiszler and Ransom, 2018).

When compared with all interseeding treatments, including the control (no cover crop), sugarbeet root yield varied in response to cover crop interseeding (Table 8). Averaged across treatments, sugarbeet root yield ranged from 81.0 Mg ha^{-1} to 87.5 Mg ha^{-1}. At Ada, the sugarbeet had the highest root yield (87.5 Mg ha^{-1}) in the treatment with brown mustard interseeded first and it was similar to the sugarbeet control (84.4 Mg ha^{-1}). All other treatments were significantly ($P<0.05$) lower yielding than brown mustard interseeded first. Evans et al. (2009) found that conservation tillage (strip tillage) and conventional tillage produced similar sugarbeet root yields under ideal conditions, but reduced root yield under unfavorable growing conditions.

Similarly, the cover crop species, interseeding time, and interaction between cover crop species and interseeding time did not affect root yield in Downer (Table 7). At Downer, the average sugarbeet root yield was extremely low (39.4 Mg ha^{-1}). Control (without any cover crop) had an average yield of 41.3 Mg ha^{-1}. The highest sugarbeet root yield of 47.4 Mg ha^{-1} was observed in camelina interseeded on the first interseeding time, and the lowest sugarbeet yield (32.5 Mg ha^{-1}) was observed in the brown mustard treatment interseeded first.

Table 7. Main and interaction effects of cover crop species (C) and interseeding time (I) on sugarbeet yield (Mg ha^{-1}) and sugar concentration (g kg^{-1}) for four site-year.

	2018				2019			
	Ada		Downer		Ada		Prosper	
Effect	Yield	Sugar	Yield	Sugar	Yield	Sugar	Yield	Sugar
	(Mg ha^{-1})	(g kg^{-1})	(Mg ha^{-1})	(g kg^{-1})	(Mg ha^{-1})	(g kg^{-1})	(Mg ha^{-1})	(g kg^{-1})
Interseeding time (I)								
First Interseeding	83.2 (5.73‡)	166 (3.24)	39.6 (12.3)	149 a† (3.75)	54.1 b (8.80)	166 a (4.77)	79.1 b (10.3)	149 (5.29)
Second Interseeding	85.1 (4.06)	167 (2.40)	39.2 (6.40)	147 b (4.70)	73.2 a (4.63)	162 b (4.29)	86.5 a (7.73)	147 (6.82)
P<F	ns	ns	ns	*0.008**	*0.0006**	*0.005**	*0.045**	ns
Cover crop species (C)								
Austrian pea	83.8 (5.34)	166 (3.98)	36.9 (9.00)	145 (3.45)	66.1 ab (12.3)	161 b (4.54)	84.7 (12.2)	148 (3.58)
Camelina	84.4 (3.65)	166 (2.45)	43.3 (8.55)	147 (2.17)	68.6 a (10.1)	164 ab (5.34)	85.5 (5.78)	151 (7.23)
Brown mustard	85.3 (6.26)	167 (2.47)	37.9 (11.5)	147 (4.84)	61.1 bc (12.0)	164 ab (3.55)	80.6 (9.47)	148 (6.60)
Rye	83.3 (5.09)	166 (2.47)	39.4 (9.90)	152 (4.21)	58.8 c (12.8)	167 a (4.90)	80.4 (11.0)	146 (6.30)
P<F	ns	ns	ns	Ns	*<0.03**	*0.027**	Ns	ns
Interaction (I × C) $LSD_{0.05}$	*0.042**	*0.043**	ns	Ns	ns	*0.013**	Ns	ns

† Different letters indicate significant difference of means at 95% significance level, according to $LSD_{0.05}$.
‡ indicates standard deviation of the mean values.

Table 8. Effect of different interseeded cover crops on sugarbeet root yield (Mg ha^{-1}), sugar concentration (g kg^{-1}) for Downer and Ada during 2018 growing season.

Interseeding time	Cover crops	Downer		Ada	
		Yield	Sugar	Yield	Sugar
		(Mg ha^{-1})	(g kg^{-1})	(Mg ha^{-1})	(g kg^{-1})
	No cover crops	41.3 (7.33‡)	143 b† (2.5)	84.4 abc (3.11)	162 c (3.5)
First Interseeding	Rye	42.5 (11.9)	153 a (4.79)	81.0 c (5.11)	166 ab (1.73)
	Camelina	47.4 (8.62)	148 ab (0.81)	83.1 bc (2.84)	167 ab (0.57)
	Pea	36.1 (12.0)	147 ab (4.24)	81.3 c (2.30)	168 a (3.60)
	Brown Mustard	32.5 (15.1)	148 ab (2.16)	87.5 a (6.92)	166 ab (2.63)
Second Interseeding	Rye	36.3 (7.89)	151 ab (4.03)	85.5 ab (4.56)	166 ab (3.30)
	Camelina	39.3 (7.26)	145 ab (2.62)	85.7 ab (5.53)	165 bc (3.32)
	Pea	37.8 (6.69)	143 b (12.9)	86.2 ab (2.30)	164 bc (3.46)
	Brown Mustard	43.3 (2.83)	146 ab (6.99)	83.1 bc (5.53)	168 a (2.31)
	$LSD_{0.05}$	ns	4.60	3.85	3.37

† Means within a column sharing a letter are not significantly (p=0.05) different from each other; ns= non-significant.
‡ indicates standard deviation of the mean values.

This study found a significant effect of interseeding time on sugarbeet roots sugar concentration at Downer in 2018 growing season (Table 7). The sugar concentration of sugarbeet root was significantly (P<0.05) lower in plots interseeded second.

Sugar concentration in sugarbeet root responded differently to the cover crop interseeding treatment. The lowest sugarbeet roots sugar concentration was extracted from the control treatment for both locations in 2018 (Table 8). When compared with all the other treatments, including the control (no cover crop), sugarbeet roots sugar concentration varied across the interseeding treatments. In Ada, highest sugarbeet roots sugar concentration was observed in the plots with pea treatment interseeded first than in pea, camelina, and control treatments interseeded second in July. Across treatments, sugarbeet sugar concentration ranged from 162 g kg^{-1} to 168 g kg^{-1} (Table 8). The control treatment with no cover crop had significantly lower sugarbeet roots sugar concentration than most treatments except for treatments where pea and camelina were interseeded on the second date. Afshar et al., (2018) also found similar lowest sucrose concentration from control treatment when living mulch was intercropped with sugarbeet.

In Downer, sugarbeet roots sugar concentration ranged widely across the treatments from 143 g kg^{-1} to 153 g kg^{-1} (Table 8). Across the interseeding treatment including the control, sugarbeet roots had the highest sugar concentration where rye was interseeded on the first date (Table 8). Sugarbeet roots sugar concentration was significantly lower in plot with no cover crop than the first-interseeded rye.

The interseeded cover crop treatments did not affect sugarbeet recoverable sugar yield per hectare for both the locations in 2018 growing season (Table 9). However, interseeded cover crop treatments increased sugarbeet production net profit up to 11% over the control in Ada and up to 28% over control in Downer in the 2018 growing season (Table 9). Interseeded cover crops treatments showed more economic return with cover crop incorporation at Ada in 2018 growing season. Economic return in sugarbeet production from interseeded cover crops ranged from \$3,589 ha^{-1} to \$3,914 ha^{-1}, which was 2-11% higher profit over the control. Similarly, in Downer, total return ranged from \$1,063 ha^{-1} to \$1,513 ha^{-1} for different interseeded treatments.

Table 9. Effect of different interseeded cover crops on recoverable sugar yield (RS Mg ha^{-1}), gross economic return (\$ ha^{-1}), and net profit over control (\$ ha^{-1}) for Ada, MN and Downer, MN during 2018 growing season.

