RELATIVE MATURITY AND ROW SPACING EFFECT ON ESTABLISHMENT OF INTERSEEDED COVER CROPS INTO SOYBEAN

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MASTER OF SCIENCE

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ABSTRACT

Low adoption to cover crops in the northern Plains is due to limited soil water for stand establishment, short growing season, and few adapted winter-hardy species. Studies were conducted to evaluate the impact of interseeded winter camelina [*Camelina sativa* (L.) Crantz] and winter rye (*Secale cereale* L.) using different soybean relative maturities, planting date, and row spacing on cover crop biomass, canopy coverage, plant density, soybean yield, and wheat (*Triticum aestivum* L.) yield the following year. Early-maturing soybean cultivars, produced increased cover crop biomass and canopy coverage, with winter rye outperforming winter camelina. Row spacing showed no effect on cover crop growth, yet narrow rows produced higher soybean yield. Spring wheat is not recommended to plant following winter rye, yet there was no negative effect from winter camelina. Interseeding cover crops into soybean in the northern Plains is possible, but relative low amounts of fall cover crop biomass is produced.

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INTRODUCTION

Cover crops are important components in sustainable agricultural systems. Including cover crops can produce value in many crop rotations worldwide with many benefits to the soil, the ecosystem, and grain yield to the following crop by increasing diversity, providing soil coverage, building soil organic matter and increasing efficiency of the nutrient cycle. Soil erosion is a major problem in soybean [*Glycine max* (L.) Merr.] production as crop residue is limited, leaving exposed soil for extended periods. In the Red River of the North Valley of North Dakota and Minnesota, where there is minimal elevation change and few natural wind barriers, cover crops can provide protection to the soil by reducing soil particle removal due to wind . The short growing season poses challenges for establishing a cover crop with conventional seeding methods following harvest and alternative methods of planting are needed for successful biomass growth and soil coverage. These studies examined the interseeding of winter camelina [*Camelina sativa* (L.) Crantz] and winter rye (*Secale cereale* L.) at different soybean stages with different maturing cultivars with narrow and wide row spacing and how the cover crops affect subsequent crop response. The information from this study will result in more accurate and detailed recommendations regarding row spacing, soybean maturity, and planting date best suited for a particular farming system. This knowledge will provide additional information for growers to select appropriate winter annual cover crops for their crop system, maximize cover crop biomass, and provide the best soil coverage.

The objectives of these studies are to evaluate interseeded cover crop development and biomass production in soybean cultivars with differing relative maturities, row spacing, and cover crop seeding rate and how covers can affect soybean and hard red spring wheat (HRSW) grain yield.

LITERATURE REVIEW

Cover Crops

Cover crops can be grasses, legumes, and other forbs that are typically planted in the fall and overwinter until the spring. They are used for erosion control, improving soil structure, moisture, and nutrient content, increasing beneficial soil biota, suppressing weeds, providing habitat for beneficial predatory insects, facilitating crop pollinators, providing wildlife habitat, and as forage for farm animals (USDA, 2020). Overwintering cover crops are planted after, or between the primary crop with the goals of surviving the winter and to resume growth in the spring. Overwintering cover crops have been proven to provide many ecological beneficial attributes, but the cover crops must produce enough biomass in the fall and or spring for these benefits to be expressed (Lu et al., 2000).

Cover crop adoption has been steadily increasing in farming operations across the United States, especially in the eastern Corn Belt. The northern Great Plains Region (North of latitude 44°, including eastern Montana, north-eastern Wyoming, most of North and South Dakota, and the Canadian Prairies) has had a slower than average adoption rate of overwintering cover crops. This is primarily due to timing of when soil moisture is available for successful cover crop stand establishment at time of seeding, shorter growing season to establish sufficient growth for overwintering for winter annuals. Another factor affecting the integration of cover crops into an existing crop is additional costs. These additional costs lead to the common economic challenges for cover crops, of how to demonstrate a measurable economic return (SARE, 2012). This is challenging, as input costs are relatively consistent while benefits can be variable.

The short season of the northern Great Plains Region causes challenges to establish a cover crop with conventional seeding methods following harvesting, so alternative methods of planting are needed for successful biomass growth. In addition, most cropping systems in this region evaluate economics on grain yield and short-term profitability, not on the value of soil health and long-term sustainability. Several studies have suggested current cropping systems are not sustainable because of limited benefits to the ecosystem (Syswerda and Robertson, 2014; Schipanski et al., 2014).

Cover crops provide many benefits to the soil, the ecosystem, and grain yield to the following crop by increasing diversity of microorganisms, providing soil coverage, enriching soil organic matter and enhancing the nutrient cycle (Robertson et al., 2015; Delgado and Gantzer, 2015). The uses of cover crops in modern farming practice will introduce different species of plants into a given field ecosystem. Different species of plants promote and/or affect the soil microbial community differently, resulting in greater soil microbial diversity while increasing plant diversity (Garbeva et al., 2004). Soil microbial diversity is critical to the maintenance of soil quality and health. Soil health is vital in sustainable agriculture, as the soil is an ecosystem that can provide essential nutrients for plant growth, retain water, serve as a firm foundation for agriculture activities, and provide a habitat for billions of microorganisms that are fundamental in organic matter decomposition (SARE, 2012).

Soil organic matter is a major component in soil productivity and can be enhanced using cover crops (Gasch and DeJong-Hughes, 2019). Green manuring, the incorporation of any crop while green or soon after flowering into the soil for the purpose of soil improvement, is a common practice in some farming operations. A major benefit obtained from this practice is the increase of organic matter content of the soil and the rapid increase in soil microorganism population. This increased organic matter content allows for faster breakdown of plant residue by microorganisms, which releases nutrients and provides a wide range of benefits to crop production. Breakdown of organic matter produces polysaccharides, which are complex sugars that act as glues in the soil to cement small soil particles into cluster or aggregates (Gasch and DeJong-Hughes, 2019; SARE, 2012). A well-aggregated soil has aeration, tills easily, is less prone to soil compaction, has increased retention of water, and has a greater water holding and infiltration rate compared to a soil with poor aggregation (DeJong-Hughes et al., 2001).

Soil erosion is a major problem in soybean production as crop residue is limited, leaving exposed soil for extended periods. In the Red River Valley, a region in Minnesota, North Dakota, and Canada drained by the Red River of the North and forms the border between Minnesota and North Dakota, soils are susceptible to wind erosion due to high wind velocities due to minimal elevation change and minimal natural wind barriers such as tree rows. The importance in finding a solution to topsoil erosion, especially following soybean production in conventionally tillage systems, is vital in the sustainability of soil health and organic matter as continued top soil loss from wind and water erosion will have detrimental effects on crop productivity of our soils and increase fertilizer inputs if current management practices continue (Franzen, 2019). Several studies have suggested current cropping systems are not sustainable because of neglect to the ecosystem (Robertson et al., 2015; Delgado and Gantzer, 2015; Schipanski et al., 2014).

Winter Camelina

Winter camelina is a short-season annual oilseed crop in the Brassicaceae family with agronomic low-input features that has been produced for the oil in Europe for over 3000 years (Putnam el at., 1993; Zubr, 1997). The popularity of camelina has increased due to its winter hardiness high level of tolerance to drought and low-temperature stress, and its ability to adapt across a wide range of environments (Gesch, 2014). Because of camelina’s desirable agronomic traits, further research is being done to improve its adoption of cultivation and cover crops use.

Winter camelina can be used to produce healthy cooking oil as it contains high levels of unsaturated fatty acids and tocopherol (Ní Eidhin et al., 2003). The fuel properties of the methyl esters in camelina seed oil have comparable properties to canola (*Brassica napus* L.) oil (Fröhlich and Rice, 2005). This fuel known as hydrotreated renewable jet fuel (HRJ) meets or exceeds the standards for aviation fuel properties of comparable petroleum jet fuel (Corporan et al., 2011). The seed meal produced after oil extraction has relatively high protein contents with valuable high levels of the Ω-3 fatty acids for the use of supplementation for animal feed applications such as fish and broiler chickens (*Gallus domesticus*) (Aziza et al., 2010; Hixson et al., 2014). However, antinutritional factors such as glucosinolates, sinapine, and tannis, which remain in the seed meal following oil pressing, may limit the amount of seed meal that might be used in monogastric animal feed (Matthäus and Zubr, 2000).

Based on the United States Department of Agriculture Plant Hardiness Zone Map, North Dakota is primarily in zone 4a, which is one of the coldest ratings given in the continental United States (USDA, 2012). Based on this information for fall seeding, North Dakota farmers need winter annual biotypes of camelina that are proven to be winter hardy and suitable for the northern Plains Region (Gesch and Cermak, 2011). Overwintering cover crops are crops that are planted after, or with the primary crop, surviving the winter and resuming growth in the spring. These types of cover crops have been proven to provide many ecological beneficial attributes, but the cover crops must produce enough biomass in the fall and/or spring for these benefits to be expressed. Camelina that is fall-seeded will remain in the rosette stage throughout the winter, with growth resuming in the spring (Berti et al., 2017).

Camelina has a small seed size, with the average thousand seed weight at 1.0 g with variations of 0.3 to 2.0 g (Vollmann et al., 2007). The tiny seed size makes seeding and establishing the crop difficult because of the need to seed at a shallow depth of 1.3 cm. Despite camelina having a-small seed size, it has the ability to be quite vigorous regarding germination and emergence. Recent studies have shown near 100% germination occurring between temperatures of 4 to 32°C (Russo et al., 2010; Allen et al., 2014). Camelina plant height at maturity is between 60 and 110 cm. Flowers are 5- to 7-mm in diameter, autogamous, pale-yellow in color, and arranged in a raceme inflorescence. The fruit of camelina is small, pear-shaped silicle, 5-mm in diameter, and contains 8 to 15 golden to brown seeds (Berti et al., 2011).

Winter Rye

Rye is the most common and reliable winter annual cover crop in the upper Midwest (Iowa, Michigan, Minnesota, North Dakota, South Dakota, and Wisconsin) because it is one of the few cover crops that can successfully establish when planted late in the growing season, it is winter hardy throughout the region, and accumulates biomass before spring planting of the subsequent crop (Snapp et al., 2005; Wilson et al., 2013; CTIC, 2017; Crowley et al., 2018). Winter rye is the hardiest of cereal crops and can be planted later in the fall than most other cover crops while still providing above average dry matter compared with other cover crops used in North Dakota (SARE, 2012). It also has an extensive root system that can lead to reduction of nitrate leaching. It is widely adaptive, growing best in cool, temperate zones, but having the ability to perform in infertile, sandy or acidic soil, and poorly prepared land. Rye can establish in very cool temperatures and will germinate at temperatures as low as 1°C and vegetative growth can begin at 3°C (SARE, 2012). With vegetative growth still active at near freezing temperatures, winter rye has a longer time compared to alternative cover crops to produce biomass and canopy coverage, which is an important factor in North Dakota. With a prolonged growing season due to the winter hardiness of winter rye, rye can be a good weed suppressor in the spring as soil canopy coverage increased rapidly (Weil and Kremen, 2007).

