INTEGRATING FABA BEAN (*VICIA FABA* ROTH) INTO CROPPING SYSTEMS AS A COVER CROP, INTERCROP, AND LATE-SEASON FORAGE COMPARED WITH OTHER LEGUME COVER CROPS IN THE UPPER MIDWEST

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Integrating faba bean (*Vicia faba* Roth) into cropping systems as a cover crop, intercrop, and late-season forage compared with other legume cover crops in the upper Midwest

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

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ABSTRACT

Faba bean (*Vicia faba* Roth) is grown worldwide as a protein source for food, used for animal feed, and is a common cover crop in Europe, but is underutilized in Midwest farming systems. Faba bean, field pea (*Pisum sativum* L.), and forage pea were evaluated for biomass and chemical composition when sown after wheat. Faba bean, forage pea, balansa clover (*Trifolium michelanium* Savi), red clover (*T. pratense* L.), and rye (*Secale cereale* L.) were evaluated similarly when intersown into maize. Cover crops after wheat had no significant biomass differences, averaging 1210 kg ha^{-1}, enough to support 1.5 animal unit month (AUM) ha^{-1} for a 450 kg cow with calf. Rye yielded the greatest (374 kg ha^{-1}) of the intercrops with faba bean averaging similarly and other intercrops averaging significantly less. Intercrops did not affect maize yield. Faba bean has similar potential as other commonly used cover crops in the Midwest.

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CHAPTER 1: INTRODUCTION, OBJECTIVES, AND LITERATURE REVIEW

Introduction

The use of cover crops is an important addition to rebuild and maintain soils in upper Midwest farming systems (Berti et al., 2019). The National Resources Conservation Service (NRCS) defines cover crops as grasses, legumes, and forbs sown for seasonal vegetative cover. Cover crops may be established between successive production crops, companion sown, or relay-sown into production crops. These cover crops may be used to reduce lost resources due to water and wind erosion, as well as increasing or maintaining soil health and organic matter, improving soil water use efficiency, and minimizing compaction (NRCS, 2014).

Faba bean (*Vicia faba* Roth) is grown worldwide as a protein source as food, feed, and as a replacement of imported soybean [*Glycine max* (L.) Merr.] meal, and is most commonly grown in China, Europe, and Ethiopia (Jensen et al., 2010). Pea (*Pisum sativum* L.) is a more accessible legume that is used as a cover crop in the upper Midwest, but faba bean may be able to fit into the system more effectively.

A handful of demonstration studies have evaluated faba bean as grain for feed by the North Dakota State University Extension Service (2016), however, little research has been performed on faba bean as a cover crop and forage for grazing in the state leading to limited available information. In 2017, 3,367 ha of faba bean grain were reported in North Dakota (FSA, 2017). Preliminary studies indicate faba bean produces up to 680 kg of biomass yield with high crude protein (CP) and high digestibility for ruminants when sown in August after wheat (*Triticum aestivum* L.) (Berti et al., 2019). Faba bean has potential become an important cover crop in wheat-based or maize (*Zea mays* L.)-soybean based upper Midwest cropping systems.

Compared with other legumes used as cover crops, faba bean is a superior N_2 fixer in symbiotic association with Rhizobia bacteria, and the hardiest European cultivars are able to tolerate up to -15ºC in vegetative stage (Jensen et al., 2010). Forage mixtures including faba bean generally have higher CP content than mixtures including pea (Strydhorst et al., 2008). This means that faba bean has potential to add more N to the system that could reduce synthetic fertilizer rates, grow later into the season than most cover crops to produce more biomass, and be a more protein rich option for late-season cattle (*Bos taurus* L.) grazing. Despite these advantages, faba bean is not used to its full potential in the USA. The use of faba bean as a cover crop shortly after wheat harvest could provide beneficial information on how it could improve upper Midwest cropping systems.

Maize and cattle are important commodities in the upper Midwest, and cattle can also graze stalks left in the field after maize harvest. However, according to Wilson et al. (2004) the protein requirements of cattle cannot be met by maize residue alone. In much of the upper Midwest, maize does not leave enough time after harvest to establish cover crops due to short growing seasons. One possible solution for both of these situations is intersowing cover crops with high protein contents into maize. Intersowing is sowing into an already established cash crop, and is important for implementing cover crops where growing seasons are too short to establish cover crops after harvest, and especially into maize-based cropping systems (Wick, 2016).

When legume species were sown at the same time as maize in Wisconsin, its yield was reduced 43 to 69% by the legumes when weeds were not controlled, and 0 to 35% depending on legume when weeds were controlled (Alford et al., 2003). It was also found that legume production was 57% higher when weeds were controlled. Legumes did not suppress weed growth, showing that weed control is still essential when intersowing. This makes intersowing at later maize growth stages a better option compared with sowing cover crops at the same time as a cash crop because there is time to control weeds before cover crops are sown (Alford et al., 2003).

Most intersowing studies in maize have been done with winter rye (*Secale cereale* L.) (Wilson et al., 2013), and intersowing with legumes has been largely overlooked. Rye is the most winter-hardy cereal and consequently survives harsh winters making it a popular option. It can also produce vegetative growth down to 3ºC (Clark, 2007).

Faba bean is a frost tolerant legume that may provide additional protein to cattle grazing maize stover if is intersown into standing maize. Red clover (*Trifolium pratense* L.) has shown better frost tolerance than pea at down to -8ºC, and balansa clover (*Trifolium michelanium* Savi) has shown better frost tolerance than other small seeded legumes at -7°C (Meyer and Badaruddin, 2001).