Interseeding time	Cover crop	Recoverable sugar yield	Economic return	Net profit over control
		(RS Mg ha^{-1})	(\$ ha^{-1})	(\$ ha^{-1})
		Ada		
	No cover crops	12.95	3522	-
First interseeding	Rye	12.75	3589	67
	Camelina	13.15	3739	217
	Pea	13.05	3761	239
	Brown mustard	13.85	3914	392
Second interseeding	Rye	13.50	3819	297
	Camelina	13.38	3728	206
	Pea	13.45	3734	212
	Brown mustard	13.28	3808	286
	$LSD_{0.05}$	ns	ns	
		Downer		
	No cover crops	5.50	1183	-
First interseeding	Rye	6.10	1502	319
	Camelina	6.56	1513	330
	Pea	4.97	1139	-44
	Brown mustard	4.54	1063	-120
Second interseeding	Rye	5.10	1214	31
	Camelina	5.37	1211	28
	Pea	5.06	1093	-90
	Brown mustard	5.94	1350	167
	$LSD_{0.05}$	ns	ns	

† Different letters indicate significant difference of means at 95% significance level, according to $LSD_{0.05}$; ns= non-significant.

Growing season- 2019

Cover crop species and its interseeding time significantly (P<0.05) affected the sugarbeet root yield and sugar concentration at Ada (Table 7). However, interseeding time and its interaction with cover crop species did not affect root yield. Sugarbeet root yield was significantly reduced if the planting time of the interseeded cover crops was early. This result support previous studies where corn grain yield was not reduced by cover crops interseeded at V3 or later in corn in the Mid-Atlantic (Curran et al., 2018), Ontario (Belfry and Van Eerd, 2016), Michigan (Baributsa et al., 2008) and Minnesota (Noland et al., 2018). Averaged across interseeding time, sugarbeet root yield for the cover crop treatments interseeded first was 54 Mg ha^{-1} and lower than that of the control (69.2 Mg ha^{-1}) (Table 7). Here, the rapid establishment of the first interseeded cover crops resulted in sugarbeet root yield reduction. Yield reduction among the cover crop species only at Ada in 2019 can be associated with less resource distribution followed by competition with cover crops. Literature also suggests that the effects of cover crop on crop yields can be highly variable, particularly in the short-term (Blanco-Canqui et al., 2015; Poeplou and Don, 2015; Vukicevich et al., 2016; Finney et al., 2017; Ruis and Blanco-Canqui, 2017).

However, interseeding cover crops later had some potential advantages over the control such as greater sugarbeet root yield (Table 10). The second-interseeded cover crop plots had a consistently higher yield than any of the treatments. Across the treatments, sugarbeet root yield ranged from 48.5 Mg ha^{-1} in the treatment with rye at first interseeding to 76.6 Mg ha^{-1} in camelina interseeded on the second date. In Prosper, sugarbeet root yield in interseeded plots was not significantly different from the control. This outcomes indicate interseeding of rye, camelina, pea, and brown mustard had no negative influence on sugarbeet root yield at Prosper, ND.

Table 10. Effect of different interseeded cover crops on sugarbeet root yield (Mg ha^{-1}), sugar concentration (g kg^{-1}) for Ada and Prosper during 2019 growing season.

		Ada		Prosper	
Interseeding time	Cover crops	Yield	Sugar	Yield	Sugar
		(Mg ha^{-1})	(g kg^{-1})	(Mg ha^{-1})	(g kg^{-1})
	No cover crops	69.2 ab† (9.06‡)	163 bcd (3.20)	80.3 (7.87)	149 (6.24)
First interseeding	Rye	48.5 d (10.0)	170 a (4.17)	76.9 (12.1)	149 (2.08)
	Camelina	60.5 bc (7.22)	168 ab (4.60)	85.3 (7.88)	151 (6.60)
	Pea	57.1 cd (9.73)	163 bcd (2.47)	78.9 (12.5)	150 (4.43)
	Brown mustard	50.3 d (3.57)	162 cd (3.61)	75.4 (9.50)	148 (8.06)
Second interseeding	Rye	69.0 ab (1.91)	164 bcd (4.03)	83.9 (10.2)	144 (8.64)
	Camelina	76.6 a (3.13)	160 cd (1.10)	85.6 (3.99)	148 (7.19)
	Pea	75.2 a (5.93)	159 d (5.66)	90.5 (10.1)	147 (2.45)
	Brown mustard	71.9 a (3.44)	165 abc (2.96)	85.9 (6.74)	147 (5.91)
	$LSD_{0.05}$	7.73	5.14	Ns	ns

† Means within a column sharing a letter are not significantly (*p*=0.05) different from each other; ns= non-significant.
‡ indicates standard deviation of the mean values.

The analysis of variance across cover crop species and interseeding time showed significant differences among the treatments for sugarbeet root sugar concentration in Ada. Sugar concentration ranged from 159 to 170 g kg^{-1} across the treatments. When compared with all interseeding treatments, including control (no cover crop), there were no difference among the treatments and control except for the rye in the first interseeding time. Sugarbeet roots had significantly ($P<0.05$) higher sugar concentration in the first interseeded rye treatment than that of the control with no cover crop. This is similar to Afshar et al., (2018) findings, where they reported the lowest sucrose concentration from the control treatment without any living mulch. Result shows sugarbeet root sugar concentration were higher for the interseeding treatment that has lower yield (Table 10). This can be explained by lower yields in grains typically will have a higher protein value at the end of a season due to a concentration effect (Peterson et al., 2019). Although not significant the trend of lower root yield with higher sugar concentration was also seen in 2019 growing season.

Averaged across the cover crop species, sugarbeet root sugar concentration ranged from 161 to 167 g kg^{-1}. Sugarbeet root had significantly higher sugar concentration with rye cover crop treatment than Austrian pea (Table 7). Results also shows that the rye has significantly lowest sugarbeet root yield among the species. In Prosper, there were no differences among the treatments. This shows no effect on sugarbeet root sugar concentration due to the interseeding of rye, camelina, pea, and brown mustard at Prosper, ND.

The cover crop treatment and its interseeding time did not affect sugarbeet recoverable sugar yield per hectare at Prosper (Table 11). However, in Ada the recoverable sugar per hectare was higher in treatments with cover crops interseeded second compared with the cover crops interseeded earlier and the control. Early competition between the cover crops and sugarbeet decrease the amount of recoverable sugar per hectare for the first interseeding time, mainly due to reduced sugarbeet root yield in cover crop treatments.

Table 11. Effect of different interseeded cover crops on recoverable sugar yield (RS Mg ha^{-1}), gross economic return (\$ ha^{-1}), and net profit over control (\$ ha^{-1}) for Ada, MN and Prosper, ND during 2019 growing season.

Interseeding time	Cover crop	Recoverable sugar yield	Economic return	Net profit over control
		(RS Mg ha^{-1})	(\$ ha^{-1})	(\$ ha^{-1})
		Ada		
	No cover crops	10.33 ab†	2339 ab	-
First interseeding	Rye	7.53 c	1822 cd	-517
	Camelina	9.32 abc	2231 abc	-108
	Pea	8.50 bc	1913 bcd	-426
	Brown mustard	7.41 c	1640 d	-699
Second interseeding	Rye	10.30 ab	2328 ab	-11
	Camelina	11.20 a	2436 a	97
	Pea	10.89 a	2317 ab	-22
	Brown mustard	10.87 a	2517 a	178
	$LSD_{0.05}$	1.10	284	
		Prosper		
	No cover crops	11.16	2176	-
First interseeding	Rye	10.71	2096	-80
	Camelina	12.08	2450	274
	Pea	10.99	2148	-28
	Brown mustard	10.49	2052	-124
Second interseeding	Rye	11.23	1992	-184
	Camelina	11.84	2278	102
	Pea	12.41	2342	166
	Mustard	11.75	2204	28
	$LSD_{0.05}$	ns	ns	

† Different letters indicate significant difference of means at 95% significance level, according to $LSD_{0.05}$; ns= non-significant.