Winter rye as a cover crop has the ability to be integrated into existing corn (*Zea mays* L.)-soybean production systems, feasibly implemented into current production systems in the Corn Belt, and has been recommended as a cost-effective strategy for improving environmental stewardship (Kladivko et al., 2014). Rye is superior among cool-season cereal cover crops for absorbing unused soil NO_3-N. It has a fast-growing fibrous root system, which helps scavenge for residual NO_3-N throughout the soil profile. Where rye has been interseeded into soybean in August, leaching losses from September to May were less than 5.6 kg of N ha^{-1} (Parkin et al., 1997). Rye also has the ability to access K from lower in the soil profile (Eckert, 1991, GRDC, 2018).

Interseeding Cover Crops into Established Soybean

Several researchers have investigated interseeding cover crops into soybean at all stages of growth (Berti et al., 2017; Mohammed et al., 2020). Interseeding involves planting of the cover crop by drilling the seed into the soil or broadcasting it before the first crop matures. The advantages of interseeding include not interfering with harvest timing or labor, provide more time for cover crop establishment, improved cover crop growth, and increased winter survival (Midwest Cover Crops Council, 2015). Interseeding usually requires special or modified equipment that is able to leave established soybean plants undamaged. A proven negative correlation between higher cover crop biomass and density and lower biomass of weeds exists. In addition, most research has shown that weeds can be suppressed effectively without yield reduction of the main crop by interseeding cover crops in organic farming systems (Uchino et al., 2012; Masilionyte et al., 2017)

Current research has shown that the camelina plants have difficulty competing with the dense canopy of soybean, and interseeding should occur during soybean reproductive stages (Berti et al., 2017). Establishment of winter camelina and winter rye by aerial broadcasting is mainly dependent on timely rainfall after sowing (Fisher et al., 2011) and seeding rates need to be increased by a minimum of 50% (SARE, 2012).

Soybean and Wheat Crop Rotation

Hard red spring wheat (*Triticum aestivum* L. emend. Thell.) is mostly grown in the upper Midwest and is a popular crop rotated with soybean. Ninety-five percent of HRSW is grown in in North Dakota, South Dakota, Montana, and Minnesota. Spring wheat is planted between April through late May, shortening the length of the cover crop growing season over other crops as cover crop termination is recommended 14 d before planting (Wick and Gasch, 2018; NRCS, 2019).

STUDY 1 - RELATIVE MATURITIES AND ROW SPACING EFFECT ON ESTABLISHMENT OF INTERSEEDED COVER CROPS INTO SOYBEAN

Objectives

The goal of this research was to evaluate how soybean row spacing and soybean maturity affect winter camelina and winter rye establishment and total biomass of these cover crops, soybean yield, and subsequent wheat yield. This was achieved through the following objectives:

1. Evaluate cover crop development and biomass production in soybean cultivars with differing relative maturities;
2. Evaluate cover crop development intercropped into soybean with different row spacing;
3. Evaluate cover crop development after soybeans are removed compared with intercropped cover crop development;
4. Evaluate the effect of cover crop growth on soybean grain yield;
5. Evaluate the wheat yield grown after the termination of the cover crop in the spring.

Materials and Methods

Experimental Design and Treatments

The experiments were conducted at three locations during the 2017 and 2018 growing seasons (Table 1). Two experiments were established at North Dakota State University's (NDSU) NW22 experiment site (46.932124°, -96.858941°) located near Fargo, ND during the 2017 and 2018 growing seasons. One was planted on soil that has been tile-drained (7.6 m between tiles) and the second on soil that was non-tile drained. The soil is a mixture of Fargo (fine, smectitic, frigid Typic Epiaquerts) and Ryan (fine, smectitic, frigid Typic Natraquerts) with 0 to 1% slope. Both are naturally poorly or very poorly drained and slowly permeable. The parent material of the soil is clayey glaciolacustrine deposits (USDA, 2015).

The second location during the 2017 growing season was at NDSU's Casselton experiment site (46.880049°, -97.246534°) located to the west of Casselton, ND. The soil is a mixture of Kindred (fine-silty, mixed, superactive, frigid Typic Endoaquolls) and Bearden (fine-silty, mixed, superactive, frigid Aeric Calciaquolls) silty clay loams with 0 to 2% slopes (Table 1). Both soil series are naturally, somewhat poorly drained, with a crop productivity rating of 92 and is considered prime farmland. The parent material of the soil is fine-silty glaciolacustrine deposits (USDA, 2015).

Table 1. Year, soil series, taxonomy, and previous crop at Fargo, Casselton, and Prosper, ND, in 2017 and 2018.

Location	Year	Soil series†	Taxonomic class†	Slope	PI ‡
				--%--	
Fargo	2017 and 2018	Fargo	Fine, smectitic, frigid Typic Epiaquerts	0-1	67
		Ryan	Fine, smectitic, frigid Typic Natraquerts		
Casselton	2017	Kindred	Fine-silty, mixed, superactive, frigid Typic Endoaquolls	0-2	92
		Bearden	Fine-silty, mixed, superactive, frigid Aeric Calciaquolls		
Prosper	2018	Kindred	Fine-silty, mixed, superactive, frigid Aeric Calciaquolls	0-2	92
		Bearden	Fine-silty, mixed, superactive, frigid Aeric Calciaquolls		
		Lindaas	Fine, smectitic, frigid, Typic Endoaquolls		

†Soil data obtained from (USDA, 2015).
‡ PI=Crop Productivity Index.

The final location used during the 2018 growing season was at NDSU's Prosper experiment site (47.003094°, -97.105893°) five miles East of Amenia, ND. The soil is a mixture of Kindred (fine-silty, mixed, superactive, frigid Typic Endoaquolls), Bearden (fine-silty, mixed, superactive, frigid Aeric Calciaquolls) and Lindaas (Fine, smectitic, frigid, Typic Endoquolld) silty clay loams with 0 to 2% slopes (Table 1). This soil is of similar soil structure as the Casselton location.

Soil samples were taken at all three locations at the beginning of each growing season in 2017 and 2018 before soybean planting. Two soil samples, to a depth of 0- to 15-cm and 15- and 61cm, were taken at each sampling location. Soil samples were tested for, NO_3-N using Vendrell and Zupancic method (1990), Olsen P (Olsen et al., 1954), K, and pH, organic matter (Table 2).

Table 2. Soil test results, before planting soybean, at all environments in 2017 and 2018.

Year	Location	Depth	NO_3-N	P	K	pH	OM†
		cm	-kg ha^{-1}	----mg kg^{-1}----			---g kg^{-1}---
2017	Casselton	0-15	30	39	313	7.7	43
		15-61	104	31	290	7.9	36
	NW22NAD	0-15	8	15	440	7.9	55
		15-61	7	6	330	8.0	36
	NW22CTD	0-15	5	16	432	7.9	55
		15-61	5	6	290	8.2	35
2018	Prosper	0-15	10	22	318	8.0	37
		15-61	118	4	131	8.3	28
	NW22NAD	0-15	19	9	330	7.8	56
		15-61	79	4	286	8.1	36
	NW22CTD	0-15	20	13	376	7.8	56
		15-61	86	7	338	8.0	40

†OM = Organic matter. NAD = naturally drained, CTD = controlled tile drained.

Each separate experiment at each location and year is called an environment. There were four replicates per environment and each replicate consisted of 20 experimental units (Table 3). The experimental unit size was 1.52 x 7.62 m. The experimental design was a randomized complete block design with a two-factor factorial arrangement within a split plot with row spacing being the main plot. Treatments included soybean row spacing, soybean relative maturity, and cover crop type; winter rye and winter camelina (Table 3).

Table 3. Treatment list for cover crop experiments at Fargo, Casselton, and Prosper, ND, 2017 and 2018.

Row spacing	Cover crop	Soybean relative maturity
--cm--	----Crop----	---Early or Late---
30.5	Winter rye	Early
30.5	Winter rye	Late
30.5	Winter camelina	Early
30.5	Winter camelina	Late
61	Winter rye	Early
61	Winter rye	Late
61	Winter camelina	Early
61	Winter camelina	Late
30.5	None	Early
30.5	None	Late
61	None	Early
61	None	Late
30.5	† Winter Rye	Early
30.5	† Winter Rye	Late
30.5	† Winter Camelina	Early
30.5	† Winter Camelina	Late
61	† Winter Rye	Early
61	†Winter rye	Late
61	† Winter Camelina	Early
61	† Winter Camelina	Late

†Soybean plants were removed at time of planting cover crop (referred to as no-soy).

Plot row spacing were narrow (30.5 cm) or wide (61 cm). Soybean relative maturities were early (0.5) or late (0.9). Cover crop treatments were none, winter camelina, and winter rye. In addition to the interseeding part of the study, eight plots for each replicate were used to represent growth of each cover crop, after removing the soybean plants just before planting and therefore the cover crops were growing without soybean competition for light, soil water, and nutrients. The treatments are designated as ‘Soy’ for plots that did not have soybean biomass removed and ‘Non-Soy’ for plots with biomass removed.

Where soybean plants were removed before cover crop seeding, soybeans were planted at 30.5 cm (narrow row spacing) and 61 cm (wide row spacing) row spacing. Four plots were grown with early-maturity soybean cultivar and four represented late-maturity cultivar. Upon R6 of early- and late-maturing soybeans, the specific maturity soybean group-designated plots had the soybean plants removed by a walk behind sickle bar mower (Troy-bilt, Valley City, Ohio), which cut soybean plants 3-cm above soil surface. For wide row spacing plots, a 1-m sample was randomly taken from Row 1 of plot, while for narrow row spacing plots, two random 1-m samples were taken from the center-two rows. For each plot, the sampling area was similar (1 m x 0.6 m or 2 m x 0.350 m).

In the whole trial, narrow row plots were planted with four soybean rows with a 30.5 cm row spacing. Wide row plots were planted with same planter as narrow row, but only two rows (row 1 and 3) were used to achieve the 61 cm row spacing. The seeding rate was 469 300 live seeds ha^{-1}. A germination test was conducted using an official seed germination testing paper (Anchor Paper Co.) at room temperature to determine a germination percentage. Both cultivars' germination percentage exceeding 95%. A Mettler Toledo XS6001S scale (Mettler-Toledo, LLC, Columbus, OH) was used to weigh out the precise amounts of soybean seed required for each plot. The seed for each experimental unit was packaged in envelopes prior to planting.