Red and balansa clovers have shown large variation in CP content likely due to changing harvest times with red clover ranging from 110 to 250 g CP kg^{-1} (Wiersma et al., 1998; Broderick et al., 2000; Ovalle et al., 2006), and balansa clover ranging from 130 to 350 g CP kg^{-1} (Dear et al., 2003; Fraser et al., 2004; Ovalle et al., 2006). Rye is a less digestible forage than most legumes but had an average of 240 g CP kg^{-1} when intersown into maize and soybean by Wilson et al. (2013). These should all be good options for increasing CP content when combined with maize residue.

Intersowing faba bean or other legumes could increase sustainability through better late-season grazing quality, reduced leaching of soil mobile nutrients, increased winter cover to help protect from soil erosion, and increased N credits for the next crop, in comparison with winter rye.

Objectives

1. Evaluate forage yield and quality of faba bean, forage pea, and field pea, when sown after wheat harvest.
2. Determine the cover crop advantages of these legumes such as ground cover and nitrogen accumulation.
3. Determine the likelihood of N credits given to the following spring crop when these legumes are grown after wheat harvest.
4. Evaluate the ability of faba bean, forage pea, balansa clover, red clover, and rye to grow when intersown into the V8 and R4 stages of maize.
5. Determine the forage quality and biomass that these intercrops are able to produce for late-season grazing.
6. Determine if the intercrops have any effect on maize yield or quality.

Literature Review

Cover Crops

The National Resources Conservation Service (NRCS) defines cover crops as grasses, legumes, and forbs sown for seasonal vegetative cover. Cover crops may be established between successive production crops, companion-sown, or relay-sown into production crops. Select species and sowing dates that will not compete with the production crop yield or harvest may be used. According to the NRCS (2014) cover crops may be used to reduce water and wind erosion, maintain or increase soil health and organic matter, increase water quality, suppress weeds and break pest cycles, enhance soil water conservation, and minimize soil compaction. Cover crops may be grazed as long as the conservation purposes are not compromised. Different species of cover crops are also often sown together in mixtures to fulfill multiple of these purposes at the same time (NRCS, 2014).

Cover crops are gaining popularity throughout the USA. Myers (2019) reports that cover crop acreage across the USA rose 50%, from 4 million ha in 2012 to 6 million ha in 2017. Cover crop usage by state according to the Census of Agriculture ranged from 350 ha in Alaska to 410,400 ha in Texas in 2017. North Dakota's cover crop acreage increased 89% within that same timeframe, from 86,500 ha in 2012 to 163,600 ha in 2017. There is still much room for improvement, with the state only growing cover crops across 4% as much land as it has maize and soybean (Myers, 2019).

Winter-hardiness

Faba bean has many frost tolerant cultivars and has been reported to produce more dry matter yield than other common cool-season legumes according to Jensen et al. (2010). Faba bean is grown as a winter annual in warm, temperate, and subtropical areas. The hardiest European cultivars are able to tolerate temperatures down to -15ºC in vegetative stage without serious injury, but optimum air temperatures for growth are typically from 18 to 27ºC (Jensen et al., 2010). Field pea grown in the upper Midwest has shown ability to grow at temperatures down to -3ºC (Schatz, 2012). Winter-hardiness of a plant depends mainly on frost tolerance, resistance against biotic stress such as gray snow mold (*Typhula incarnata*), and tolerance to abiotic conditions such as waterlogging in saturated soils (Arbaoui et al., 2008). Arbaoui et al. (2008) also found that controlled temperature frost tests indicated that frost tolerance is a significant component to winter-hardiness, but low temperature is not the only factor determining survival. As temperatures decrease in the fall, plants acclimate to the changing conditions by altering fatty acid composition in cell membranes, proline content, and electrolyte leakage. None of these traits on its own had a strong correlation with frost tolerance, so a plant's ability to tolerate low temperatures depends on a combination of all these factors (Arbaoui et al., 2008). When compared with field pea, faba bean had slightly lower winter-kill, and both had less winter-kill than white lupin (*Lupinus albus* L.). All had large within-species variation, showing a need for more intensive breeding and cultivar selection (Annicchiarico and Iannucci, 2007).

Red clover and pea showed similar survival at one week after sowing at temperatures down to -6ºC, but when exposed to the same temperature two weeks after sowing, red clover had 56% survival and pea only had 6% (Meyer and Badaruddin, 2001). Balansa clover had the best frost tolerance of four small-seeded legumes tested, achieving the most biomass of cold-acclimated plants at -7ºC (Hekneby et al., 2006).

Nitrogen fixation, nitrate scavenging, and nitrogen credits to following crop

Faba bean has the highest reliance on N_2 fixation for growth in comparison with other cool-season legumes like pea and lupin (*Lupinus angustifolius* L.), which leads to high N benefit for following crops. Faba bean has been shown to attain high amounts of N derived from the atmosphere (Ndfa) ranging between 75 and 90% of its total shoot N (Hardarson et al., 1991; Hauggaard-Nielsen et al., 2009; Peoples et al., 2009), whereas pea Ndfa ranged between 50 and 70% (Hauggaard-Nielsen et al., 2009; Peoples et al., 2009; Jensen et al., 2010). Jensen et al. (2010) reported that, on a global average, faba bean fixes 154 kg N ha^{-1} and pea fixes 86 kg N ha^{-1}. In a study done in Alberta, Canada by Lupwayi and Soon (2015), 184 kg N ha^{-1} was fixed by faba bean, and 65 kg N ha^{-1} was fixed by forage pea. According to the study done by Hardarson et al. (1991) in Austria, 80 to 90% of the shoot N was Ndfa in faba bean when fertilized with 20 kg N ha^{-1} of ammonium sulfate. When fertilizer rates were increased to 100, 200, and 400 kg N

ha^{-1}, shoot Ndfa was about 80%, 60%, and 43% respectively, showing that increasing fertilizer rates from 20 to 100 kg N ha^{-1} only reduced Ndfa about 10%. In all rates, more than 90 kg N ha^{-1} was fixed by faba bean. The total N and dry matter yield of faba bean was not affected by the N fertilizer treatments. This shows that faba bean is a strong N_2 fixer even when there is readily available N in the soil. Several studies have reported N credits of up to 100 to 200 kg N ha^{-1} for crops grown after a full-season faba bean crop (Peoples et al., 2009; Jensen et al., 2010).