Overall, the response of sugarbeet root yield to interseeded cover crops was dependent on the factors such as nutrient availability, soil moisture, cover crop species grown, and sowing time (Abdin et al., 1998; Curran et al., 2018). Interseeded cover crop treatments had minimal to no negative effects on sugarbeet root yield compared with control. Several other studies in various states found no differences in the main crop yield due to cover crops interseeded into the standing crop at different main crop stages (Scott et al., 1987; Baributsa et al. 2008; Uchino et al., 2012; Belfry and Van Eerd, 2016; Berti et al., 2017; Geizler and Ransom, 2018; Curran et al., 2018; Noland et al., 2018; Peterson et al., 2019). This outcome led us to conclude that there was minimal competition between the interseeded cover crop and sugarbeet.

However, the results also showed sugarbeet root yield reduction when the interseeding occurs very early in the season. In South Dakota, Bich et al. (2014) saw reduced corn yield when cover crops were interseeded at V3, but no yield effect was measured when cover crops were interseeded at V5. Another example, planting after the V5 growth stage in maize did not negatively impact maize yield, but seeding at V2 reduced yield (Curran et al., 2018).

Cover crop species had no effects on sugar concentration, except at Ada in the 2019 growing season. The sugarbeet sugar concentration, in Ada in 2018 growing season, was highest for rye followed by brown mustard, camelina, and pea. Previous research also has shown a positive impact on sugarbeet root quality traits by increasing sugar concentration and decreasing root impurities (Afshar et al., 2018). This can be explained by higher N removal from the field with a large amount of rye and brown mustard biomass during the late growing stage of sugarbeet as was previously reported in other studies (Carter et al., 1976; Carter and Traveller, 1981; Anderson and Peterson, 1988; Allison et al, 1998; Afshar et al., 2018). It has been reported that lower N availability at the later growth stages of sugarbeet is important in increasing sucrose percent and decreasing SLM (Stevens et al., 2007). Increased availability of N from Austrian pea may also explain lower sugar concentration, since high N can reduce sugar concentration in sugarbeet (Allison et al., 1998; Afshar et al., 2019).

The sugarbeet with first interseeded cover crop treatments had higher sugar concentration compared with the control. Most of the studies on changes in sugar content response to N application reported a decrease in sugar concentration with increasing N supply (Carter et al., 1975; Halverson and Hartman, 1975; Halverson and Hartman, 1980; Anderson and Peterson, 1988; Afshar et al., 2019). It is possible that the removal of soil N by the cover crops might be responsible for increased sugar content in the cover crop treatments. As it have been reported that less N availability at the later growth stages of sugarbeet is important in increasing sucrose percent (Afshar et al., 2019). Averaged across the cover crop species, a significant effect of species interseeded was observed only in Ada for the 2019 growing season. This shows cover crop interseeding under sugarbeet can be a potential strategy to reduce excess deep soil nitrate and increase recoverable sugar yield and profit. However, the results showed no differences between treatments in residual soil N in the top 15-cm in all sites.

Residual Soil Nitrate

When compared with the other interseeding treatments and the no cover crop treatment, the only significant difference in soil inorganic-N level at harvest (0-15 cm depth) was observed at Ada in 2018 (Table 12).The result showed no difference between the control and interseeded treatments except second interseeded brown mustard. The amount of residual soil inorganic-N ranged from 4.04 to 6.53 kg N ha^{-1} across the interseeded cover crop treatments (Table 12). The highest amount of soil inorganic-N was seen for the treatment with second interseeded brown mustard. The lowest soil inorganic-N level was seen with second interseeded pea. In Downer, the results show soil inorganic-N levels at the time of harvest were similar between the control compared with the plots with cover crops.

Table 12. Effect of different interseeded cover crops on soil inorganic-N (kg N ha^{-1}) within 0-15 cm depth at sugarbeet harvest for four site-year.

Interseeding time	Cover crop	2018 Ada	2018 Downer	2019 Ada	2019 Prosper
		--------------(kg N ha^{-1})--------------			
	No cover crops	4.71 b†	6.37	24.3	13.1
First interseeding	Rye	4.17 b	6.35	14.2	11.7
	Camelina	4.88 b	7.16	18.4	10.9
	Pea	5.42 ab	4.43	25.7	28.6
	Brown Mustard	5.02 b	7.95	22.8	10.8
Second interseeding	Rye	5.18 ab	7.12	27.4	10.1
	Camelina	4.65 b	6.09	31.1	10.2
	Pea	4.04 b	6.33	32.7	14.6
	Brown Mustard	6.53 a	5.55	29.0	12.5
	$LSD_{0.05}$	1.22	NS	NS	NS

† Means within a column sharing a letter are not significantly (p=0.05) different from each other; NS= non-significant.

The results for both the locations in 2019 show soil inorganic-N levels at the time of harvest were similar between the control compared with the plots with cover crops (Table 12). In Ada, the result show numerically lower residual soil inorganic-N (14.2 kg N ha^{-1}) with first interseeded rye (Table 12). Such reduction in soil inorganic-N in the cover crop plot can be related to the cover crop biomass N accumulation.

The results showed no differences between treatments in residual soil N within 0- 15 cm depth at all sites; but no deep nitrogen analysis was conducted. Our findings are consistent with results from Dean and Weil (2009), where they found cover crops caused minimal changes in the soil for short-term study in Mid Atlantic US.

Overall, there was no evidence of N competition from the cover crop with sugarbeet, based on soil N level at sugarbeet harvest. Besides addition to its potential for leaching reduction, the nutrient recycling ability of crops can be considered a strategy to reduce fertilizer need in the subsequent crop in the rotation (Peterson et al., 2019). In the southeast of France, Amose et al. (2014) observed that legumes interseeded into wheat increased the N uptake of the succeeding spring crops (spring wheat and maize), and increased the grain yield. Cover crops in rotations in substitution to bare soil have been pointed out as a strategy to regulate nutrients and prevent soil N leaching during spring (Tonnito et al., 2016). So, with the potential to provide additional ecosystem services, like reducing erosion and improving soil and water quality, cover crop can be an important addition to the sugarbeet farming system in the RRV.

CONCLUSION

Our research highlighted that cover crops could be interseeded within sugarbeet with careful consideration of species selection and planting time. Variability existed in the effect of interseeding time and cover crop species on biomass production and N accumulation by cover crops across the four site-years. Differences in biomass production for different locations were probably due to growing conditions, species grown, and soil N availability. Interseeding cover crops early allowed more time for biomass accumulation before sugarbeet canopy closure. Therefore, interseeding cover crops early may be a good option for minimizing soil movement and preventing in-season nutrient loss in sugarbeet cropping systems.

The highest sugarbeet root yield and sugar concentration were observed with the interseeded cover crop treatment. Root yield was not affected by cover crop interseeded at late interseeding time. Some cover crops treatments had potential to increase economic return for both sites and years.

In general, it was observed that interseeding cover crops had minimal to no negative effects on sugarbeet yield, quality parameters, and economic return. For some species, early planting resulted in the loss of root yield and profitability. We did not find a single species that works best in terms of the effect on root yield or sugar concentration. Thus, growers should assess their needs and long-term goals before adopting a cover crop management strategy in sugarbeet.

This research provided useful insight for cover crop use in sugarbeet, yet more can be explored. Future research is needed but not limited to (i) evaluating the effect of different seeding rates on interseeded cover crop biomass production within sugarbeet, (ii) introducing different winter cover crop species or species mix for sugarbeet across the RRV, per the needs of growers, and (iii) assessing cover crop's ecosystem services such as increased nutrient cycling, soil erosion control, and water infiltration.

REFERENCES

Abdin, O.A., B.E. Coulman, D.C. Cloutier, M.A. Faris, and D.L. Smith. 1997. Establishment, development and yield of forage legumes and grasses as cover crops in grain corn in eastern Canada. J. Agron. Crop Sci. 179:19-27.