The early maturity soybean cultivar used was Asgrow brand 'AG0536', which has a relative maturity of 0.5 and for the late maturity the cultivar was Asgrow 'AG0934' which has a relative maturity of 0.9. They both are Roundup Ready 2 Yield soybeans, carry resistance to soybean cyst nematode (*Heterodera glycines)*, have *Phytophthora* spp. resistance (Table 4), and the seed was coated with Acceleron (a.i. pyraclostrobin and metalaxyl) seed treatment. Both cultivars were also inoculated with Vault SP (*Bradyrhizobium japonicum*) inoculum (BASF, Ludwigshafen, Germany) at a rate of 1.8 g kg^{-1} on the day of planting to encourage nodulation.

Table 4. Soybean cultivars used and descriptive features.

Cultivar	Company	Maturity	Phytophthora	Company IDC[†]	SCN[‡]	Canopy	Plant height
0536	Asgrow	0.5	3[§]	2	R	Medium	Medium tall
0934	Asgrow	0.9	3	4	R	Medium	Medium short

[†] IDC = iron deficiency chlorosis. NDSU IDC scored on 1-5 scale (1=green, 5=dead) from Goos and Johnson (2001). Company IDC scored on 1-9 scale (1=green 9=dead).

[‡]SCN = soybean cyst nematode. R=resistant.

[§] Resistant to race 3.

Cover crops were planted when the soybean reached the R6 growth stage (Fehr et al., 1971); dates varied based on relative maturity respectively, as indicated in Table 5. Staging of soybean was based on NDSU Soybean Production Field Guide, which defines R6 as full seed – pod containing a green seed that fills the pod cavity at one of the four uppermost nodes on the main stem with a fully developed leaf (Kandel and Endres, 2019). The winter rye cultivar Rymin was planted at a rate of 67 kg live seeds ha^{-1}. The winter camelina cultivar Joelle was planted at a rate of 10 kg live seeds ha^{-1}. Testing for germination percent was conducted before planting, using a ragdoll method with three replicates, each containing 100 seeds of each cover crop. In 2017, a 95% germination rate was determined for rye and 90% for camelina. In 2018, a 96% germination rate was determined for rye and 90% for camelina.

For wide-row plots, cover crops were planted in two parallel rows using a customized v-hoe with two blades spaced to make parallel furrows 15.3-cm apart. The parallel rows were planted in the center of two-planted soybean rows (row 1 and 3). A single additional cover crop row was planted 15.3-cm from soybean Row three on the opposite side of the row resulting in three total cover crop rows. For the narrow row spacing, a single furrow was made in the center between all soybean rows, 15.3 cm from each corresponding row, between row one and two and row three and four, resulting in three cover crop rows. Furrows were made to the depth of 1.3 cm for camelina and 2.5 cm for rye.

No fertilizer was applied before or during the growing season. Weeds were controlled using two applications of Roundup PowerMAX (a.i. 48.7% glyphosate, N-(phosphonomethyl) glycine, in the form of its potassium salt) (Monsanto Co., St. Louis, MO) prior to the planting of the cover crops. The herbicide was applied using TeeJet AIXR 110015 nozzles at a rate of 1.6 L ha^{-1} in 94 L ha^{-1} water and a spray pressure of 200 kPa. Along with chemical application, hand weeding was used when needed to control weed escapes. Disease and insect pressure were monitored throughout the season and Mustang Max (a.i. 9.15% Zeta-cypermetrin*S-Cyano) (FMC Corporation, Philadelphia, PA) foliar insecticide was used against soybean aphid (*Aphis glycines* Matsumura) at a rate of 292 mL ha^{-1}.

A HRSW germination test was conducted using an official seed germination testing paper (Anchor Paper Co.) at room temperature. Germination was found to exceeded 95%. A Mettler Toledo XS6001S scale (Mettler-Toledo, LLC, Columbus, OH) was used to weigh out the wheat seed required for each plot based on germination percent and seed weight. The seed for each plot was packaged in envelopes prior to planting. In 2018, the NDSU HRSW cultivar Glenn was used and in 2019, the cultivar SY Ingmar.

Spring wheat was planted only at the NW22 location. Experiments were planted as soon as field conditions were favorable in early May, with seven rows spaced 18.3-cm apart using a seeding rate of 2 739 000 live seeds ha^{-1}. The plots were planted with a Great Plains 3P605NT no-till planter (Great Plains Ag, Salina, KS). Seeds were planted to a depth of approximately 2 cm. Nitrogen (N) was applied at a rate of 120 kg and 130 kg ha^{-1} in 2018 and 2019, respectively.

Weeds were controlled with a foliar applied herbicide sprayed at 200 kPa using TeeJet 8001 XR nozzles using 94 L ha^{-1} water. In 2018, Wolverine Advanced (a.i 4.56% fenoxaprop-p-Ethyl, 6.13% bromoxynil octanoate, 5.93% bromoxynil heptanoate, 1.5% pyrasulfotole) was used at a rate of 2 L ha^{-1}. In 2019, Supremacy (a.i 36% fluroxypry, 4.5% thifensulfuron-methyl, 1.5% tribenuron) at a rate of 439 mL ha^{-1} and Axial XL (a.i. 5.05% pinoxaden) at a rate of 1.2 L ha^{-1}.

Data Collection

Management and observations dates are provided in Tables 5. Soybean plant density was determined shortly after soybean emergence (VE) by randomly selecting one-linear meter near the center-two rows of the plot. Then, counting all plants within 1 m in both inner two rows of each narrow row plots and both rows for wide row plots. Location for stand counts was randomly chosen in the near the middle half of the plot. Plant density was calculated as plants per ha^{-1}.

Measurements of photosynthetically active radiation (PAR) were made on cloudless days between 1100 and 1400 h using an AccuPAR LP-80 Ceptometer (Decagon Devices, Pullman, WA) at cover crop planting and soybean harvest. Measurements for wide row plots were taken by centering the ceptometer between the two cover crop rows between soybean rows, parallel with the direction of planting in order to measure the amount of the light available to the cover crops. For narrow row plots, the ceptometer was placed directly above the center cover crop row between soybean rows two and three at three random locations within the row. Measurements were recorded at ground level in each plot or directly above currently growing cover crop.

Table 5. Dates of important measurements and field operations at Fargo, Casselton, and Prosper ND, in 2017, 2018, and 2019.

Measurement/Operation	Fargo	Casselton	Fargo	Prosper
	------------------	Date	--------------------	
	2017		2018	
Soil test/plant	8 May	10 May	14 May	11 May
First herbicide application	12 June	12 June	13 June	4 June
Second herbicide application	7 July	7 July	2 July	21 June
Insecticide	25 Aug.	25 Aug.	12 July, 11 Aug	18 July, 11 Aug
Soybean plant density count	15 June	12 June	13 June	19 June
Vigor/greenness score	30 June	30 June	13 June	19 June
Early maturity soybean biomass	14 Aug.	17 Aug.	4 Aug.	5 Aug.
Late maturity soybean biomass	23 Aug.	23 Aug.	21 Aug.	21 Aug.
Early maturity cover crop planting	18 Aug.	17 Aug.	8 Aug.	8 Aug.
Late maturity cover crop planting	24 Aug.	24 Aug.	22 Aug.	23 Aug.
First emerged cover crop first planting date	23 Aug.	22 Aug.	28 Aug.	23 Aug.
First emerged cover crop second planting date	20 Sept.	21 Sept.	3 Sept.	3 Sept.
First PAR‡ light reading	28 Aug.	30 Aug.	26 Aug.	26 Aug.
Second PAR light reading	11 Sept.	21 Sept.	NA	NA
Cover crop canopeo§ 1	20 Sept.	21 Sept.	3 Sept.	NA†
Cover crop canopeo 2	6 Oct.	12 Oct.	22 Sept.	NA
Cover crop canopeo 3	31 Oct.	3 Nov.	21 Oct	NA
Biomass	1 Nov.	2 Nov.	22 Oct	NA
Stand counts	13 Oct.	12 Oct.	22 Oct	NA
Harvest	6 Oct.	4 Oct.	18 Sept.	19 Sept.
	2018		2019	
Spring cover crop canopeo	12 May	13 May	12 May	NA
Spring cover crop biomass	12 May	13 May	12 May	NA
Spring wheat planting	16 May	NA†	31 May	NA‡
Wheat canopeo	13 June	NA	16 June	NA
Wheat herbicide application	13 June	NA	2 July	NA
Wheat harvest	17 Aug.	NA	6 Sept.	NA

†No wheat was planted at Casselton in 2018.
‡PAR = photosynthetically active radiation
§Canopeo = tool for calculating canopy coverage percentage

Data Collection – Cover Crops

Cover crop development was evaluated by measuring cover crop emergence, plant height, percent ground cover, aboveground biomass, and light interception. Emergence was recorded when the hypocotyl of camelina and coleoptile of rye were physically visible above the soil surface. To estimate emergence percentage, current plant stand, winter survival, and the number of cover crop plants, cover crop plants were counted within the center-two rows of soybeans extending 0.5 -m along soybean rows. Sampling area was 50 cm x 30.5 cm for narrow row plots and 25 cm x 61 cm for wide row plots. Stand count values were then calculated to plants per square meter. Cover crop plots were counted in the fall after all cover crops had emerged and in the spring before termination.

Canopy coverage, defined as a percentage of green plant matter, which covers the soil, was measured using the mobile phone application Canopeo, made available by the Oklahoma State University Department of Plant and Soil Sciences, following cover crop emergence, before first killing frost, and before termination in the following spring. Pictures used for canopy coverage data were taken in the center of each plot at a height of 1-m, allowing 15-cm from the outside of last soybean row. Picture data was then processed using Canopeo application, which resulted in a percentage of green tissue within the area of the picture.

Cover crop biomass was collected in the fall before the first killing frost, and in the following spring, preceding cover crop termination and subsequent wheat planting. Biomass was sampled by using a randomly placed meter stick positioned parallel with each cover crop row. Two biomass sample locations were used in each plot, one per planted cover crop row and an average of the two samples was used for the biomass calculation. This average represented sampling from 1 m by 30.5 cm.

Biomass samples were created by cutting all cover crop plants at the base of plants nearest to soil. Samples were then place in a dryer at a temperature of 40°C until the biomass sample showed no difference in weight during a 24-h period. Samples were then individually placed into a tray and foreign material was removed before being weighed, using a Mettler Toledo XS6001S scale (Mettler-Toledo, LLC, Columbus, OH).

Data Collection -Wheat

Canopy coverage was measured using Canopeo, made available by the Oklahoma State University Department of Plant and Soil Sciences, during the tillering in mid-June (Table 5). Pictures used for canopy coverage data were taken in the center of each plot at a height of 1 m, allowing 15 cm from the outside of last wheat row. Picture data was then processed using the Canopeo application, which resulted in a percentage of green tissue within the area of the picture.