Red and balansa clover had similar concentrations of Ndfa when grown as annual forages in Alberta, Canada with 81.5 and 85.5% Ndfa, respectively (Ross et al., 2009). In a study performed in Chile by Ovalle et al. (2006), they reported concentrations of Ndfa of 95.9 and 92.6% for red clover and balansa clover, respectively. There does seem to be some variability in Ndfa with another study in southern New South Wales reporting that balansa clover only had 66% Ndfa (Dear, 2003).

Legumes can also reduce soil NO_3-N leaching by scavenging residual soil NO_3-N, with shoot uptake values ranging from 92 to 276 kg N ha^{-1} for faba bean (Jensen et al., 2010) and 104 kg N ha^{-1} for pea (Hauggaard-Nielsen et al., 2009). Intersowing of faba bean into maize or other cereals is being studied and put into practice in China due to the enhanced N_2 fixation seen from faba bean when intercropped (Zhang et al., 2004; Li et al., 2009). Additionally, faba bean has shown a high degree of complementarity when intersown with barley (*Hordeum vulgare* L.) in southern Sweden, demonstrating that faba bean intersown with a cereal increased its Ndfa by 10 to 15% over when it was grown alone, and pea Ndfa increased 8% (Hauggaard-Nielsen et al., 2009). Faba bean intersown into maize for silage reduced residual NO_3-N at the end of the season compared with sole maize (Stoltz and Nadeau, 2014).

Legume benefits to the following crop are well known, but the data is inconsistent. Stevenson and Van Kessell (1996) concluded that wheat yield consistently was 43% greater when preceded by pea compared with wheat as preceding crop, with up to 14 kg N ha^{-1} of the extra 27 kg N ha^{-1} (Ndfa x total N content) accumulated in the wheat attributed to fixed N_2. Beckie et al. (1997) had similar results finding that the N credit benefit of pea residue to the following crop was 25 kg N ha^{-1}. Lupwayi and Soon (2009) found that 7.5 kg N ha^{-1} was released by pea residue to the subsequent crop. Faba bean was the only crop with a positive N balance after harvest when compared with lupin, pea, and oat (*Avena sativa* L.) (Hauggaard-Nielsen et al., 2009), indicating it would be the only crop providing mineralized N to following crops in southern Sweden. Cupina et al. (2011) found that field pea contributed 165 kg N ha^{-1} to the following crop after it was used as a cover crop over a mild winter in Serbia. Lupwayi and Soon (2015) reported that legume green manure residues released 80% of their C and N contents in the following season, whereas legumes harvested at maturity released 45 to 70% of their C and N contents. Lupwayi and Soon (2016) reported that wheat showed significant increases in N uptake, C accumulation, biomass, and yield succeeding legume crops, whether they were harvested at maturity or grown for green manure. No response from canola (*Brassica napus* L.) in the season following wheat (two seasons after legumes) were observed. However, increases in all parameters of barley in the year after the canola (three seasons after legumes) were seen from harvested legumes compared with green manure legumes (Lupwayi and Soon, 2016). Couedel et al. (2018) found that legume cover crop residues grown in the fall provided 35 to 54 kg N ha^{-1} as green manure to the following crop in France. These differences can be attributed to disparity in soil and weather, especially rainfall, and how they affect mineralization of crop residues (Lupwayi and Soon, 2009; Jensen et al., 2010).

Although rye is not a legume and does not fix N_2, it is known for its dense root system, ability to accumulate nutrients, and to reduce NO_3-N leaching (Clark, 2007). When aerially broadcasted onto maize stover in October, rye consistently accumulated more N in its biomass than winter wheat, averaging 17.9 kg N ha^{-1} in Maryland (Fisher et al., 2011). In Minnesota, intersown cover crops including red clover, pea, and rye showed no difference in intercrop N accumulation in the fall (Noland et al., 2018). A rye and radish (*Raphanus sativus* L.) mixture intersown into maize and soybean in a silty loam soil in early September reduced subsurface drainage NO_3-N losses in both fall and spring evaluations, reducing NO_3-N load from 48 kg ha^{-1} to an average of 25 kg ha^{-1} (Ruffatti et al. 2019). Another study by Kaspar et al. (2007) in Iowa saw similar results in a fine loamy soil with rye sown shortly before soybean and maize harvest reducing subsurface drainage NO_3-N load from 51 kg ha^{-1} to 20 kg ha^{-1}. Since rye is winter-hardy, it is also able to accumulate and stabilize large amounts of soil NO_3-N in the spring.

In contrast to possible N benefits of legume cover crops, rye may reduce following maize yields if not terminated at least 15 days before maize sowing (Krueger et al., 2011). This could be due to reduced soil water, allelopathic effects, or maize seedling pathogens harbored in rye roots (Bakker et al., 2016).

Other ecosystem services

Due to their N_2 fixation, legumes provide other ecosystem services by reducing the amount of synthetic N that needs to be applied. According to Kopke and Nemecek (2010) in Switzerland, they save energy by reducing the amount of mineral N that needs to be applied in cereal systems. Just for manufacturing and transport, up to 16.1 kg of CO_2 equivalent of greenhouse gases (GHG) are emitted per kg of N produced. In today's most efficient fertilizer plants 1 kg of mineral N is equivalent to at least 1 L of diesel fuel. With faba bean grain yield of

4 Mg ha^{-1}, enough symbiotically-fixed N_2 is produced to equal 180 L of diesel fuel, or offset 480 kg of CO_2 emissions. Consequently, the use of legumes reduces GHG emissions and ozone degradation. As with many other cover crops, the use of legumes can also reduce acidification and eutrophication by enhancing soil porosity, also improving soil macro and microbiological activity, and reducing nutrient leaching and run off (Kopke and Nemecek, 2010).