Acharya, K., G. Yan, and M. Berti. 2019. Can winter camelina, crambe, and brown mustard reduce soybean cyst nematode populations? Indus. Crops and Prod. 140:111637.

Afshar, R.K., C. Chen, J. Eckhoff, and C. Flynn. 2018. Impact of a living mulch cover crop on sugarbeet establishment, root yield and sucrose purity. Field Crops Res. 223:150–154.

Afshar, R.K., A. Nilahyane, C. Chen, H. He, W.B. Stevens, and W.M. Iversen. 2019. Impact of conservation tillage and nitrogen on sugarbeet yield and quality. Soil and Tillage Res.191: 216–223.

Allison, M.F., M.J. Armstrong, K.W. Jaggard, and A.D. Todd. 1998. Integration of nitrate cover crops into sugarbeet (*Beta vulgaris*) rotations. I. Management and effectiveness of nitrate cover crops. J. Agric. Sci. 130:53-60.

Allison, M.F., M.J. Armstrong, K.W. Jaggard, and A.D. Todd. 1998. Integration of nitrate cover crops into sugarbeet (*Beta vulgaris*) rotations: II. Effect of catch crops on growth, yield and N requirement of sugarbeet. J. Agric. Sci. 130:61–67.

Amossé, C., M.H. Jeuffroy, M. Bruno, and C. David. 2014. Contribution of relay intercropping with legume cover crops on nitrogen dynamics in organic grain systems. Nutr. Cycling Agroecosyst. 98:1–14.

Anderson, F.N., and G.A. Peterson. 1988. Effect of incrementing nitrogen application on sucrose yield of sugarbeet. Agron. J. 80(5):709–712.

Andersen, B.J., D.P. Samarappuli, A. Wick, and M.T. Berti. 2020. Faba bean and pea can provide late-fall forage grazing without affecting maize yield the following season. Agronomy 10(1): 80.

Appelgate, S.R., A.W. Lenssen, M.H. Wiedenhoeft, and T.C. Kaspar. 2017. Cover crop options and mixes for upper Midwest corn-soybean systems. Agron. J. 109:1-17.

Bakht, J., M. Shafi, M.T. Jan, and Z. Shah. 2009. Influence of crop residue management, cropping system and N fertilizer on soil N and C dynamics and sustainable wheat (*Triticum aestivum* L.) production. Soil and Till. Res. 104(2):233–240.

Baraibar, B., M.C. Hunter, M.E. Schipanski, A. Hamilton, and D.A. Mortensen. 2018. Weed suppression in cover crop monocultures and mixtures. Weed Sci. 66:121-133.

Baranski, M., H. Caswell, R. Claassen, C. Cherry, K. Jaglo, A. Lataille. andK. Zook. 2018. Agricultural conservation on working lands: Trends from 2004 to present. Washington, DC.

Baributsa, D.N., E.F. Foster, K.D. Thelen, A.N. Kravchenko, D.R. Mutch, and M. Ngouajio. 2008. Corn and cover crop response to corn density in an interseeding system. Agron. J. 100:981-987.

Basche, A.D., and G.E. Roesch-Mcnally. 2017. Research topics to scale up cover crop use: Reflections from innovative Iowa farmers. J. Soil Water Conserv. 72(3):59A-63A.

Bavougian, C.M., and P.E. Read. 2018. Mulch and groundcover effects on soil temperature and moisture, surface reflectance, grapevine water potential, and vineyard weed management. PeerJ 6: e5082.

Belfry, K.D., and L.L. Van Eerd. 2016. Establishment and impact of cover crops intersown into corn. Crop Sci. 56:1245-1256.

Berti, M., D. Samarappuli, B.L. Johnson, and R.W. Gesch. 2017. Integrating winter camelina into maize and soybean cropping systems. Ind. Crops Prod. 107:595-691.

Berti, M., and D. Samarappuli. 2018. How does sowing rate affect plant and stem density, forage yield, and nutritive value in glyphosate-tolerant alfalfa?. Agronomy. 8(9):169.

Bich, A.D. 2013. Impacts of spring-interseeded cover crops on late-emerging weed suppression and ground cover in corn (*Zea mays* L.) production systems. Theses and Dissertations. 1376.

Bich, A.D., C.L. Reese, A.C. Kennedy, D.E. Clay, and S.A. Clay. 2014. Corn yield is not reduced by mid-season establishment of cover crops in northern Great Plains environments. Crop Manag. 13(1):1-8.

Blake, G. R., and K. H. Hartge. 1986. Bulk density. *In* A. Klute ed., Methods of soil analysis Part. 1. 2nd ed. (pp. 363–375). Agron. Monogr. 9. Madison, WI: ASA, CSSA and SSSA

Blanco-Canqui, H., R.B. Ferguson, V.L. Jin, M.R. Schmer, B.J. Wienhold, and J. Tatarko. 2014. Can cover crop and manure maintain soil properties after stover removal from irrigated no-till corn? Soil Sci. Soc. Am. J. 78:1368-1377.

Blanco-Canqui, H., T.M. Shaver, J.L. Lindquist, C.A. Shapiro, R.W. Elmore, C.A. Francis, and G.W. Hergert. 2015. Cover crops and ecosystem services: Insights from studies in temperate soils. Agron. J. 107(6): 2449–2474.

Blanco-Canqui, H., M. Sindelar, C.S. Wortmann, and G. Kreikemeier. 2017. Aerial interseeded cover crop and corn residue harvest: Soil and crop impacts. Agron. J. 109:1344-1351.

Brandi□Dohrn, F.M., M. Hess, J.S. Selker, R.P. Dick, S.M. Kauffman, and D.D. Hemphill. 1997. Nitrate leaching under a cereal rye cover crop. J. Envt. Quality 26(1): 181–188.

Brooker, A.P., K.A. Renner, and C.L. Sprague. 2020. Interseeding cover crops in corn. Agronomy Journal 112(1): 139–147.

Büchi, L., C.-A. Gebhard, F. Liebisch, S. Sinaj, H. Ramseier, and R. Charles. 2015. Accumulation of biologically fixed nitrogen by legumes cultivated as cover crops in Switzerland. Plant and Soil 393(1-2): 163–175.

Carter, J.N., and D.J. Traveller. 1981. Effect of time and amount of nitrogen uptake on sugarbeet growth and yield. Agron. J. 73:665-671.

Carter, J.N., C.H. Pair, and D.T. Westerman. 1975. Effect of irrigation method and late season nitrate nitrogen concentration on sucrose production by sugarbeets. J. of the A.S.S.B.T. 18:332-342.

Chapagain, T., E.A. Lee, and M.N. Raizada. 2020. The potential of multi-species mixtures to diversify cover crop benefits. Sustainability. 12(5): 2058.

Chatterjee, A., and D.E. Clay. 2017. Cover crops impacts on N scavenging, nitrous oxide emissions, N fertilizer replacement, erosion, and soil health. *In*: Soil Fertility Management in Agroecosystems, ed. A. Chatterjee, and D. Clay pp 76-89. Madison, WI: ASA, CSSA, and SSSA.

Cherr, C.M., J.M.S. Scholberg, and R. Mcsorley. 2006. Green manure approaches to crop production: A synthesis. Agron. J. 98(2): 302–319.

Clark, A.J., A.M. Decker, J.J. Meisinger, and M.S. McIntosh. 1997a. Kill time of vetch, rye, and a vetch–rye mixture: I. Cover crop and corn nitrogen. Agron. J. 89:427–434.

Clark, A.J., A.M. Decker, J.J. Meisinger, and M.S. McIntosh. 1997b. Kill time of vetch, rye, and a vetch–rye mixture: II. Soil moisture and corn yield. Agron. J. 89:434–441.

Clark, A.J., J.J. Meisinger, A.M. Decker, and F.R. Mulford. 2007. Effects of a grass-selective herbicide in a vetch-rye cover crop system on nitrogen management. Agron. J. 99(1): 36–42.