The HRSW and soybean plots were harvested, after physiological maturity (Fehr et al., 1971; Zadoks et al., 1974), using a Wintersteiger Classic plot combine (Wintersteiger Ag, Ried, Austria). Seed samples were cleaned using a Clipper seed cleaner (Ferrell-Ross, Bluffton, IN), and the seed samples were then weighed for yield on a Mettler Toledo XS6001S scale (Mettler-Toledo, LLC, Columbus, OH). Moisture and test weight were determined using a GAC 2100 moisture tester (DICKEY-John Corp., Minneapolis, MN) and observations were corrected to 13% and 13.5% moisture content, for soybean and HRSW, respectively. Soybean oil and protein contents were not significantly different among treatments and are not reported in this document.

Statistical Analysis

Statistical analysis was conducted using a randomized complete block design with a two-factor factorial arrangement within a split plot arrangement, with row spacing being the main plot. All dependent variables were analyzed with a mixed model (PROC MIXED) on SAS 9.3 (SAS Institute Inc., Cary, NC). Row spacing, cultivar, and cover crops were considered fixed variables, and environment was considered a random variable.

Plots with soybean biomass removed were analyzed separately and designated as 'non-soy' plots. The data were analyzed for each environment in 2017 and 2018 separately. Due to adverse growing conditions, no plots were harvested at Prosper in 2018 and no data were included in the analysis. After confirming homogeneity of variance (error mean squares within a 10-fold range), data was then combined and analyzed over all locations and years (considered environments) of the study. Treatment means were separated using Fisher's protected least significant difference (LSD) at the 95% level of confidence ($P \leq 0.05$). The LSDs were calculated for each individual environment and the combined analysis. The ANOVA tables below (Table 6 and 7) show degrees of freedom, mean squares and significance for each source of variation at Fargo 2017-2018 and Casselton 2018.

No differences were witnessed between row spacings for 'No-soy' plots and data was combined for analysis. Cultivar differences were also not available since soybean biomass was removed, eliminating the differences in soybean plant senescence differences. Analysis was done for both cover crops, winter camelina and rye, and soy versus no-soy plots (Table 6).

Table 6. Analysis of variance and mean squares for two soybean conditions (Soy) and two cover crops (CC), across five environments (env) in Fargo, ND 2017, 2018 and 2019, and Casselton, ND, 2018.

SOV†	df	Fall canopy coverage	Fall canopy coverage	Spring canopy coverage	Fall biomass	Spring biomass	CC stand count
Env	4	0.273	0.216	0.128	2015.1*	3798.5*	2514
Rep(env)	15	0.047*	0.069*	0.068*	178.4*	48.1	1484*
Soy	1	1.329*	2.187*	1.930*	3986.2*	812.1	59245*
Env x Soy	4	0.054	0.053	0.029	312.1	511.3	437
CC	1	0.175*	0.947*	0.539*	2353.9*	1584.5*	31972*
Env x CC	4	0.013	0.059	0.063	164.0	145.9	385
Soy x CC	1	0.036	0.098	0.037	4.8	61.8	11846
Env x Soy x CC	4	0.040*	0.022	0.021	137.2*	112.7*	1408*
Residual	270	0.007	0.011	0.011	32.8	45.5	345

†SOV = Sum of variance

* = significant at ($p \leq 0.05$).

Table 7. Analysis of variance and mean squares for two row spacings (RS), two cultivars (Cul) and two cover crops (CC), across five environments (env) in Fargo 2017, 2018 and 2019, and Casselton, ND, 2018.

SOV†	df	Fall canopy coverage	Fall canopy coverage	Spring canopy coverage	Fall biomass	Spring biomass	Soybean yield	Spring CC stand count	Light reading 1	Light reading 2	df	Wheat yield	Wheat canopy coverage
Env	4	0.0439	0.0323	0.0223	633.7	820.3*	6531173*	564	0.0645	1.026*	3	22543640*	0.4332
Rep(env)	15	0.0132*	0.0149*	0.0218*	57.8*	57.8*	598695*	736	0.0190*	0.031	11	665821*	0.1535
RS	1	0.0032	0.0101	0.0004	28.4	37.7	1983581*	52	0.3610*	0.220	1	1241365	0.0984
Env x RS	4	0.0017	0.0031	0.0028	10.4	26.8	205522	79	0.0469	0.078*	3	312542	0.0087
Cul	1	0.0255	0.1461*	0.3152*	199.5	64.1*	1131392*	7886*	0.0012	0.117	1	1312528	0.5355
Env x Cul	4	0.0038	0.0097	0.0081	58.0	7.7	8707	120	0.0010	0.063*	3	10154	0.0153
CC	1	0.0256	0.2191*	0.1503*	1055.7*	505.8*	57963	2540*	0.0053	0.011	1	857852*	0.4897*
Env x CC	4	0.0056*	0.0488*	0.0643*	260.3*	97.5*	237473	912*	0.0087	0.009	3	56851*	0.1141*
RS x CC	1	0.0000	0.0024	0.0015	4.5	2.5	57708	34	0.0003	0.006	1	66563	0.0089
Env x RS x CC	4	0.0000	0.0015	0.0017	4.0	5.3	109773	96	0.0032	0.013	3	141523	0.0101
RS x Cul	1	0.0013	0.0024	0.0043	10.6	29.6	4621	2	0.0021	0.014	1	6595	0.0055
Env x RS x Cul	4	0.0012	0.0014	0.0049	10.7	49.5	55564	152	0.0009	0.009	3	74852	0.0098
CC x Cul	1	0.0068	0.0484	0.0347	95.6	78.9	621545	218	0.0059	0.002	1	565624	0.4685
Env x CC x Cul	15	0.0005	0.0048	0.0074	6.8	8.1	148295	491*	0.0025	0.008	11	132456	0.0145
RS x CC x Cul	1	0.0011	0.0025	0.0016	28.4	25.7	21513	139	0.0014	0.009	1	32524	0.0075
Env x RS x CC x Cul	8	0.0015	0.0064*	0.0068	31.2*	18.4	180505	341	0.0029	0.005	6	198555	0.0135
Residual Error	90	0.0010	0.0031	0.0060	13.3	16.1	149295	215	0.0038	0.006	69	178325	0.0098

†SOV = Sum of variance

* = significant at ($p \leq 0.05$).

Results and Discussion

During the 2018 growing season at the Prosper research location, cover crop growth was severely inhibited based on observations made on 3 September. Emergence and vigor of both species of cover crop at both planting dates were excellent, as soil conditions were ideal, and precipitation was abundant with nearly 40.6 mm of rain following the first cover crop planting date on 8 August. On 3 September, visual observation showed nearly a 50% reduction in cover crop stand. Cover crop leaves and stem showed symptoms of chewing of the leaves and clipping of seedling stems, destroying the growing point of both species. High levels of field crickets (*Gryllus pennsylvanicus*) and the two-striped grasshopper (*Melanoplus bivittatus*) were observed throughout the growing season despite the use of Mustang Maxx (a.i. 9.15% Zeta-cypermetrin*S-Cyano) (FMC Corporation, Philadelphia, PA) foliar insecticide at a rate of 292 ml ha^{-1} on 18 July, which is labeled to sufficiently control crickets and grasshoppers.

On 7 September, cover crop stands were diminished to an estimated 10% of cover crop stand remaining with most plots destroyed. By 13 September, no cover crop plants were remaining at the Prosper location. No cover crop observation or data recording was obtainable from this location. Prosper cover crop data were not analyzed due to incomplete data collection and insufficient data. Peterson et al., (2019) also reported that insects may reduce cover crop stands.

In the fall of 2016, the NW22 Fargo, ND research plots were converted to a no-till management system. This system increases the amount of residue present at the soil surface compared with conventional tillage methods. Since the 2016 growing season was advantageous to HRSW growth, excess wheat residue was still present during the planting of cover crops in 2017. This residue inhibited precise cover crop planting depths, reducing stands and plant vigor.

In 2017, HRSW yields and biomass (crop before planting soybean and cover crops in 2018) were reduced compared with 2016, in addition the combine harvester was adjusted by lowering the cutting bar to reduce excess wheat stubble. During cover crop planting in 2018, HRSW residue was reduced compared with 2017. The Casselton research site in 2017 showed ideal soil conditions during planting, with very low levels of HRSW crop residue.

Winter camelina showed difficulties overcoming high residue areas due to residual HRSW stubble and soybean leaves. During the late-planting date in 2017 and both planting dates in 2018, soybean senescence coincided with cover crop emergence. Soybean leaf drop completely covered the small seedlings of camelina. At this time, winter rye was typically between 3- to 5-cm in height, allowing the soybean senesced leaves to be push to one side of the leaf blade of the rye plant. The rye was able to emerge from soybean leaf residue quickly due to placement and height of the plant compared with the prostrate rosette leaf arrangement produced from winter camelina. This leaf arrangement yet showed benefit to camelina early in the growing season, allowing the plant to increase canopy coverage immediately compared with rye. At the seedling stage of rye, canopy coverage only significantly increased following the beginning of tiller development.

Weather Data

The production years for 2017 and 2018 varied greatly, especially in precipitation amounts (Table 8) and mean average temperatures (Table 9). The 2017 growing season consistently had below average monthly rainfall amounts when compared with historical averages. The only month with above average rainfall was September, which is a critical month for cover crop growth before going dormant in the fall. The early-soybean maturity cover crop planting date in 2017 was 17 August at Casselton and 18 August at Fargo, respectively.

Precipitation of 5.85 mm was received on 16 August, resulting in ideal planting condition for the first planting dates at both locations. Following cover crop planting, no precipitation event greater than 2.5 mm occurred until 15 September. This resulted in no germination of the second cover crop planting date until 20 and 21 September (Table 5).

Since no precipitation was received for over a month, early-planted cover crops struggled to survive. High crop residue from soybean leaf senescence also greatly inhibited the growth of the early-planted cover crops as it smothered the plants Once the plants were smothered, the drought stress was compounded and resulted in retarded growth or plant death. Peterson et al., (2019) stated that rapid leaf senescence can also stress winter camelina plants, as cover crop plants can acclimate to low light conditions of less than 20% PAR under the canopy and with rapid leaf drop, cover crop plants were not able to adapt to higher solar radiation. The late-planted cover crops emerged following soybean senescence and were able to germinate through the crop residue.

Table 8. Monthly total rainfall for 2017, 2018, and 2019 historical data at Fargo, Casselton, and Prosper ND.

	Total rainfall					
	Fargo				Casselton†	Prosper†
Month	2017	2018	2019	Historical‡	2017	2018
	---------------------------------mm---------------------------------					
April	25	6	25	35	17	4
May	26	44	70	71	17	54
June	57	123	83	99	88	79
July	23	81	121	71	50	65
August	58	101	90	65	53	65
September	70	64	107	65	152	79
October	20	58	88	55	7	67
Total	280	477	584	461	366	413

† Weather station located at Prosper 5NW (NDAWN, 2018).