Late-season cattle grazing

The process of growing, harvesting, storing, transporting, and feeding make owning cattle a costly and time-intensive practice in the winter. In beef cattle production, feed is the costliest part of the operation (Lawrence and Strohbehn, 1999). Another costly part of feeding in a feedlot, is the spread of diseases (Strauch, 1991). Manure can contain bacteria, viruses, parasites, yeasts, and fungi that can be harmful to both humans and cattle. Even clinically healthy animals may be excreting these pathogens (Strauch, 1991). There are multiple treatments that can be used to sanitize sewage sludge with varying degrees of effectiveness, which typically reduce the amount of pathogens, but do not eliminate them (Strauch, 1991). Wheat harvested in August in the upper Midwest leaves ample time for grazing of residue and cover crop growth throughout the fall and into winter. Spreading cattle out to graze, and effectively reducing the manure concentration in an area, could be a good way to help ensure cattle health, along with reducing the need for manure management. In addition, spring calving can be done on green rye which avoids muddy conditions while reducing diseases.

Both maize and cattle are important agricultural commodities in the U.S. as a whole and in the state of North Dakota. In 2017, 1.4 million hectares of maize were sown and there were a reported 1.81 million cattle in North Dakota (NASS, 2016). Many times, these two commodities are being raised in the same area and cattle are able to graze the maize stalks after harvest which occurs anytime between October and December. Typically, cattle begin grazing maize residue from late October to mid-November and may continue through February (McGee et al., 2013). This keeps cattle out of the feedlot later into fall and provides for cheaper feed. However, cattle's protein requirements cannot be fulfilled by grazing post-harvest maize residue alone (Wilson et al., 2004), thus intersown forage crops could be an important supplement. The husk and leaf of maize residue have high palatability, but only make-up 39% of the total residue with a weighted average of 65 g CP kg^{-1}. Stalks and cobs make up the rest of the residue and have low palatability and fiber digestibility, typically averaging 40 g CP kg^{-1} (Wilson et al., 2004). Consequently, cattle will likely only eat stalks and cobs once the more palatable plant parts are gone. Wilson et al. (2004) found that the average total digestible nutrients of maize residue consumed could range from 50-60%. Utilization rate of maize residue increased with stocking rate when grazed by growing cattle, and 65-72% of utilized residue was leaf and husk (Fernandez-Rivera and Klopfenstein, 1989). Reducing stocking rates can significantly increase cattle weight gain (Wilson et al., 2004).

Forage quality of annual legumes

Faba bean has been used as forage in other countries, usually in mixture with oat, triticale (*Triticosecale* Witt.), or barley. Forage yield of oat-faba bean and triticale-faba bean mixture fluctuated between 10 and 22 Mg ha^{-1} and forage CP yield ranged between 1.0 and 3.3 Mg ha^{-1} in studies conducted in Greece (Dordas and Lithourgidis, 2011; Dhima et al., 2014). Faba bean-barley mixture was evaluated in comparison with sole barley or other legumes in Canada. Faba bean mixture had higher CP than sole barley and barley-pea mixture (Strydhorst et al., 2008) and silage maize-faba bean than sole maize (Stoltz and Nadeau, 2014). Similarly, faba bean silage had the highest CP (220 g kg^{-1}) content compared with pea (178 g kg^{-1}), and soybean (197 g kg^{-1})

silage (Mustafa and Seguin, 2003), thus faba bean may be a superior forage for grazing. Lambs (*Ovis aries* L.) grazing on faba bean grew significantly faster (220 g head^{-1} day^{-1}) than lambs grazing field pea (186 g d^{-1}), or lupin (166 g d^{-1}) (Warner et al., 1998).

There are significant differences in both biomass quantity and quality between faba bean cultivars. Wegi et al. (2018) reported that biomass yield of five cultivars ranged from 3.3 to 5.1 Mg ha^{-1}. When 70% faba bean biomass were mixed with 30%, 2:1 wheat bran and niger (*Guizotia abyssinica* L.) seed cake and fed to Arsi-Bale sheep, crude protein digestibility ranged from 475 to 619 g kg^{-1}, and average daily gain of the sheep ranged from 38 to 65 g d^{-1} (Wegi et al., 2018). Large differences can also be seen in quantity and quality at different plant stages of forages. When comparing faba bean with forage pea, Iglesias and Lloveras (1998) found that faba bean produced more forage yield at pod fill than at initial flowering, but pea produced more forage than most other cool-season legumes at earlier stages of development. Wichmann et al. (2005) also found that pea had faster dry matter accumulation than faba bean or lupin.

Pea grown in the upper Midwest and harvested for forage at maturity produced 5.1 Mg ha^{-1} at 150 g kg^{-1} water content with 170 g kg^{-1} of CP. Pea can also be intersown with a grass such as barley or oat. Adding a grass to pea can increase hay yields to 5.7 Mg ha^{-1} when intersown (Anderson and Ilse, 2012). When comparing forage and semi-leafless pea, forage pea was found to have higher CP forage yield (Soto-Navarro et al., 2012) and averaged higher DM yield than semi-leafless pea cultivars (Uzun et al., 2005; Turk and Albayrak, 2012). According to Anderson and Ilse (2012), freshly weaned calves preferred pea and pea-barley hay over grass hay. Calves were fed these hays at 30% forage in a 121 Mcal net energy for gain kg^{-1} (NEg) ration made-up of barley, maize, distiller's grains, and supplements for two months. This was followed by a 3.5-month finishing period of 15% forage in 137 Mcal NEg rations. Calves on pea and pea-barley forage gained 304 g d^{-1} and 240 g d^{-1}, respectively, more than calves on rations with grass hay alone; making pea hay worth 230% of the grass hay. Due to the high CP in legume forages leading to possible digestion issues, Amiri and Shariff (2012) concluded that a combination of legume and grass species is a way to provide the needed feeding and protein requirements to grazing livestock without the risk of bloating.