Cook, R.J. and R.J., Veseth. 1991. Wheat health management. American. Phytopathological Society,St Paul, Minnesota, USA.

Couëdel, A., L. Alletto, H. Tribouillois, and É. Justes. 2018. Cover crop crucifer-legume mixtures provide effective nitrate catch crop and nitrogen green manure ecosystem services. Agri. Ecosyst. and Envt. 254: 50–59.

Cousin, R. 1997. Peas (*Pisum sativum* L.). Field Crop Res. 53:111-130.

Crowley, K.A., H.M.V. Es, M.I. Gómez, and M.R. Ryan. 2018. Trade-offs in cereal rye management strategies prior to organically managed soybean. Agron. J. 110(4): 1492–1504.

Crusciol, C.A.C, A.S. Nascente, G.P. Mateus, E. Borghi, E.P. Leles, and N.C.B. Santos. 2013. Effect of intercropping on yields of corn with different relative maturities and palisadegrass. Agron. J. 105:599-606.

Crusciol, C.A.C., G.P. Mateus, A.S. Nascente, P.O. Martins, E. Borghi, and C.M. Pariz. 2012. An innovative crop-forage intercrop system: Early cycle soybean cultivars and palisadegrass. Agron. J. 104:1085-1095.

Curran W.S., R.J. Hoover, S.B. Mirsky, G.W. Roth, M.R. Ryan, V.J. Ackroyd, J.M. Wallace, M.A. Dempsey, and C.J. Pelzer. 2018. Evaluation of cover crops drill interseeded into corn across the Mid-Atlantic region. Agron. J. 110:435-443.

Daryanto, S., B. Fu, L. Wang, P.-A. Jacinthe, and W. Zhao. 2018. Quantitative synthesis on the ecosystem services of cover crops. Earth-Science Reviews 185: 357–373.

Dean, J.E., and R.R. Weil. 2009. Brassica cover crops for nitrogen retention in the mid-atlantic coastal plain. J. of Envt. Quality 38(2): 520–528.

Ding, G., X. Liu, S. Herbert, J. Novak, D. Amarasiriwardena, and B. Xing. 2006. Effect of cover crop management on soil organic matter. Geoderma 130(3-4): 229–239.

Duiker, S.W., and W.S. Curran. 2005. Rye cover crop management for corn production in the northern mid-atlantic region. Agron. J. 97(5): 1413–1418.

Etemadi, F., M. Hashemi, O. Zandvakili, A. Dolatabadian, and A. Sadeghpour. 2018. Nitrogen contribution from winter□killed faba bean cover crop to spring□sown sweet corn in conventional and no□till systems. Agron. J. 110(2): 455-462.

Fakhari, R., H. Khanzade, R. Mammadova, A. Tobeh, and S. Moharramnezhad. 2015. Effects of interseeding cover crops and split nitrogen application on weed suppression in forage maize. Albanian J. of Agri. Sci. 14(3): 278-285.

Finney, D.M., C.M. White, and J.P. Kaye. 2016. Biomass production and carbon/nitrogen ratio influence ecosystem services from cover crop mixtures. Agron. J. 108(1): 39–52.

Finney, D., J. Buyer, and J. Kaye. 2017. Living cover crops have immediate impacts on soil microbial community structure and function. J. of Soil and Water Conserv. 72(4): 361–373.

Fortuna, A., R.L. Blevins, W.W. Frye, J. Grove, and P. Cornelius. 2008. Sustaining soil quality with legumes in no□tillage systems. Commun. Soil Sci. Plant Analysis. 39(11-12): 1680–1699.

Frye, W.W., R.L. Blevins, M.S. Smith, S.J. Corak, and J.J. Varco. 1988. Role of annual legume cover crops in efficient use of water and nitrogen. *In*: B.G. Ellis, W. L. Hargrove, (Ed.), cropping strategies for efficient use of water and nitrogen. ASA Spec. Publ. 51. ASA, CSSA, SSSA, Madison, WI. p. 129-154.

Gallo, K.P., C.S.T. Daughtry, and M.E. Bauer. 1985. Spectral estimation of absorbed photosynthetically active radiation in corn canopies. Remote Sens. Environ. 17:221–232.

Geiszler, M.M. and J.K. Ransom. 2018. Interseeding cereal rye and winter camelina into corn in North Dakota. North Dakota State University of Ag. And Applied Sci, Fargo, ND.

Gesch, R.W., D.W. Archer, and M.T. Berti. 2014. Dual cropping winter camelina with soybean in the northern Corn Belt. Agron. J. 106:1735-1745.

Gesch, R.W., H.L. Dose, and F. Forcella. 2017. Camelina growth and yield response to sowing depth and rate in the northern Corn Belt USA. Ind. Crops. Prod. 95:416-421.

Gruver, J., R.R. Weil, C. White, and Y. Lawley. 2019. Radishes – A new cover crop for organic farming systems. Available online: http://www.extension.org/pages/64400/radishes-a-new-cover-crop-for-organic-farmingsystems#/u6lj3hz2ny0> (Accessed September 2020).

Gselman, A., and B. Kramberger. 2008. Benefits of winter legume cover crops require early sowing. Australian J. of Agri. Research 59(12): 1156.

Halverson, A.D. and G.P. Hartman. 1975. Long term nitrogen rates and sources influence sugarbeet yield and quality. Agron. J. 67:389-393.

Halverson, A.D., G.P. Hartman, D.F. Cole, V.A. Haby, and D.E. Baldridge. 1978. Effect of N fertilization on sugarbeet crown tissue production and processing quality. Agron. J. 70:876-880.

Halverson, A.D. and G.P. Hartman. 1980. Response of several sugarbeet cultivars to N fertilization: Yield and crown tissue production. Agron. J. 72:665-669.

Hansen, N.C., B.L. Allen, R.L. Baumhardt, and D.J. Lyon. 2012. Research achievements and adoption of no-till, dryland cropping in the semi-arid US Great Plains. Field Crops Res. 132:196-203.

Hartwig, N.L., and H.U. Ammon. 2002. Cover crops and living mulches. Weed Science 50(6): 688–699.

Hively, W.D., and W.J. Cox. 2001. Interseeding cover crops into soybean and subsequent corn yields. Agron. J. 93(2): 308–313.

Humphreys, M.T., K.W. Freeman, R.W. Mullen, D.A. Keahey, R.K. Teal, and W.R. Raun. 2003. Canopy reduction and legume interseeding in irrigated continuous corn. J. Plant Nutr. 26:1335–1343.

Ichiki, H., N. Van Nang, K. Yoshinaga, M. Miyazaki, and Y. Ueka. 2013. Wind-proof seedbed for reducing wind damage at early germination stage of direct sowing sugar beet. J. of the Jap. Soc. of Agri. Mach.75 (2):89-99.

Iqbal, N., A. Khaliq, and Z.A. Cheema. 2020. Weed control through allelopathic crop water extracts and S-metolachlor in cotton. Infor. Pro. in Agr. 7(1): 165–172.

Jahanzad, E., A.V. Barker, M. Hashemi, A. Sadeghpour, T. Eaton, and Y. Park. 2017. Improving yield and mineral nutrient concentration of potato tubers through cover cropping. Field Crops Res. 212: 45–51.

Jian, J., X. Du, M.S. Reiter, and R.D. Stewart. 2020. A meta-analysis of global cropland soil carbon changes due to cover cropping. Soil Bio. and Biochem. 143: 107735.

Jilling, A., D. Kane, A. Williams, A.C. Yannarell, A. Davis, N.R. Jordan, R.T. Koide, D.A. Mortensen, R.G. Smith, S.S. Snapp, K.A. Spokas, and A.S. Grandy. 2020. Rapid and distinct responses of particulate and mineral-associated organic nitrogen to conservation tillage and cover crops. Geoderma 359: 114001.