‡Historical data represent a 30-year average 1981-2010 (NDAWN, 2018).

The two cover crops planted late, also did not have to compete for solar radiation with the soybean plant, allowing the young plants to overcome early season plant stresses quicker, which produced stronger more vigorous plants. The 2018 growing season had above average moisture accumulation following both cover crop planting dates, resulting in more developed cover crops during soybean senescence. This allowed the cover crops to handle the substantial amount of soybean residue produced during senescence when compared with the 2017 growing season.

Monthly average air temperatures were 6°C higher in the month of April in 2017 compared with 2018. The month of April is important for cover crop growth, especially in the upper Midwest since March is historically below 0°C, and not suitable for plant growth. In addition, cover crops are typically terminated at the end of April or early May, leaving limited favorable growing temperatures for cover crop plant development.

Table 9. Monthly average air temperature and solar radiation 2017, 2018, and 2019, and historical data for average air temperature at Fargo, ND.

	Average air temperature				Average solar radiation †		
Month	2017	2018	2019	Historical‡	2017	2018	2019
	--------------^{o}C------------------				-----langley§----		
March	-1.5	-3.0	-3.0	-2.3	308	325	379
April	7.6	1.7	4.0	6.8	417	479	394
May	14.0	18.0	8.6	14.0	465	500	449
June	19.8	21.4	16.3	19.0	565	551	496
July	22.3	21.7	21.3	21.6	571	555	556
August	19.3	20.6	19.3	20.7	440	440	452
September	16.5	15.0	16.6	15.1	323	329	297
October	8.7	4.4	7.9	7.5	230	186	182
Total					3013	3368	3205

† No historical data available.

‡ Historical data represent a 30-year average 1981-2010 (NDAWN, 2019).

§Total incident solar radiation flux density is measured in Watts per m^2 at approximately 7 ft (2 m) above the soil surface with a pyranometer. The solar radiation energy units reported are Langleys (Ly) per day or MJ/m^2 day One Langley = 1 calorie per cm^2.

Solar radiation during cover crop growing season show higher values for 2017-2018 compared to 2018-2019. April witnessed the largest difference with a nearly 18% reduction in 2018 and 2019 (Table 9).

Soy versus No-soy

No-soy plots were designed to simulate an environment for cover crop growth without light, nutrient, or water competition from soybean plants. The interseeded cover crops at the R6 growth stage competed heavily with fully established soybean plants and explaining the reduced cover crop growth from this competition. All metrics showed significant differences between soy and no-soy treatments, except spring cover crop biomass (Table 10). Although removal of soybean plants resulted in higher canopeo readings and biomass compared with the soy treatment, the cover crops spring biomass from the no-soy plots was 50% lower than the biomass recorded in the fall. This 206 kg ha^{-1} decrease between fall and spring can be attributed to winterkill and limited spring growth. Since the rye in the no-soy plots produced numerous tillers in the fall, it was slower to recover through foliar growth.

Table 10. Mean fall and spring cover crop canopy coverage, cover crop biomass, and cover crop stand count readings for soybean present and soybean removed plots across five environments in Fargo and Casselton, ND, from 2017, 2018 and 2019.

Treatment	Fall canopy coverage	Fall canopy coverage	Spring canopy coverage	Fall biomass	Spring biomass	Fall stand counts
	----------------%----------------			------- kg ha^{-1}------		plants m^{-2}
Soybean	4.6 b[†]	8.1 b	14.0 b	158 b	202	75 b
No-soybean[‡]	17.5 a	24.7 a	29.6 a	410 a	316	167 a

[†] Within a column, mean followed by a different letter are significantly different at $p \leq 0.05$.

[‡] Plots had soybean biomass removed at time of cover crop planting.

The less advanced soy plots had not produced rye tillers in the fall and camelina stayed in the rosette stage both had limited foliar growth, resulting in better spring tillering of rye and faster foliar growth for winter camelina.

No-soybean Cover Crops

Winter camelina produced lower canopeo readings and biomass compared with rye (Table 11). Winter camelina had a slower establishment period, which set the plant behind rye. When observing and comparing rye and winter camelina visual through both the fall and spring data collections, plots were easily distinguishable even from a far distance. Rye had higher canopy coverage and biomass compared with camelina mass, as was also reported in other research (Peterson et al., 2019: Berti et al, 2017; Mommend et al., 2020). Winter camelina had more plants compared with rye.

Table 11. Mean fall and spring cover crop canopy coverage, cover crop biomass and cover crop stand count readings for two cover crops across five environments planted in Fargo, ND 2017 and 2018 and Casselton, ND 2017 and 2018.

Cultivar	Fall canopy coverage		Fall canopy coverage		Spring canopy coverage		Fall biomass		Spring biomass		Fall stand counts	
	------------------%------------------						-------- kg ha^{-1} -----				plants m^{-2}	
Winter camelina	8.7	b†	10.9	b	17.7	b	315	b	223	b	154	A
Winter rye	13.4	a	21.8	a	25.9	a	505	a	410	a	89	B

† Within a column, mean followed by a different letter are significantly different at $p \leq 0.05$.

Soybean

Row Spacing

Difference in cover crop observations were expected (Table 12) but precipitation timing and amounts may greatly affect these differences. No significant differences were observed for all cover crop metrics shown in Table 12. Despite the increased light availability to the interseeded cover crops (Table 13). Narrow-row spacing produced increased soybean yield compared with wide-row spacing as expected and are recommended in North Dakota State University Extension (Kandel, 2020). This difference can be attributed to the decreased light absorption by the soybean plants in wider rows, as shown by the increased PAR1 light readings showing increased light available to the cover crops (Table 13).

Table 12. Mean fall and spring cover crop canopy coverage, cover crop biomass, and cover crop stand count readings for two row spacings across five environments planted in Fargo, ND 2017 and 2018 and Casselton, ND 2017 and 2018.

Row spacing	Fall canopy coverage	Fall canopy coverage	Spring canopy coverage	Fall biomass	Spring biomass	Fall stand count
	----------------%----------------			---------- kg ha^{-1}----------		plants m^{-2}
Wide (61 cm)	4.9	8.9	14.1	171	220	79
Narrow (30.5 cm)	4.2	7.3	13.9	141	184	81
LSD 0.05	ns	ns	ns	ns	ns	ns

ns = non-significant.

Table 13. Mean soybean yield and PAR light readings for two row spacings across five environments in Fargo, ND 2017 and 2018, and Casselton, ND, 2017.

Row spacing	Soybean yield		PAR light 1†		PAR light 2†
	-----kg ha^{-1}-----		-------------------%-------------------		
Wide (61 cm)	2287	b‡	27.0	a	59.1
Narrow (30.5 cm)	2467	a	19.2	b	65.2

†Photosynthetically active radiation (PAR) reaching the cover crop, converted to a percentage of available sunlight. PAR 1 and PAR 2.

‡Within a column, mean followed by a different letter are significantly different at $p \leq 0.05$.

Based on this research, narrow row-soybean planting is recommended since cover crop differences were non-significant and soybean yield is increased. This difference of 180 kg ha^{-1} higher yield in narrower rows results in a per hectare net income gain of \$52.91 ha^{-1} when using a soybean price of \$0.294 kg^{-1} when comparing 30.5-cm with 60-cm row spacing. The net loss for wider rows would be difficult to justify with the cover crop metric not significantly different between 30.5- and 61-cm row spacing (Table 12).

Cultivar

Where the cover crop was planted earlier (in the early cultivar) the second fall and spring cover crop canopy coverage was higher as well as the fall biomass, spring biomass and stand counts (Table 14). The later maturing soybean cultivar produced significantly higher soybean yields with an average difference of 137 kg ha^{-1} relative to the earlier maturity soybean (Table 15). Higher yields for later maturing soybean cultivars was also reported by Kandel (2020) and Egli (1993). The difference of 137 kg ha^{-1} in this study resulted in a per hectare reduced income of \$42.26 ha^{-1}, when using \$0.294 kg^{-1} soybean price when the earlier maturing cultivar was used compared with the later maturing cultivar.

Table 14. Mean fall and spring cover crop canopy coverage, cover crop biomass, and cover crop stand count readings for two cultivars across five environments in Fargo and Casselton, ND, from 2017, 2018 and 2019.

Cultivar	Fall canopy coverage	Fall canopy coverage	Spring canopy coverage	Fall biomass	Spring biomass	Fall Stand count
	-------------------	%	-------------------	---------- kg ha^{-1}	----------	plants m^{-2}
Early (AG0536)	3.3	11.1 a†	18.4 a	193 a	226 a	98 a
Late (AG0934)	5.8	5.0 b	9.6 b	118 b	180 b	52 b

† Within a column, mean followed by a different letter are significantly different at $p \leq 0.05$.

Table 15. Mean soybean yield and PAR light readings for two cultivars across five environments in Fargo, ND 2017 and 2018, and Casselton, ND 2017.

Cultivar	Soybean yield		PAR light 1†	PAR light 2
	-----kg ha^{-1}-----		------------------%------------------	
Early (AG0536)	2308	b‡	23.3	64.5
Late (AG0934)	2445	a	22.8	59.9

†Photosynthetically active radiation (PAR), reaching the cover crop, converted to a percentage of available sunlight.

‡Within a column, mean followed by a different letter are significantly different at $p \leq 0.05$.

Cover Crop

Biomass produced by winter rye at all timings, (fall 2017 and 2018, and spring 2018 and 2019) was significantly higher compared to winter camelina despite increased stand counts by camelina during both growing seasons (Table 16). These differences are consistent with no-soy cover crop differences (Table 11). Winter camelina showed difficulties during establishment compared with rye, especially in high residue plots.

Table 16. Mean fall and spring cover crop canopy coverage, cover crop biomass, and cover crop stand count readings for two cover crops across five environments in Fargo and Casselton, ND, from 2017, 2018 and 2019.

Cover crop	Fall canopy coverage	Fall canopy coverage		Spring canopy coverage		Soybean yield	Fall biomass		Spring biomass		Stand count	
	------------------%------------------					----------- kg ha^{-1}-----------					plants m^{-2}	
Winter Camelina	3.2	4.4	b	11.0	b†	2411	72	b	144	b	89	a
Winter rye	5.8	11.8	a	17.1	a	2367	242	a	259	a	62	b

† Within a column mean followed by a different letter are significantly different at $p \leq 0.05$.

Spring soil coverage in this study was similar to other studies for winter rye and camelina (Peterson et al., 2019; Berti et al, 2017; Mohammed et al., 2020). Another study suggested at least 30% of the soil surface should be covered to protect the soil from water and wind erosion (Allmaras and Dowdy, 1985).