Mixtures of timothy (*Phleum pratense* L.), red clover, and alsike clover (*Trifolium hybridum* L.) are commonly grown in Atlantic Canada for forage. Red clover was shown to be a good competitor when grown with timothy, making up 75% of the biomass in the first growing season, with the mixture yielding 8.79 t ha^{-1} and containing 28 g kg^{-1} of N (Kunelius et al., 2006). Red clover CP ranges from 110 to 250 g kg^{-1} across harvest times and different soil types (Wiersma et al., 1998; Broderick et al., 2000; Ovalle et al., 2006). Pure red clover stands have been found to produce 2 to 5 Mg ha^{-1} of biomass (Ovalle et al., 2006; Ross et al., 2009). Adding red clover to grass silage increased feed intake and milk production of dairy cattle (Bertilsson et al., 2002). Red clover silage fed to cattle led to 0.2 kg d^{-1} weight gain in Holstein cattle, when alfalfa (*Medicago sativa* L.) silage led to a 0.13 kg d^{-1} weight decrease. Balansa clover N content can range from 21 to 57 g kg^{-1} (Dear et al., 2003; Fraser et al., 2004; Ovalle et al., 2006), consistently having one of the highest N contents and biomass production of six forage legumes tested by Ovalle et al. (2006).

Although rye is not a legume, it also produces biomass rich in N with concentrations averaging 38 g N kg^{-1} when broadcast intersown into maize and soybean (Wilson et al., 2013). Rye is typically a less digestible forage than legumes, but has good grazing value as it may be grazed in late fall and spring due to its winter annual growth. Grazing is best done while the plant is still in vegetative stages due to digestibility of rye biomass rapidly decreasing with the advance of growth stages (Keles et al., 2016). Rye is able to produce high quality hay when in its boot stage (Clark, 2007).

Intersowing

Intersowing is sowing crops into an already established cash crop, and it is important for implementing cover crops into a maize-soybean rotation where the growing season is too short for them to be established after harvest. In the upper Midwest, the growing season is not long enough to establish cover crops after maize is harvested, making intersowing the best option. Baributsa et al. (2008) found that using reduced maize sowing densities can significantly increase intercrop biomass when using red clover and chickling vetch (*Lathyrus sativus* L.). When legume species were sown at the same time as maize, maize yields were reduced 43 to 69% by the legumes when weeds were not controlled, and 0 to 35% depending on legume when weeds were controlled (Alford et al., 2003). It was also found that legume production was 57% higher when weeds were controlled. Legumes did not suppress weed growth, showing that weed control is still essential when intersowing. This also makes intersowing a better option compared with sowing cover crops at the same time as a cash crop because there is time to control weeds before cover crops are sown (Alford et al., 2003). Multiple reports have concluded that intersowing does not affect maize grain yield when done after the V5-V8 growth stage, when side dressing fertilizer is common (Baributsa et al., 2008; Noland et al., 2018). However, Ruffatti et al. (2019) found maize yield reduction of 7 to 22% in some environments when intersown in early September.

Intersown cover crop establishment typically ranges from June to October. In a study done in 1987 at the Agronomy Research Farm in Aurora, NY, cover crops intersown on 19 June produced more biomass than cover crops intersown on 1 August when maize was at mid-silk.

Fisher et al. (2011) also concluded that earlier intersowing dates were better for winter cover crops with earlier intersowing dates consistently accumulating more N than later sowing dates. It was also found in a study in Wyoming that when multiple sowing dates were used, the earliest sowing date (2 September) produced the greatest amount of above ground biomass and decreased thereafter. Using the more productive intersowing date, it was determined that the grazing season could be extended 6 to 12 days (Meeks et al., 2016).

Intersowing cover crops into standing maize can be done a few ways, most commonly through aerial sowing (Noland et al., 2018). Aerial broadcasting allows for multiple field conditions and sowing into various maize growth stages, but typically relies on rainfall soon after broadcasting, and limits what crops can be sown. Wilson et al. (2013) concluded that precipitation within a week after broadcasting rye was essential for establishment, accounting for 43% of the difference in biomass between environments. Significant rainfall soon after sowing was also concluded to be crucial for a successful establishment by multiple other studies (Clark, 2007; Fisher et al., 2011). Methods involving incorporation after broadcasting cover crops were found to have consistently better establishment by Fisher et al. (2011). Noland et al. (2018) compared different intersowing methods including broadcast, broadcast with light incorporation, and high-clearance drilling of intercrops with varying seed sizes at the V7 maize stage. Large-seeded intercrops like rye, pea, oat, and hairy vetch (*Vicia villosa* Roth) saw the most benefits from being drilled. Small-seeded intercrops like red clover saw benefit from both drilling and broadcast with incorporation. Field pennycress (*Thlaspi arvensis* L.) establishment was similar for all intersowing methods evaluated (Noland et al., 2018). These results show that using a specialized high-clearance drill allows for intersowing of larger-seeded cover crops with better establishment, but this is limited to intersowing up to about V8 stage of maize, without damaging the standing crop. Hakansson et al. (2013) reported that seed size is correlated to optimum sowing depth, with larger seeds preferring deeper sowing depth, and Noland et al. (2018) had similar conclusions. Multiple studies have concluded that better seed to soil contact improves cover crop establishment (Boyd and Van Acker, 2003; Wilson et al., 2013), but Hakansson et al. (2013) and Noland et al. (2018) concluded that this is dependent on seed size. Noland et al. (2018) reported that drilling small seeds such as field pennycress can decrease their emergence if sown too deep.