Kaspar, T., and J. Singer. 2015. The use of cover crops to manage soil. Soil Management: Building a Stable Base for Agriculture: 321–337.

Kaye, J.P., and M. Quemada. 2017. Using cover crops to mitigate and adapt to climate change. A review. Agron. for Sust. Dev. 37(1):4.

Keeling, J.W., A.G. Matches, C.P. Brown, and T.P. Karnezos. 1907. Comparison of interseeded legumes and small grains for cover crop establishment in cotton. Agron. J. 88(2): 219–222.

Ketterings, Q.M., S.N. Swink, S.W. Duiker, K.J. Czymmek, D.B. Beegle, and W.J. Cox. 2015. Integrating cover crops for nitrogen management in corn systems on northeastern US dairies. Agron. J. 107:1365-1376.

Koch, H.J.998. Rotation fallow before sugarbeet influence of the position of the fallow in the crop rotation and the crop cover on the risk of nitrate leaching and yield and quality of sugarbeet. Sugar industry. 123: 894-898.

Kramberger, B., Gselman, A., Kristl, J., Lesnik, M., Sustar, V., Mursec, M., and Podvrsnik, M. 2014. Winter cover crop: The effects of grassclover mixtyure proportion and biomass management on miaze and the apparent residual N in the soil. Euro. J. of Agron. 55, 63–71.

Kreykenbohm, L., T. Lickfett, and E. Przemeck. 1999. Aspects of sugarbeet nutrition with green fallow derived nitrogen. Zuckerindustrie. 124:221–222

Krueger, E.S., T.E. Ochsner, P.M. Porter, and J.M. Baker. 2011. Winter rye cover crop management influences on soil water, soil nitrate, and corn development. Agron. J. 103:316-323.

Kumar, K., and K.M. Goh. 2002. Recovery of 15 N-labelled fertilizer applied to winter wheat and perennial ryegrass crops and residual 15 N recovery by succeeding wheat crops under different crop residue management practices. Nutri. Cyc.in Agroecosyst. 62(2):123-130.

Kumar, K., and K.M. Goh. 2002. Management practices of antecedent leguminous and non-leguminous crop residues in relation to winter wheat yields, nitrogen uptake, soil nitrogen mineralization and simple nitrogen balance. Eur. J. Agron. 16(4): 295–308.

Kuo, S., U.M. Sainju, and E.J. Jellum. 1997. Winter cover cropping influence on nitrogen in soil. Soil Sci. Soc. Am. J. 61(5): 1392–1399.

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

Langdale, G.W., Blevins, R.L., Karlen, D.L., McCool, D.K., Nearing, M.A., Skidmore, E.L., Thomas, A.W., Tyler, D.D. and Williams, J.R. 1991. Cover crop effects on soil erosion by wind and water. Cover crops for clean water, pp.15-22.

Liang, S., J. Grossman, and W. Shi. 2014. Soil microbial responses to winter legume cover crop management during organic transition. Eur. J. Soil Biol. 65:15-22.

Maddonni, G.A., M.E. Otegui, and A.G. Cirilo. 2001. Plant population density, row spacing and hybrid effects on maize canopy architecture and light attenuation. Field Crops Res. 71:183-193.

Masiunas, J.B. 1998. Production of vegetables using cover crop and living mulches—A review. J. Veg. Crop Prod. 4:11–31.

Martinez-Feria, R.A., R. Dietzel, M. Liebman, M.J. Helmers, and S.V. Archontoulis. 2016. Rye cover crop effects on maize: A system-level analysis. Field Crops Res. 196: 145–159.

Mazzoncini, M., T.B. Sapkota, P. Bàrberi, D. Antichi, and R. Risaliti. 2011. Long-term effect of tillage, nitrogen fertilization and cover crops on soil organic carbon and total nitrogen content. Soil and Tillage Res. 114(2): 165–174.

Mcdaniel, M.D., L.K. Tiemann, and A.S. Grandy. 2014. Does agricultural crop diversity enhance soil microbial biomass and organic matter dynamics? A meta-analysis. Eco. Appli. 24(3): 560–570.

Mohammadi, G.R., and M.E. Ghobadi. 2010. The effects of different autumn-seeded cover crops on subsequent irrigated corn response to nitrogen fertilizer. Agri. Sci.01(03): 148–153.

Möller, K., and H.-J. Reents. 2009. Effects of various cover crops after peas on nitrate leaching and nitrogen supply to succeeding winter wheat or potato crops. J. Plant Nutri. and Soil Sci. 172(2): 277–287.

Moyer, J.R., R.E. Blackshaw, E.G. Smith, and S.M. McGinn. 2000. Cereal cover crops for weed suppression in a summer fallow-wheat cropping sequence. Can. J. Plant Sci. 80:441–449.

Muhammad, I., U.M. Sainju, F. Zhao, A. Khan, R. Ghimire, X. Fu, and J. Wang. 2019. Regulation of soil CO_2 and N_2O emissions by cover crops: A meta-analysis. Soil and Tillage Res. 192: 103–112.

Mulvaney, R.L. 1996. Nitrogen—inorganic forms. Methods of soil analysis: Part 3 Chemical methods, 5;1123-1184.

Mutchler, C.K., and L.L. Mcdowell. 1990. Soil loss from cotton with winter cover crop. Transactions of the ASAE 33(2): 0432–0436.

Myers, R. 2019. A preliminary look at state rankings for cover crop acreage based on census of agriculture information. Sustainable agriculture network. Available online: https://files.constantcontact.com/c7de6aab001/914daacf-ca6d-4549-a57f-a2b3f861ec15.pdf (accessed on 31 January 2020).

Myers, R., and C. Watts. 2015. Progress and perspectives with cover crops: Interpreting three years of farmer surveys on cover crops. J. Soil Water Conserv. 70(6): 125A-129A.

NCR SARE and CTIC. 2016. 2015-2016 Cover crop survey report. http://www.sare.org/Learning-Center/From-the-Field/NorthCentral-SARE-From-the-Field/2016-Cover-Crop-Survey-Analysis (Accessed Sept. 2019).

Nielsen, R.D., G.B. Muckel, A. Mendenhall, D.T. Lightle, B.C. Wight, H.R. Sinclair, H.P. Terpstra, S.W. Walman, J.D. Vrana, D. Buland, S.C. Stover. 1997. America's northern plains: An overview and assessment of natural resources. USDA NRCS.

Nielsen, D.C., D.J Lyon, G.W. Hergert, R.K. Higgins, F.J. Calderon, and M.F. Vigil. 2015. Cover crop mixtures do not use water differently than single-species plantings. Agron. J. 107:1025-1038

Nielsen, D.C. 2018. Influence of latitude on the US Great Plains East-West precipitation gradient. Agri. and Env. Letters 3(1): 170040.

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

Ohnami, M. 2009. Minimizing the meteorological damage on sugar beet direct sowing cultivation. Sugar and Starch Information of Agriculture and Livestock Industries Corporation, September 2009 Issue.

O'neal, M.R., M. Nearing, R.C. Vining, J. Southworth, and R.A. Pfeifer. 2005. Climate change impacts on soil erosion in Midwest United States with changes in crop management. Catena 61(2-3): 165–184.

Pantoja, J.L., K.P. Woli, J.E. Sawyer, and D.W. Barker. 2015. Corn nitrogen fertilization requirement and corn-soybean productivity with a rye cover crop. Soil Sci. Soc. Am. J. 79(5): 1482–1495.

Papendick, R. 1987. Tillage and water conservation: experience in the Pacific Northwest. Soil Use and Manage. 3(2): 69–74.

Papendick, R.I., and D.E. Miller. 1977. Conservation tillage in the Pacific Northwest. J. Soil Water Cons. 32: 49–56.

Peterson, A.T., M.T. Berti, and D. Samarappuli. 2019. Intersowing cover crops into standing soybean in the US upper Midwest. Agronomy 9(5): 264.