Wheat

Growing rye before planting wheat resulted in reductions in HRSW canopy coverage and yield (Table 17). These differences were visually obvious and statistically significant and consistent with other research (Peterson et al., 2019; Nielsen et al., 2016) with rye reducing wheat canopy cover by almost 20% (51.1 vs 41.0 %) and yield by 277 kg ha^{-1}. When the overwintering winter rye resumed growth in the spring, the rye also utilized nutrients and water reducing the amount of available water for the subsequent spring wheat crop, which impacted development. Research has shown that winter rye produces allelopathic compounds which reduces other grasses growth (Moyer at el., 2009), can increase root diseases (Bakker et al., 2016), and reduce soil N supply which can negatively impact yield (Thomas et al., 2017: Krueger et al., 2011). Wheat canopy cover and wheat yield were similar after camelina or without a previous cover crop in the soybean (check).

Table 17. Mean soybean yield for two cover crops averaged across five environments in Fargo, ND 2017 and 2018 and Casselton, ND 2017 and mean wheat canopy coverage and yield across four environments in Fargo, ND 2017 and 2018.

Cultivar	Wheat cover		Soybean yield	Wheat yield	
	----%----		----------kg ha^{-1}----------		
Winter camelina	52.3	a†	2411	2783	a
Winter rye	41.0	b	2367	2534	b
Check	51.1	a	2368	2811	a

† Within a column, mean followed by a different letter are significantly different at $p \leq 0.05$.

Summary of Results

The goal of this research was to evaluate how soybean row spacing and soybean maturity affect winter camelina and winter rye establishment and total biomass of these cover crops, soybean yield, and subsequent wheat yield between these factors.

Results:

1) The early maturing cultivar with 0.5 maturity had higher cover crop soil cover percent later in the fall and early in the spring and 63.6 % more biomass production in the fall (193 vs 118 kg ha^{-1}) and 25.6 % more biomass in the spring (226 vs 180 kg ha^{-1}) compared with growing cover crops in the late maturing (0.9) cultivar, when cover crops were planted at the R6 growth stage of each cultivar (Table 14). The 0.9 maturity soybean cultivar yield was 137 kg ha^{-1} more than the 0.5 maturity cultivar, which yielded 2308 kg ha^{-1} (Table 15).
2) There was not difference in spring or fall biomass production between 30.5 cm or 61 cm soybean row spacing. Narrow row spacing had 7.9% higher soybean yield compared with wider row spacing (Table 13).
3) Winter rye had more percent ground cover in the fall and spring and higher biomass yield in the fall (242 kg ha^{-1}) and spring (259 kg ha^{-1}) compared with camelina biomass of 72 kg ha^{-1} in the fall and 242 kg ha^{-1} in the fall (Table 16). Removal of the soybean plants at cover crop seeding resulted in 505 and 315 kg ha^{-1} rye and camelina fall biomass, respectively (Table 11), which is 209% and 438% more rye and camelina fall biomass, respectively when cover crops were interseeded into soybean.
4) Both cover crops did not reduce soybean yield compared with the check (Table 17).

5) Canopy coverage and wheat yield was reduced from interseeded cereal rye into soybean compared to winter camelina and check plot. Differences of 10% lower HRSW canopy coverage were observed, resulting in 277 kg ha^{-1} in lost yield (Table 17).

Conclusions

When seeding cover crops into early- maturing soybean cultivars, cover crops will produce increased cover crop growth resulting in increased biomass and canopy coverage, compared to when seeding into a later maturing soybean cultivar. However, the opportunity cost of planting an earlier maturing cultivar is larger due to the loss of soybean yield compared with later maturing cultivar. Base on this study it is not recommended to plant an early-maturing cultivar as the loss of revenue does not seem to be compensated by an increase in cover crop biomass of 75 kg and 46 kg ha^{-1} in the fall or spring, respectively. More research needs to be conducted to find if long-term economic benefits from interseeding cover crops will offset the yield reduction due to the utilization of an earlier maturing cultivar.

There is no significant difference in fall or spring biomass production with wide row spacing compared with the narrow row spacing, despite increased light availability during the first PAR reading. It is recommended to plant soybean in narrow row spacing (30.5 cm compared with 61 cm) as soybean yields were significantly higher than wide row spacing. No effect or soybean yield reduction was witness after the interseeding of the cover crops. This proves competition of cover crops to soybean plant, when planted at the R6 of the soybean cultivar, was negligible and that no economic soybean yield loss should be expected.

It is not recommended to plant HRSW following the interseeding of rye into soybeans, as winter rye will affect the growth and yield of the HRSW crop. However, winter camelina interseeding into soybean had no effect on HRSW and can be utilized as cover crop in the soybean followed by wheat crop rotation.

STUDY 2 - ESTABLISHMENT OF INTERSEEDED COVER CROPS IN SOYBEAN AND THEIR EFFECT ON A SUBSEQUENT WHEAT CROP

Objectives

The goal of this research was to evaluate how cover crop seeding rates affect winter camelina and winter rye establishment when interseeded into soybean, and what the cover crop influence was on soybean as well as the subsequent wheat yield. This was achieved through the following sub-objectives:

1. Evaluate cover crop development and biomass production in soybean cultivars with differing relative maturity;
2. Evaluate cover crop development and biomass production when interseeded into soybean with different sowing rates;
3. Evaluate the effect of cover crop growth on soybean grain yield;
4. Evaluate hard red spring wheat (HRSW) for vigor, canopy cover, and yield when grown following the spring termination of cover crops.

Materials and Methods

Experimental Design and Treatments

Two cover crop experiments were conducted during each of the 2016 and 2017 growing seasons with data collection on spring wheat in 2017 and 2018. Each of the experiments were considered a separate environment. The experiments were established at North Dakota State University's (NDSU) NW22 experiment field (46.932124°N, -96.858941°W) located near Fargo, ND. Producers potentially can drill a cover crop or broadcast the seed. In southern US locations broadcasting via airplane is common (SARE, 2012). The method of establishment was not an objective in this trial. Therefore, in one experiment the cover crop was direct planted and in the second experiment simulated air seeding was used to represent possible establishment methods. The soil at NW22 is a mixture of Fargo (fine, smectitic, frigid Typic Epiaquerts) and Ryan (fine, smectitic, frigid Typic Natraquerts) silty clay. Both are naturally poorly or very poorly drained and slowly permeable. The parent material of the soil is clayey glaciolacustrine deposits (USDA, 2015).

There were four replicates per experiment and each replicate consisted of 20 experimental units. The experimental unit size was 1.52 x 7.62 m. The experimental design was a randomized complete block with a partial factorial arrangement. Treatments included soybean relative maturity (cultivar), cover crop type and cover crop seeding rate. Soybean relative maturities included 0.4, 0.5, 0.8 and 0.9 with soybean cultivars listed in Table 18. Cover crop treatments were none (control), camelina, and rye. Cover crop seeding rate treatments were 100% of seeding rate and 75% of seeding rate. Cover crop treatments, winter camelina and cereal rye, and 100% and 75%, seeding rate were combined during statistical analysis to make five treatments (Camelina100, Camelina75, Rye100, Rye75, and Check).

All soybean cultivars were Roundup Ready 2 Yield, carried resistance to soybean cyst nematode (*Heterodera glycines*) (except AG0434), had phytophthora resistance, and were treated with Acceleron (a.i. pyraclostrobin and metalaxyl) seed treatment. Acceleron seed treatment is a fungicide combination providing protection from seed and soil borne diseases such as but not limited to; Pythium (*Pythium irregulare*), Phytophthora (*Phytophthora sojae*), Fusarium (*Fusarium solani*), and Rhizoctonia *(Rhizoctonia solani)* The cultivars were also inoculated with Vault SP (*Bradyrhizobium japonicum*) inoculum (BASF, Ludwigshafen, Germany) at a rate of 1.8 g kg^{-1} seed on the day of planting to encourage nodulation. The same cultivars were used in both growing seasons to reduce variation in soybean maturity timing, plant structure and yield potential differences.

Table 18. Soybean cultivars used and descriptive features.

Cultivar	Company	Maturity	IDC[†]	SCN[‡]	Canopy	Plant height
AG0434	Asgrow	0.4	2.0	None	Medium bushy	Medium
AG0536	Asgrow	0.5	1.6	R	Medium bushy	Medium tall
AG0835	Asgrow	0.8	1.8	R	bushy	Medium tall
AG0934	Asgrow	0.9	2.1	R	Medium bushy	Medium short

[†] IDC = iron deficiency chlorosis. IDC scored on 1-5 scale (1=Green, 3=Yellow, 5=Dead) (Helms, 2010).
[‡]SCN = soybean cyst nematode. R=resistant SCN using PI347654 source.

All soybean plots were planted as soon as field conditions were favorable in early to mid-May, with four soybean rows spaced 30.5-cm apart and using a seeding rate of 469 300 live seeds ha^{-1}. The plots were planted with a Hege 1000 no-till planter (Hege Company, Waldenberg, Germany). Seeds were planted to a depth of approximately 3 cm. A germination test was conducted using a moist paper towel at room temperature to find a germination percentage with all cultivars germination percentage exceeding 95%. A Mettler Toledo XS6001S scale (Mettler-Toledo, LLC, Columbus, OH) was used to weigh out the precise amounts of soybean seed required for each plot based on germination percent and seed size. The seed for each plot was packaged in envelopes prior to planting.

A HRSW germination test was conducted using an official seed germination testing paper (Anchor Paper Co.) at room temperature. The HRSW germination percentage, exceeded 95%. A Mettler Toledo XS6001S scale (Mettler-Toledo, LLC, Columbus, OH) was used to weigh out the precise amounts of wheat seed required for each plot based on germination percent and seed size. The seed for each plot was packaged in envelopes prior to planting. In 2017 and 2018, the HRSW cultivar Glenn was used. All HRSW plots were planted as soon as field conditions were favorable in early May, with seven rows spaced 18.3-cm apart using a seeding rate of 2 739 000 live seeds ha^{-1}. The plots were planted with a Great Plains 3P605NT no-till planter (Great Plains Ag, Salina, KS). Seeds were planted to a depth of approximately 2 cm.

The previous crop at the NW22 experiment site was corn (*Zea mays* L.) in 2015. Conventional tillage management practices were used in the 2015 growing season. The previous crop before soybean in 2017 was wheat (grown in 2016). No-till management has been used for the first time at the NW22 research site in the spring of 2016 and has been continued during the subsequent seasons.