Maize light interception can also play a large role in intercrop production. Reduced light under the maize canopy along with its influence on soil temperature (Starks, 1996) can affect seed germination. Maize canopies can intercept ≥80% of photosynthetically active radiation (PAR) between V12 and R4 (Gallo et al., 1985), leaving limited PAR for intercrops to convert into energy. Belfry and Van Eerd (2016) intersowed rye and hairy vetch into standing maize for seed production. This seed maize was de-tasseled before pollination, along with having male rows removed after pollination. This likely increased light penetration to the intercrops and achieved much higher intercrop biomass at maize harvest (Belfry and Van Eerd, 2016).

Red clover intersown on standing maize has been found to achieve yields of 70 to 4,800 kg ha^{-1} across different maize densities (Broderick et al., 2000), and 70 to 300 kg ha^{-1} at 75,000 maize plants ha^{-1} (Baributsa et al., 2008), while Noland et al. (2018) reported 30 to 115 kg ha^{-1} of red clover biomass across different intersowing methods. Ross et al. (2001) found that both red and balansa clover are competitive, reducing brown mustard [*Brassica juncea* (L.) Czern.] growth and regrowth when sown after cool-season cereals. Balansa clover has been shown to be a competitive forage legume in Australia by Dear et al. (2006), who found that it was one of the best legumes tested at suppressing herbicide-resistant annual ryegrass (*Lolium rigidum* L.), producing 1.3 Mg ha^{-1} biomass in just six weeks. When grown out for forage, balansa clover can range from 0.6 to 10.4 Mg ha^{-1} depending on climate, more often averaging 2 to 4 Mg ha^{-1} (Fraser et al., 2004; Ovalle et al., 2006; Ross et al., 2009; Neal et al., 2010).

Rye is a commonly used cover crop in the upper Midwest due to its winter hardiness and good establishment in adverse conditions. Noland et al. (2018) found that rye produced significantly more biomass when drill intersown (61 kg ha^{-1}) rather than broadcast or broadcast with incorporation (21 kg ha^{-1}), but there was no sowing method effect on amount rye biomass produced in the next spring. Rye also accumulated similar amounts of N to all other intercrops in the experiment including red clover and a mixture with oat, pea, and radish, with an overall average of 1.3 kg N ha^{-1} (Noland et al., 2018). Wilson et al. (2013) achieved similar broadcast intersown rye biomass with most sites yielding less than 50 kg ha^{-1}, but some sites produced up to 0.51 Mg ha^{-1}. Rye has been found to reach biomass yields of 0.72 Mg ha^{-1} (Belfry and Van Eerd, 2016) when intersown with maize for seed.

CHAPTER 2: LEGUME COVER CROPS AFTER WHEAT HARVEST

Abstract

Faba bean (*Vicia faba* Roth) is grown worldwide but is a new cover crop in Midwest farming systems. This study was conducted to determine faba bean late-season forage quality when sown after hard red spring wheat (*Triticum aestivum* L.) harvest, cover crop advantages, and the effect on the following spring crop. Faba bean, and field and forage pea (*Pisum sativum* L.) were evaluated for biomass and forage quality. Cover crop treatments averaged 1.3 Mg ha^{-1} biomass yield, enough to support 1.5 animal unit months (AUM) ha^{-1} for a 450 kg cow (*Bos taurus* L.) with calf. Crude protein was greatest in faba bean cv. 'Boxer' (304 g kg^{-1}) and least in field pea (264 g kg^{-1}). Cover crops had no effect on maize (*Zea mays* L.) the following season. Faba bean is a suitable Midwest cover crop, providing greater quality forage than other commonly used legumes.

Materials and Methods

Field establishment and experimental design

The experiments were conducted in 2017 and 2018 at two North Dakota State University (NDSU) research sites at Prosper, ND (-97°1143' W, 46°9997' N; 281-m elevation), and Hickson, ND (-96°8259' W, 46°6335' N; 281-m elevation). The soil type in Prosper is a Kindred-Bearden silty clay loam (Fine-silty, mixed, superactive frigid Typic Endoaquolls; Bearden: Fine-silty, mixed, superactive, frigid Aeric Calciaquolls), and the soil type in Hickson is a Hagne-Fargo silty clay loam (Hagne: Fine, smectitic, frigid Typic Calciaquerts; Fargo: Fine, smectitic, frigid Typic Epiaquerts) (Web Soil Survey, 2017). Daily temperature and rainfall were monitored by the North Dakota Agricultural Weather Network (NDAWN) stations nearest to each site.

The experimental design was a randomized complete-block design with four replicates, sown at two environments in August of 2017 and 2018 after the harvest of 'Glenn' wheat (*Triticum aestivum* L.). Wheat was grown during the season and cover crops were sown after wheat harvest. Wheat was drilled using a Great Plains 15-cm row space planter (Great Plains, Salinas, KS) at 4,450,000 pure live seeds (PLS) ha^{-1} on 25 April 2017 and 2 May 2018 in Hickson, and on 20 April 2017 and 15 May 2018 in Prosper. Wheat in Hickson was fertilized with 88 kg N ha^{-1} and 24 kg P_2O_5 ha^{-1} both years and Prosper was fertilized with 90 kg N ha^{-1} of N and 17 kg P_2O_5 ha^{-1} both years. Wheat was harvested with on 8 August 2017 and 9 August 2018 in Hickson, and on 5 August 2017 and 8 August 2018 in Prosper.