Poeplau, C., and A. Don. 2015. Carbon sequestration in agricultural soils via cultivation of cover crops – A meta-analysis. Agr. Ecosyst. Environ. 200: 33–41.

Poromarto, S.H., and B.D. Nelson. 2010. Evaluation of northern-grown crops as hosts of soybean cyst nematode. Plant Health Prog. 11(1): 24.

Rathke, G., T. Behrens, and W. Diepenbrock. 2006. Integrated nitrogen management strategies to improve seed yield, oil content and nitrogen efficiency of winter oilseed rape (*Brassica napus* L.): A review. Agr. Ecosyst. Environ.117 (2-3): 80–108.

Ruark, M.D., M.M. Chawner, M.J. Ballweg, R.T. Proost, F.J. Arriaga, and J.K. Stute. 2018. Does cover crop radish supply nitrogen to corn? Agron. J. 110:1513-1522.

Ruis, S.J., H. Blanco-Canqui, C.F. Creech, K. Koehler-Cole, R.W. Elmore, and C.A. Francis. 2019. Cover Crop Biomass Production in Temperate Agroecozones. Agron. J. 111(4): 1535–1551.

Sainju, U.M., and B.P. Singh. 2008. Nitrogen storage with cover crops and nitrogen fertilization in tilled and non-tilled soils. Agron. J. 100(3).

Sainju, U.M., and B.P. Singh. 2001. Tillage, cover crop, and kill-planting time effects on corn yield and soil nitrogen. Agron. J. 93:878–886.

Sainju, U.M., W.F. Whitehead, and B.P. Singh. 2005. Biculture legume-cereal cover crops for enhanced biomass yield and carbon and nitrogen. Agron. J. 97(5): 1403–1412.

SARE, Sustainable Agriculture Research and Education. 2007. Managing cover crops profitably. 3rd ed. SARE, College Park, MD. Available at http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition (verified 20 April 2017).

SARE CTIC. 2020. Annual Report 2019-2020 Cover Crop Survey, Joint publication of the Conservation Technology Information Center, the North Central Region Sustainable Agriculture Research and Education Program, and the American Seed Trade Association. Washington, DC.

Sarrantonio, M. and E. Gallandt. 2003. The role of cover crops in North American cropping systems. J. Crop Prod. 8(1-2): 53–74.

Scott, T.W., J.M. Pleasant, R.F. Burt, and D.J. Otis. 1987. Contributions of ground cover, dry matter, and nitrogen from intercrops and cover crops in a corn polyculture system. Agron. J. 79(5): 792–798.

Sigdel, S., and A. Chatterjee. 2020. Do cover crop and soil-mediated legacy influence succeeding wheat production? Commun. Soil Sci. Plant Analysis. 51(11): 1514–1524.

Siller, A.R.S., K.A. Albrecht, and W.E. Jokela. 2016. Soil erosion and nutrient runoff in corn silage production with kura clover living mulch and winter rye. Agron. J. 108(3): 989–999.

Singer, J.W. 2008. Corn belt assessment of cover crop management and preferences. Agron. J. 100(6): 1670–1672.

Smith, H.J., F.A. Gray, and D.W. Koch. 2004. Reproduction of *Heterodera schachtii* Schmidt on resistant mustard, radish, and sugarbeet cultivars. J. Nematol. 36:123–130.

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.

Stewart, D.W., C. Costa, L.M. Dwyer, D.L. Smith, R.I. Hamilton, and B.L. Ma. 2003. Canopy structure, light interception, and photosynthesis in maize. Agron. J. 95:1465-1474.

Stevens, W.B., R.G. Evans, J.D. Jabro, and W.M. Iversen. 2010. Nitrogen availability for sugarbeet affected by tillage system and sprinkler irrigation method. Agron. J.102(6): 1745–1752.

Thapa, R., S.B. Mirsky, and K.L. Tully. 2018. Cover crops reduce nitrate leaching in agroecosystems:a global meta-analysis. J. Envt. Quality 47(6): 1400–1411.

Thelen, K.D. 2006. Interaction between row corn row width and yield: Why it works. Online. Crop Manage. doi: 10.1094/CM-2006-0227-03-RV.

Thomas, B.W., X. Hao, F.J. Larney, C. Goyer, M.H. Chantigny, and A. Charles. 2017. Non-legume cover crops can increase non-growing season nitrous oxide emissions. Soil Soil Sci. Soc. Am. J. 81(1): 189–199.

Thomsen, I.K. 2005. Nitrate leaching under spring barley is influenced by the presence of a ryegrass catch crop: Results from a lysimeter experiment. Agric. Ecosyst. Environ. 111:21–29.

Thorup-Kristensen, K., and D.B. Dresbøll. 2010. Incorporation time of nitrogen catch crops influences the N effect for the succeeding crop. Soil Use and Management 26(1): 27–35.

Tonitto, C., M. David, and L. Drinkwater. 2006. Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: A meta-analysis of crop yield and N dynamics. Agric. Ecosyst. Environ. 112(1): 58–72.

Tonitto, C., and J.E. Ricker-Gilbert. 2016. Nutrient management in African sorghum cropping systems: applying meta-analysis to assess yield and profitability. Agron. Sust. Dev. 36(1):10

Tribouillois, H., J. Constantin, and E. Justes. 2018. Analysis and modeling of cover crop emergence: Accuracy of a static model and the dynamic STICS soil-crop model. Euro. J. Agron. 93: 73–81.

Uchino, H., K. Iwama, Y. Jitsuyama, T. Yudate, and S. Nakamura. 2009. Yield losses of soybean and maize by competition with interseeded cover crops and weeds in organic-based cropping systems. Field Crops Res. 113:342-351.

USDA, ERS. 2015. U.S. sugar production. Available at http://www.ers.usda.gov/topics/crops/sugar-sweeteners/background.aspx#production

USDA-National Agricultural Statistics Service. 2019. Crop production annual summary. https://www.nass.usda.gov/Publications/Ag_Statistics/2019/Chapter02.pdf (accessed July, 2020)

U.S. Department of Agriculture. 2013. Summary Report: 2010 National Resources Inventory, Natural Resources Conservation Service, Washington, DC, and Center for Survey Statistics and Methodology, Iowa State University, Ames, Iowa. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1167354.pdf (accessed July, 2020)

Vanek, S., H. Wien, and A. Rangarajan. 2005. Time of interseeding of lana vetch and winter rye cover strips determines competitive impact on pumpkins grown using organic practices. HortScience 40(6): 1716–1722.

Vaughan, J.D., and G.K. Evanylo. 1998. Corn response to cover crop species, spring desiccation time, and residue management. Agron. J. 90(4): 536–544.

Vukicevich, E., T. Lowery, P. Bowen, J.R. Úrbez-Torres, and M. Hart. 2016. Cover crops to increase soil microbial diversity and mitigate decline in perennial agriculture. A review. Agron. Sust. Dev. 36(3).

Wall, G.J., E.A. Pringle, and R.W. Sheard. 1991. Intercropping red clover with silage corn for soil erosion control. Canadian Journal of Soil Science 71(2): 137–145.

Wayman, S., C. Cogger, C. Benedict, D. Collins, I. Burke, and A. Bary. 2015. Cover crop effects on light, nitrogen, and weeds in organic reduced tillage. Agroecology and Sustainable Food Systems 39(6): 647–665.

Wilson, M. 2012. Factors affecting the successful establishment of an overseeded winter rye cover crop in northern climates. Ph.D. diss, Univ. of Minnesota, St. Paul.

Wilson, M.L., J.M. Baker, and D.L. Allan. 2013. Factors affecting successful establishment of aerially seeded winter rye. Agronomy Journal 105(6): 1868–1877.