Winter camelina cultivar Joelle was planted at 6.72 kg ha^{-1} live seeds for the 100% seeding rate treatments and 5.04 kg ha^{-1} for 75% rate treatments to a depth of 1.3 cm. The quantity of winter camelina seeds per kg can be upwards of 770 000 seed kg^{-1} compared with 39 000 seeds kg^{-1} for rye (Putnam, 1993). The rye cultivar 'Rymin' was planted at 67.2 kg ha^{-1} for the 100% seeding rate treatments and 50.4 kg ha^{-1} for 75% rate treatments to the depth of 2.5 cm. Germination testing was conducted before planting using a ragdoll method with three replicates containing 100 seeds for each cover crop. For both 2016 and 2017 growing seasons, a 95% germination rate was determined for rye and 90% for camelina. All cover crops were interseeded into established soybean at the R7 growth stage of the 0.4 maturity cultivar, using direct and broadcast seeding methods in each of the experiments, respectively in 2016 and 2017. Staging of soybean was based on NDSU Soybean Production Field Guide, which defines R7 as beginning maturity – one normal pod on the main stem that has reached its mature pod color (Kandel and Endres, 2019). Important field operation and measuring dates are provided in Table 19.

For the direct seeding method cover crops were planted in a single furrow in the center of all soybean rows, 15.25 cm from each corresponding row, resulting in three cover crop rows per experimental unit. Furrows were made to the depth of 1.3 cm for camelina and 2.5 cm for rye using a standard garden hoe. No furrows were made in the control plot (without cover crops). Both seeding methods involved placing the cover crop seed into three equal envelopes to improve consistency of seeding rate. For direct seeding, one envelope per row was used and for the broadcast sowing method seeds were distributed equally between the soybean rows, with one packet used for each third of the plots. Seed was spread by hand approximately 10 cm above the soybean canopy by walking between Row 2 and Row 3 of the soybean plots. During broadcast planting, soybean canopy coverage exceeded 90%, resulting in cover crop seeds being prevented from reaching the soil directly. However, no cover crop seeds were observed on soybean leaf blades following cover crop seeding, as all seeds dropped unto the soil surface.

Table 19. Dates of important measurements and field operations at Fargo, ND, in 2016, 2017, and 2018.

Measurement/operation	Fargo	
	------Date------	
	2016	2017
Soil test/ soybean planting	6 May	6 May
First herbicide application	9 June	9 June
Second herbicide application	30 June	-
Insecticide	25 Aug.	25 Aug.
Soybean stand count	15 June	15 June
Cover crop planting	22 Aug.	22 Aug.
Cover crop canopeo reading	15 Nov.	31 Oct.
Soybean harvest	27 Sept.	6 Oct.
	2017	2018
Spring cover crop canopeo reading	1 May	13 May
Spring cover crop biomass	1 May	13 May
Cover crop termination	6 May	16 May
Wheat planting	6 May	16 May
Wheat canopeo reading	9 June	9 June
Wheat harvest	22 Aug.	16 Aug.

Plant heights were obtained prior to harvest at physiological maturity for soybean and HRSW. Three separate measurements from the soil surface to the uppermost node on the plant were recorded within each plot. Measurements were then averaged. Fertilizer was broadcast-applied during the spring before the HRSW at a rate 112 kg per ha^{-1} of N using urea (46-0-0).

Weeds in soybean plots were controlled twice prior to the planting of the cover crops using (a.i. 48.7% glyphosate, N-(phosphonomethyl) glycine, in potassium salt form) Roundup PowerMAX (Monsanto Co., St. Louis, MO) and (12.6% (E)-2-[1-[[(3-chloro-2-propenyl)oxy]imino]propyl]- 5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one) and SelectMax (Valent U.S.A. Corporation, Walnut Creek, CA). For HRSW plots, (4.56% fenoxaprop-p-Ethyl, 1.5% pyrasulfotole, 6.13% bromoxynil octanoate, 5.93% bromoxynil heptanoate) Wolverine Advanced (Bayer CropScience LP, Research Triangle Park, NC) was used to control selective postemergent grassy and broadleaf weeds. The herbicides were applied using TeeJet 8001 XR nozzle at a rate of 1.6 L ha^{-1} in 94 L ha^{-1} water and a spray pressure of 200 kPa. Along with chemical application, mechanical means were used to control weed escapes. Cover crops were terminated in the spring using Roundup WeatherMAX.

In 2017 and 2018, (a.i. 9.15% S-Cyano(3-phenoxyphenyl)methyl (+/-)-cis/trans-3-(2,2-dichloethenyl)-2,2-dimethylcyclopropanecarboxylate) Mustang Maxx (FMC Corporation, Philadelphia, PA) was applied at a rate of 1.75 L ha^{-1} to both soybean and HRSW as soybean aphid (*Aphis glycines* Matsumura) levels in soybean and grasshopper (Orthoptera: Acrididae) thresholds in HRSW surpassed thresholds as described by NDSU (Kandel and Endres, 2019; Knodel et al., 2020).

The soybean and HRSW plots were harvested, after physiological maturity (Fehr et al., 1971; Zadoks et al., 1974), using a Wintersteiger Classic plot combine (Wintersteiger Ag, Ried, Austria). Seed samples were cleaned using a Clipper seed cleaner (Ferrell-Ross, Bluffton, IN), and seed samples were then weighed for yield on a Mettler Toledo XS6001S scale (Mettler-Toledo, LLC, Columbus, OH). Moisture and test weight were determined using a GAC 2100 moisture tester (DICKEY-John Corp., Minneapolis, MN) and observations were corrected to 13% and 13.5% moisture content, for soybean and HRSW, respectively. Soybean oil and protein contents were not significantly different between treatments and are not reported in this document.

Soybean plant density was determined shortly after emergence (VE), by randomly selecting one linear m near the center of the plot. Then, counting all plants within the linear m in both inner two rows.

Canopy coverage, defined as a percentage of green plant matter, which covers the soil, was measured using the mobile phone application 'Canopeo' developed by the Oklahoma State University Department of Plant and Soil Sciences, following cover crop emergence, before the first killing frost, and before termination in the spring. Canopeo measures the fractional green canopy cover through an image processed through the Canopeo application providing a green canopy coverage percentage (Patrignani and Ochsner, 2015). Canopy coverage data was also collected for HRSW, that was planted in the following year, after cover crops were terminated in the second week of June. Pictures used for canopy coverage data were taken in the center of each plot at a height of 1 m, allowing 15 cm from the outside of last soybean row. Picture data were then processed using Canopeo application, which resulted in a percentage of green tissue within the area of the picture.

Cover crop biomass was collected in the spring preceding termination and subsequent HRSW planting. Biomass was sampled from an area within a 30.5 cm x 50 cm plastic square

($0.1525\ m^2$), The square was randomly tossed into each half of the lengthwise portion of each plots, creating two samples per plot An average of the two samples was used for the biomass calculation. Biomass samples were created by cutting all cover crop plants within the square at the soil level. Samples were then place in a dryer at a temperature of 40°C until biomass sample showed no difference in weight during 24 h. Samples were then individually removed and placed on a tray where foreign material was removed before weighing the sample using a Mettler Toledo XS6001S scale (Mettler-Toledo, LLC, Columbus, OH).

Weather data for the 2016, 2017, and 2018 growing seasons were obtained from the North Dakota Agricultural Weather Network (NDAWN) at the Fargo weather station located in Fargo, ND (46.897°N, -96.812°W). Average monthly values for air temperature, solar radiation, and total precipitation amounts were used.

Statistical Analysis

Statistical analysis was conducted using a randomized complete block design with a two-factor factorial arrangement. All dependent variables were analyzed with a mixed model (PROC MIXED) on SAS 9.3 (SAS Institute Inc., Cary, NC). Cultivars and cover crops were considered fixed variables, and environment was considered a random variable.

After confirming homogeneity of variance (error mean squares of each environment within a 10-fold range of each other), data were then combined and analyzed over all locations and years (considered environments) of the study. Treatment means were separated using Fisher's protected least significant difference (LSD) at the 95% level of confidence ($P \leq 0.05$). The LSDs were calculated for each individual environment and the combined analysis. The ANOVA (Table 20) shows degrees of freedom for each source of variation at NW22 in Fargo, ND from 2016 to 2018.

Table 20. Analysis of variance and mean squares for four cultivars (Cul) and five cover crops (CC) across four environments (env) in Fargo, ND, 2016-2018.

SOV	df	Wheat canopy coverage	Soybean yield	Wheat yield	df[†]	Fall canopy coverage	Spring canopy coverage	CC biomass
Env	3	2.232*	505990	21717067*	3	0.5369*	0.3736*	1556563*
Rep (Env)	12	0.007*	542972*	853373*	12	0.0597*	0.0177*	81544*
Cultivar	3	0.001	1614987*	95644	3	0.0239*	0.0035	35460
Env x Cul	9	0.003	117854*	67174	9	0.0121*	0.0019	23671
Cover Crop	4	0.273*	70538	1102703*	3	0.1413*	0.3046*	973545
Env x CC	12	0.096*	41174	1045313*	9	0.0223*	0.0717*	267847*
Cul x CC	12	0.001	23022	52859	9	0.0039	0.0018	20706
Env x Cul x CC	36	0.002	32093	95382	27	0.0026	0.0018	17095
Error	228	0.003	26699	105005	180	0.0060	0.0026	14737

*significant at ($p \leq 0.05$).

[†]Cover crop check plots removed from data.

Results and Discussion

Weather Data

The production years 2016 and 2017 differed for total precipitation and air temperature as observed by NDAWN weather stations (Table 21 and 22). During the 2016 interseeding of the cover crops, below average precipitation during seeding was followed by above average rainfall amounts in September and October. Differences were also observed between growing seasons for spring data collection. The spring of 2017 had below average precipitation, yet with soil moisture levels greater than that of 2018 (due to lower precipitation during the 2017) (Table 21).

Lower canopy coverage percentages for both HRSW and cover crops were observed during the 2017 growing season compared with the value for the 2016 and 2018 growing seasons (data not presented). The 2017 growing season only had 280 mm of precipitation compared with 487 and 477 mm for 2016 and 2018, respectively (Table 21). This difference was the leading factor in lower cover crop cover values, causing lower germination rates, irregular germination, and difficulties during the cover crop planting. In addition, below average temperatures as compared with the historical average during the months of March, April of 2018 (Table 22) negatively affected the already inhibited s cover crops, resulting in low biomass growth. Solar rotation between 2016-2017 and 2017-2018 cover crop growing season were constantly higher during 2017-2018 season.

Table 21. Monthly total rainfall for 2016, 2017, 2018, and historical data at Fargo, ND.

	Total rainfall			
	Fargo			
Month	2016	2017	2018	Historical†
	----------------------------mm----------------------------			
April	59	25	6	35
May	33	26	44	71
June	69	57	123	99
July	132	23	81	71
August	48	58	101	65
September	80	70	64	65
October	64	20	58	55
Total	484	280	477	461

† Historical data represents a 30-yr average from 1981-2010 (NDAWN, 2018).

Table 22. Monthly average air temperature and solar radiation for 2016, 2017, and 2018, and historical data for average air temperature at Fargo, ND.