Cover crop treatments included five faba bean (*Vicia faba* Roth) cultivars (Fanfare, Boxer, Laura, Snowdrop, and Tabasco), two pea (*Pisum sativum* L.) cultivars (Arvika forage pea and Nette semi-leafless field pea), and one check plot without cover crop. After wheat (*Triticum aestivum* L.) harvest, a leaf blower (BR 200, Stihl, Waiblingen, Germany) was used to clear extra wheat chaff from the plots to ensure an even sowing depth of 4-cm. All seeds were treated with inoculant (*Penicillium bilaiae, Rhizobium leguminosarum*) (TagTeam, Monsanto Company, St. Louis, MO) at 6.1 kg ha^{-1} shortly before sowing. Cover crops were directly (no-till) sown with a plot drill (XL Plot seeder, Wintersteiger, Austria) into the wheat stubble on 22 August 2017 and 13 August 2018 in Hickson, and on 14 August 2017 and 16 August 2018 in Prosper (Table 1).

Each experimental unit had eight cover crop rows 15-cm apart and was 7.6-m in length. Prior to sowing, cover crop cultivars were tested for germination. Cover crops were sown at 150,000 pure live seeds (PLS) ha^{-1} and 67 kg ha^{-1} PLS for faba bean and pea, respectively. For faba bean, seeds for each plot were counted because of the variability of seed size among cultivars (Table 2). Besides a burn down application of glyphosate (*N*-(phosphonomethyl) glycine) (1.4 kg a.i. ha^{-1}) in both environments in 2018 to kill volunteer wheat before cover crop sowing, no herbicides or fertilizers were used on the cover crops.

Table 1. Sowing and harvest of cover crops with weather data at each environment.

Environment	Sowing date	Biomass harvest	Total rainfall†	Average temp	Coldest temp	Coldest temp date	GDD‡
			mm	----ºC ----			°C
Hickson 2017	22 August	26 October	81	14	-4	10 October	440
Hickson 2018	13 August	15 October	176	13	-7	11 October	436
Prosper 2017	14 August	25 October	161	14	-4	10 October	526
Prosper 2018	16 August	16 October	201	12	-11	12 October	409

† Total rainfall, temperature (temp), and growing degree days (GDD) measured from cover crop sowing to biomass harvest dates at each environment (mid-late August to mid-late October).
‡ Growing degree days calculated with 7ºC as the base temperature.

In the spring following these cover crops, Peterson Farm Seed 75K85 VT2PRO (85-day maturity) maize (*Zea mays* L.) was sown in 56-cm rows at a population of 79,262 plants ha^{-1} (MaxEmerge XP, John Deere, Moline, IL) on 10 May 2018 in Hickson and 15 May 2018 in Prosper on the previous year's cover crops plots. Each experimental unit was the same as the cover crop plots, consisting of three 56-cm maize rows 7.6-m in length. Maize was left unfertilized expecting to determine the difference in mineralization and release of N from the previous cover crop biomass. Glyphosate (*N*-(phosphonomethyl) glycine) (1.4 kg a.i. ha^{-1}) was applied throughout the season for weed control according to common practice.

Table 2. Seed weight and sowing rate of cover crop cultivars.

Crop	Cultivar	100-seed weight	Sowing rate
		g	PLS ha^{-1}
Faba bean	Fanfare	60.65	150,000
	Boxer	57.43	150,000
	Laura	57.73	150,000
	Snowdrop	35.28	150,000
	Tabasco	47.25	150,000
Field pea	Nette	19.17	350,000
Forage pea	Arvika	15.79	424,000

Plant sampling and analysis

Cover crop stand was recorded by counting 1-m^2 in each plot once emergence was determined to be finished. The percent area of ground coverage for all cover crops was determined before the first killing frost with the Canopeo © application (Canopeo, Oklahoma State University, Stillwater, OK) with pictures taken from 1-m above the canopy. Pictures were taken on 30 October 2017 in Prosper and 2 October 2018 in both Hickson and Prosper in 2018. Pictures from Hickson in 2017 were not available.

Shortly before the first expected killing frost, biomass samples were collected by clipping all aboveground biomass in 0.2-m^2 from each cover crop plot. This was done on 26 October 2017 and 15 October 2018 in Hickson, and 25 October 2017 and 16 October 2018 in Prosper. Carrying capacity of the cover crop biomass was calculated assuming 50% harvest efficiency using the NDSU Grazing Calculator Application (NDSU Grazing Calculator, North Dakota State University, Fargo, ND). The leaves and stems of the collected plants were separated, dried at 70°C until constant weight, and weighed to determine dry weight and leaf:stem ratio. In the calculation of this ratio, tendrils on the pea plants were counted as stems and stipules were counted as leaves, although tendrils are technically modified-leaves and stipules are leaf-like. The leaf:stem ratio was calculated this way because, tendril composition is similar to stem rather than leaf, while stipules are similar to leaves. After this was calculated, dried samples were ground to pass a 1-mm sieve with a mill (E3703.00, Eberbach Corporation, Bellville, MI).

Ground cover crop samples were analyzed using near-infrared reflectance spectroscopy (NIRS) with an XDS analyzer (Foss, Denmark) for N, P, and ash. Crude protein was calculated by multiplying N content by 6.25. Biomass N accumulation was calculated by multiplying the dry matter biomass yield by the total N content.