Wortman, S.E., and J.O. Dawson. 2015. Nitrogenase activity and nodule biomass of cowpea (*Vigna unguiculata* L. Walp.) decrease in cover crop mixtures. Commun. Soil Sci. Plant Analysis. 46(11): 1443–1457.

Wortman, S.E., C.A. Francis, and J.L. Lindquist. 2012. Cover crop mixtures for the Western Corn Belt: Opportunities for increased productivity and stability. Agron.J.104 (3): 699–705.

APPENDIX

Table A1. Monthly average air temperature, 30-year average air temperature, monthly total rainfall, and 30-year average total rainfall during growing season at each experimental sites taken from NDAWN weather station.

Site	Year	Growing season	Average Air Temperature	30 year Average Air Temperature	Total rainfall	30 year Total Rainfall
			---------- (˚C) -------------		-------- (mm)--------	
Downer, ND	2018	May	18	14	14	80
		June	21	19	148	104
		July	22	22	117	82
		August	20	21	92	68
		September	14	15	63	75
Ada, MN	2018	May	17	13	63	82
		June	20	19	78	114
		July	21	21	63	93
		August	19	20	67	70
		September	14	15	74	67
Ada, MN	2019	May	11	13	63	82
		June	18	19	68	114
		July	21	21	103	93
		August	18	20	94	70
		September	15	15	106	67
Prosper, ND	2019	May	11	13	60	78
		June	19	19	122	100
		July	22	21	156	88
		August	18	20	102	67
		September	15	15	148	66
		Oct	5	7	77	62

Table A2. Levene's Test for Homogeneity of Aboveground cover crop biomass yield (Mg ha^{-1}) Variance.

ANOVA of Absolute Deviations from Group Means.

Source	DF	Sum of Squares	MS	F Value	*Pr* > F
env	3	8.3693	2.7898	14.85	<.0001*
Error	124	23.2944	0.1879	-	

* Significant at $p \leq 0.05$.

Table A3. Levene's Test for Homogeneity of Sugarbeet Yield Variance.

ANOVA of Absolute Deviations from Group Means.

Source	DF	Sum of Squares	MS	F Value	Pr > F
env	3	599.7	199.9	6.85	0.0003*
Error	124	3618.1	29.2	-	

* Significant at $p \leq 0.05$.

Table A4. Levene's Test for Homogeneity of Sugar Content Variance.

ANOVA of Squared Deviations from Group Means.

Source	DF	Sum of Squares	MS	F Value	Pr > F
env	3	1.307	0.4357	3.07	0.0303*
Error	124	17.582	0.1418	-	

* Significant at $p \leq 0.05$.

Table A5. ANOVA for main and interaction effects of cover crop species (CC) and interseeding time (I) on aboveground cover crop biomass yield (kg ha^{-1}) at Ada and Downer, MN for 2018.

	Downer			Ada		
SOV	df	MS	F Value	df	MS	F Value
Rep	3	655726	4.43*	3	25480	7.52*
I†	1	10113517	68.29*	1	41175	4.05
CC‡	3	1139296	7.69*	3	6427	0.63
I*CC	3	901568	6.09*	3	39169	3.85*
Error	21	148102	-	21	10155	-
CV (%)		35			80	

* Significant at $p \leq 0.05$.

† I, interseeding time.

‡ CC, cover crop.

Table A6. ANOVA for Main and interaction effects of cover crop species (CC) and interseeding time (I) on aboveground cover crop biomass yield (kg ha^{-1}) at Ada, MN and Prosper, ND for 2019.

	Prosper			Ada		
SOV	df	MS	F Value	df	MS	F Value
Rep	3	349843	1.09	3	133463.4	0.73
I†	1	9148696	28.63*	1	17110884	94.11
CC‡	3	351430	1.10	3	1574794	8.66
I*CC	3	135320	0.42	3	218436.5	1.2
Error	21	319532	-	21	181819.7	-
CV (%)		86			33	

* Significant at $p \leq 0.05$.
† I, interseeding time.
‡ CC, cover crop.

Table A7. ANOVA table for main and interaction effects of cover crop species (CC) and interseeding time (I) on sugarbeet root yield at Ada and Downer, MN for 2018 growing seasons.

	Downer			Ada		
SOV	df	MS	F Value	df	MS	F Value
Rep	3	105.92	1.15	3	149.72	19.68*
I†	1	1.48	0.02	1	28.88	3.80
CC‡	3	62.79	0.68	3	6.41	0.84
I*CC	3	148.66	1.62	3	36.93	4.85*
Error	21	92.01	-	21	7.60	-
CV (%)		24.35			3.27	

* Significant at $p \leq 0.05$.
† I, interseeding time.
‡ CC, cover crop.

Table A8. ANOVA table for main and interaction effects of cover crop species (CC) and interseeding time (I) on sugarbeet root yield at Ada, MN and Prosper, ND for 2019 growing seasons.

	Prosper			Ada		
SOV	df	MS	F Value	df	MS	F Value
Rep	3	60.8	0.64	3	133.14	4.97
I†	1	429.2	4.54*	1	2922.30	109.09
CC‡	3	65.6	0.61	3	161.90	6.04
I*CC	3	51.8	0.55	3	11.97	0.45
Error	21	94.5	-	21	26.78	-
CV (%)		11.7			8.14	

* Significant at $p \leq 0.05$.
† I, interseeding time.
‡ CC, cover crop.

Table A9. Analysis of Variance (ANOVA) for cover crop interseeding treatment on sugarbeet root yield at Ada and Downer, MN, 2018.

		Ada			Downer	
SOV	df	MS	F Value	df	MS	F Value
Rep	3	157.1	22.63*	3	111.7	1.29
Treatment	8	19.9	2.86*	8	81.1	0.94
Error	24	6.9	-	24	86.5	
CV (%)		3.1			23.4	

* Significant at $p \leq 0.05$.

Table A10. Analysis of Variance (ANOVA) for cover crop interseeding treatment on sugarbeet root yield at Ada, MN and Prosper, ND, 2019.

		Ada			Prosper	
SOV	df	MS	F Value	df	MS	F Value
Rep	3	178.8	6.37*	3	96.2	1.12
Treatment	8	444.3	15.83*	8	97.2	1.13
Error	24	28.1	-	24	85.9	-
CV (%)		8.3			11.2	

* Significant at $p \leq 0.05$.

Table A11. Analysis of Variance (ANOVA) for cover crop interseeding treatment on sugarbeet root sugar concentration at Ada and Downer, MN, 2018.

	Ada			Downer		
SOV	df	MS	F Value	df	MS	F Value
Rep	3	3.17	5.92*	3	4.45	4.42*
Treatment	8	1.55	2.91*	8	3.89	3.82*
Error	24	0.53	-	24	1.02	-
CV (%)		1.40			2.17	

* Significant at $p \leq 0.05$.

Table A12. Analysis of Variance (ANOVA) for cover crop interseeding treatment on sugarbeet root sugar concentration at Ada, MN and Prosper, ND, 2019.

	Ada			Prosper		
SOV	df	MS	F Value	df	MS	F Value
Rep	3	2.80	2.26	3	2.30	13.57*
Treatment	8	4.76	3.84*	8	2.16	1.27
Error	24	1.24	-	24	1.17	-
CV (%)		2.15			2.77	

* Significant at $p \leq 0.05$.

Table A13. Information regarding price, revenue from agricultural products and operation cost of 2018 and 2019 growing season for sugarbeet payment calculator.

American Crystal Sugar Payment Calculator 2018	
Other Sugar Losses Per Ton	56.4
Price per Pound	0.29250
Agri Products per Ton	6.88
Operation Costs per Ton	42.38

American Crystal Sugar Payment Calculator 2019	
Other Sugar Losses Per Ton	39.9
Price per Pound	0.29500
Agri Products per Ton	6.81
Operation Costs per Ton	52.49

Figure A1. Fallow sugarbeet field during non-growing season.

Figure A2. Regrowth of rye cover crop biomass after winter (April, 2019).