	Average air temperature				Average solar radiation †		
Month	2016	2017	2018	Historical‡	2016	2017	2018
	-------------------C^o----------------------				-----langley§----		
March	3.3	-1.5	-3.0	-2.3	280	308	325
April	6.3	7.6	1.7	6.8	337	417	479
May	15.5	14.0	18.0	14.0	509	465	500
June	20.0	19.8	21.4	19.0	561	565	551
July	22.0	22.3	21.7	21.6	525	571	555
August	21.1	19.3	20.6	20.7	477	440	440
September	16.8	16.5	15.0	15.1	325	323	329
October	9.7	8.7	4.4	7.5	188	230	186

† No historical data available.

‡ Historical data represent a 30-yr average from 1981 to 2010 (NDAWN, 2018).

§Total incident solar radiation flux density is measured in Watts per m^2 at approximately 7 ft (2 m) above the soil surface with a pyranometer. The solar radiation energy units reported are Langleys (Ly) per day or MMJ/m^{-2} day^{-1}. One Langley = 1 calorie cm^{-2}.

Cultivar and Cover Crops

Cultivar

Interseeded cover crops into different cultivars at the R6 stage of the early maturity cultivar, produced no soybean yield reductions compared to the check plot which is consistent with previous research (Berti et al., 2017; Peterson et al., 2019; Mohammed et al., 2020) Cover crop fall canopy coverage percentages followed expected outcomes with the greatest value associated with the 0.4 soybean maturity and lowest with 0.9 (Table 23). These differences were expected due to 0.4 maturity soybean cultivar entering plant senescence much quicker than the 0.9 cultivar, allowing for greater light penetration and decreased competition of the soybean with the interseeded cover crops (Kandel, 2020). Despite increased canopy coverage percentages from the cover crops in the earlier maturity soybean group, biomass differences were not observed in the combined data (Table 23).

Table 23. Mean fall and spring canopy coverage and cover crop biomass for four soybean cultivars across four environments in Fargo, ND, from 2016, 2017, and 2018.

Cultivar	Fall canopy coverage		Spring canopy coverage	Cover crop biomass
	-----------%-----------			---- kg ha^{-1}----
AG0434	12.6	a†	10.7	234
AG0536	11.5	a	10.3	193
AG0835	10.0	a	9.4	216
AG0934	8.2	b	9.1	182
LSD 0.05			ns	ns

†Within a column, mean followed by a different letter are significantly different at p≤0.05. ns = not significant.

If the goal of seeding the cover crop is increased soil coverage, early- maturing soybean cultivars may have the advantage over late-maturing cultivars. Although, increase in higher relative maturities resulted in greater soybean yield, while decreasing yield as relative maturity lower (Table 24) (Egli, 1993). Soybean plant density was not affected between cultivar treatments, and soybean stand counts were non-significant.

The greatest increase, averaged across all environments, was shown between the AG0434 (2340 kg per ha^{-1}) and AG0934 (2675 kg per ha^{-1}), which resulted in an increase of $17.37 ha , using a $0.294 kg^{-1} price, for the increased yield cultivar AG09034. This negative return for the benefit of reduced competition of the soybean plant (for AG0434) needs to be evaluated on an as needed basis to determine best economic return for an interseeding cover crop system. This paper does not analyze the cost-benefit analysis of the increased biomass's benefit for reduced fertilizer and herbicide cost, and soil health long-term benefits. Several studies have been conducted about economic returns on cover crops (Plastina et al., 2018; Bergtold et al., 2019; Myers et al., 2019) yet further research is suggested to improve grower decision making of maximum cover crop economic benefit to improve sustainability of interseeding.

Table 24. Mean soybean and wheat yield and wheat canopy coverage readings for four soybean cultivars averaged across four environments in Fargo, ND, from 2016, 2017, and 2018.

Cultivar	Soybean yield		Wheat yield	Wheat canopy coverage
	-----------kg ha^{-1}-----------			----%----
AG0434	2037	d†	2715	47.8
AG0536	2154	c	2631	48.0
AG0835	2270	b	2665	47.8
AG0934	2365	a	2677	48.4
LSD 0.05			ns	ns

†Within a column, mean followed by a different letter are significantly different at $p \leq 0.05$.

Further research needs to be conducted to show the economic return resulting from the additional cover crop grow achieved by planting an early-maturing soybean cultivar compared with the yield and monetary loss associated with planting an early-maturing soybean cultivar.

Cover Crops by Seeding Rate Interaction

Nearly all cover crop treatments metrics were significantly different when comparing winter rye and winter camelina (Table 25). No significant differences were found between seeding rate treatments, although all 100% seeding rate treatments produced larger values. The lower seeding rates would allow for reduced cover crop seed expense. Despite no differences between seeding rates in this study, several studies have suggested positive results for 100% seeding rate treatments (Putnam, 1993; Zubr, 1997).

Rye treatments canopeo and biomass values observed upwards of three times those of the winter camelina values (Table 25). These values were consistent across all environments and replications in addition to values shown in Study 1 and other research (Peterson et al., 2019; Mohammed et al., 2020). No economical or soil nutrient analysis was done in this study to show the economic impact of these differences, yet based on this study's data, rye was superior compared with camelina.

Table 25. Mean fall and spring canopy coverage and cover crop biomass for cover crops across four environments in Fargo, ND, from 2016, 2017, and 2018.

Cultivar	Fall canopy coverage		Spring canopy coverage		Spring cover crop biomass	
	-----------%-----------				---- kg ha^{-1}----	
Camelina100	7.0	b†	4.3	b	103	b
Camelina75	6.4	b	3.7	b	97	b
Rye100	16.2	a	16.1	a	321	a
Rye75	12.8	a	15.5	a	304	a

†Within a column, mean followed by a different letter are significantly different at $p \leq 0.05$.

For the HRSW growing seasons of 2017 and 2018, the termination of the cover crops was conducted using an application of Roundup WeatherMAX applied the same day as HRSW planting. Glyphosate produces plant death by translocation of the herbicide, which inhibits a key enzyme, acetylcholinesterase that plants use to make amino acids. This process is relatively slow, taking on upwards of 10 to 14 d to produce plant death. Winter camelina seemed to show a higher sensitivity to glyphosate and resulted in plant death much quicker than rye. Ten days after termination, winter camelina was visually eliminated with limited competition to the HRSW. Winter rye took 30 d to 45 d to become eliminated and by this time, the HRSW was nearly 35% canopy coverage and beginning to tiller.

An advantage of chemical elimination of the cover crop is protection to the soil from wind erosion and excess sunlight resulting in preventing moisture loss or crusting, compared with tillage. The wheat after cereal rye plots were significantly inhibited in growth and vigor as expected which is constant with previous research (Nielsen et al., 2016).

Table 26. Mean soybean and wheat yield and wheat canopy coverage for five cover crops across four environments in Fargo, ND, from 2016, 2017, and 2018.

Cultivar	Soybean yield	Wheat yield		Wheat canopy coverage	
	-----------kg ha^{-1}-----------			----%----	
Camelina100	2208	2718	a†	52.0	a
Camelina75	2193	2767	a	51.7	a
Rye100	2197	2507	b	40.1	b
Rye75	2175	2562	b	41.9	b
Check	2262	2808	a	51.9	a
LSD 0.05	ns				

†Within a column, mean followed by a different letter are significantly different at $p \leq 0.05$.

This difference was caused by the substantial biomass growth produced by cereal rye, 312.5 kg ha^{-1} average of both rates, as compared with winter camelina at 100 kg ha^{-1} average of both rates (Table 25), respectively. These biomass differences compounded by late termination of cover crops, canopy coverage differences, and slower herbicide (glyphosate) action in rye (Table 26) resulted in the significant differences of the wheat cover percentage and yield.

The substantial biomass growth inhibition due to the late termination of the cover crops was exacerbated by the no-till tillage system as crop residue was high. Since the rye showed canopy cover percentages averaging above 38% at termination, germinating HRSW plants were easily covered by the dying cereal rye plants. This difference between rye and camelina or check plots was easily observed, with the cereal rye plots expressing stunting, chlorosis, and poor vigor.

Wheat yields expressed significant differences for cover crop treatments (Table 26), especially during the 2017 growing season (data not presented). Yields were reduced due to excessive crop residue left by rye crop as mentioned with data results for biomass and canopy coverage. The economic loss using data between check plots (2808 kg $ha^{-1)}$ and rye plots (2535 kg ha^{-1}) (Table 26) were about \$60.33 ha $^{-1}$ using a price of \$0.221 kg^{-1} for wheat. With this amount economic loss, planting rye before growing HRSW is not recommended. The benefit from annual cover crop growth was not monetized in this study. Further research is needed to correctly analyze economic benefits.

Summary of Results

The goal of this research was to evaluate how cover crop seeding rates affect winter camelina and winter rye establishment when interseeded into soybean, and what the cover crop influence was on soybean as well as the subsequent wheat yield.

Results:

1. The early maturing cultivar with 0.4 maturity had higher cover crop soil cover percent later in the fall and early in the spring with 53.7 % more canopy coverage in the fall (12.6% vs 8.2%) compared with the 0.9 maturity cultivar, when cover crops were

planted at the R6 growth stage of the early maturing cultivar. Yet, biomass production was not significantly different between soybean cultivars.

2. Cover crop seeding rates comparing 100 to 75% seeding rate, show no significantly different biomass values.
3. Interseeded cover crops into different cultivars at the R6 stage of the early maturity cultivars produced no soybean yield reductions compared to the check plot which is consistent with previous research 2020
4. Growing HRSW after interseeded cereal rye resulted in reduced yields vs winter camelina and check plots, with yield reduction of 301 kg ha^{-1} for the 100% rye seeding rate. This was expected as the by HRSW canopeo values after rye were significantly lower compared with camelina and check plots, and the visual stress observed during the summer months was obvious.

Conclusions

Earlier maturing soybean cultivars will produce increased cover crop growth resulting in increased canopy coverage. However, the opportunity cost of planting an earlier maturing cultivar may be larger due to the loss of soybean yield compared with the later maturing cultivar. Base on this study it is not recommended to plant an earlier maturing cultivar as the loss of revenue does not seem to be compensated by an increase in cover crop coverage. More research needs to be conducted to find if long term economic benefits from interseeding cover crops will offset the yield reduction due to the utilization of an earlier maturing cultivar.

Winter rye has the great potential of higher biomass production and soil coverage through cover crop canopy coverage compared with camelina. It is recommended to use the 100% rates when interseeding if seed cost differences are negligible. If seed prices are high a reduced seeding rate could be considered.

It is not recommended to plant HRSW following the interseeding of rye into soybeans, as cereal rye will affect the growth and yield of the HRSW crop. Winter camelina interseeding into soybean had no effect on the HRSW crop and can be used for this crop rotation, however, the biomass of camelina in the spring was limited with 103 and 97 kg ha^{-1}, for 100% and 75% camelina seeding rate, respectively.

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