Maize was harvested on 24 October 2018 in Hickson and 18 October 2018 in Prosper (HP 5 combine, Almaco, Nevada, IA). A 7.6-m row from the center of each plot was harvested for grain yield. A 56-cm row maize harvester was not available, so cobs were removed by hand and placed into the 76-cm row maize harvester. Grain from each plot was tested for water content and test weight (Mini GAC 2500, Dickey-John, Auburn, IL). Before this, maize biomass yield was determined by cutting and weighing 1-m of maize row, 10-cm above the ground. After recording this weight, these plants were harvested for grain, but two were saved from each plot to determine harvest index. These two whole maize plants were dried at 70°C until constant weight. Maize cobs were separated by hand and shelled (SCS-2, Agriculex, Ontario, Canada). Dry grain and stover were then weighed separately. Harvest index was calculated using the equation:

$$Harvest\ index = \frac{dry\ grain\ weight}{total\ biomass\ weight}\ x\ 100$$

Maize grain and biomass were not analyzed for chemical composition since no significant differences were found in the other yield parameters tested.

Soil sampling and analysis

Composite soil samples were taken at 0- to 15-cm and 0- to 60-cm across each rep after wheat harvest (Table 3). Composite soil samples taken at the 0- to 15-cm depth were tested for soil pH, organic matter, P (Olsen et al., 1954), and K with the ammonium acetate method (Warncke and Brown, 1998) with a Buck Scientific Model 210 VGP Atomic Absorption Spectrophotometer (Buck Scientific, East Norwalk, CT). Composite soil samples taken from 0- to 60-cm depth were analyzed for NO_3-N using the Vendrell and Zupancic (1990) method. Composite samples were taken on 29 August in Hickson and 21 August in Prosper in 2017, and on 17 August in Hickson and 7 September in Prosper in 2018.

Table 3. Soil sample results taken after wheat harvest and before cover crop sowing at each environment.

Environment	pH†	Organic matter	Phosphorus	Potassium	NO_3-N‡
		g kg^{-1}	----- mg kg^{-1}	------	kg ha^{-1}
Hickson 2017	7.6	55	12	310	54.8
Hickson 2018	7.5	52	10	337	21.3
Prosper 2017	7.4	36	25	234	93.8
Prosper 2018	7.3	42	28	185	12.5

† pH, organic matter, P, and K, all sampled from 0-15 cm depth.
‡ NO_3-N sampled from 0-60 cm depth.

Soil samples were collected from each experimental unit after cover crop death in late fall. These soil samples were only analyzed for NO_3-N, from 0- to 60-cm depth. This was done on 3 November in both Hickson and Prosper in 2017, and 13 November in Hickson and 6 November in Prosper in 2018. The difference between the soil NO_3-N in the composite sample after wheat harvest and soil NO_3-N after cover crop harvest was considered the change in NO_3-N.

Soil samples were taken from each maize plot in the spring following cover crops at 0- to 60-cm and analyzed for NO_3-N on 8 June 2018 in both environments. Soil samples were also taken from each experimental unit at 0- to 60-cm and analyzed for NO_3-N after maize harvest on 13 November in Hickson and 6 November in Prosper in 2018. The difference between these spring and post-harvest soil NO_3-N samples in each plot was considered the change in NO_3-N. All evaluations were recorded for each plot of each replicate in all four environments.

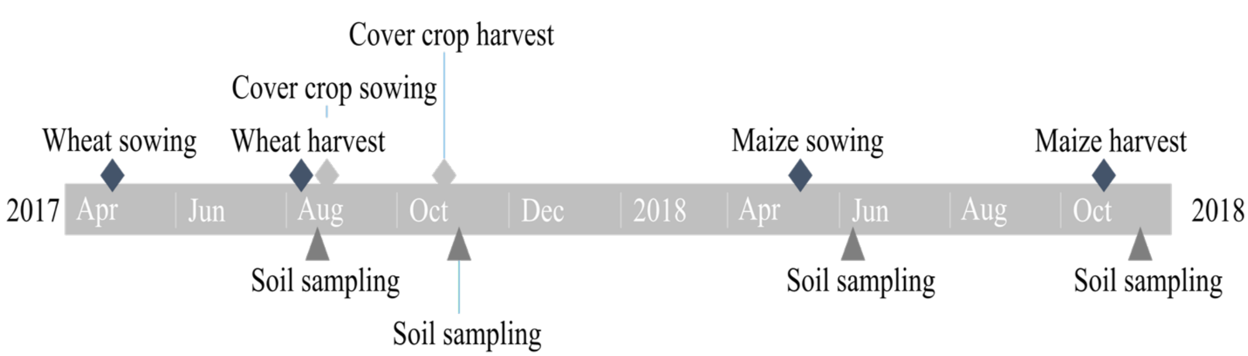

Figure 1. General timeline of sowing and harvesting of various crops and soil sampling throughout the experiment.

Statistical analysis

Statistical analysis was conducted using standard procedures for a randomized complete-block design. Biomass yield and forage quality data was analyzed using analysis of variance with the GLM procedure of SAS (version 9.4, SAS Institute, Inc. 2005). Each location-year was analyzed separately and tested for homogeneity of variances before combining them. Each location-year combination was considered an environment and a random effect, while cover crops and grain crops were considered fixed effects in the analysis. All interactions of fixed effects with environment were considered random in the analysis. The mean separation test was an *F*-protected least significant differences (LSD) ($P \leq 0.05$).

Results and Discuassion

Weather

Both 2017 environments received lower rainfall than the 30-yr average throughout the whole growing season except the month of September (Fig. 2A, 2B, Table 4). The Hickson 2017 environment, received 94 mm less rainfall than the 30-yr average in the late summer and fall from July through October, and the Prosper 2017 environment received 21 mm less rainfall than the 30-yr average from July through October (Fig. 2A). Prosper 2017, received 86 mm more rainfall than the 30-yr average in September relieving some possible water deficiency that had built up throughout the growing season (Fig. 2B). Hickson 2017, only received 6 mm of rainfall more than average in September making its total rainfall below average to be much higher than Prosper 2017. Despite their low rainfall, both of these environments had average temperatures throughout the growing season.

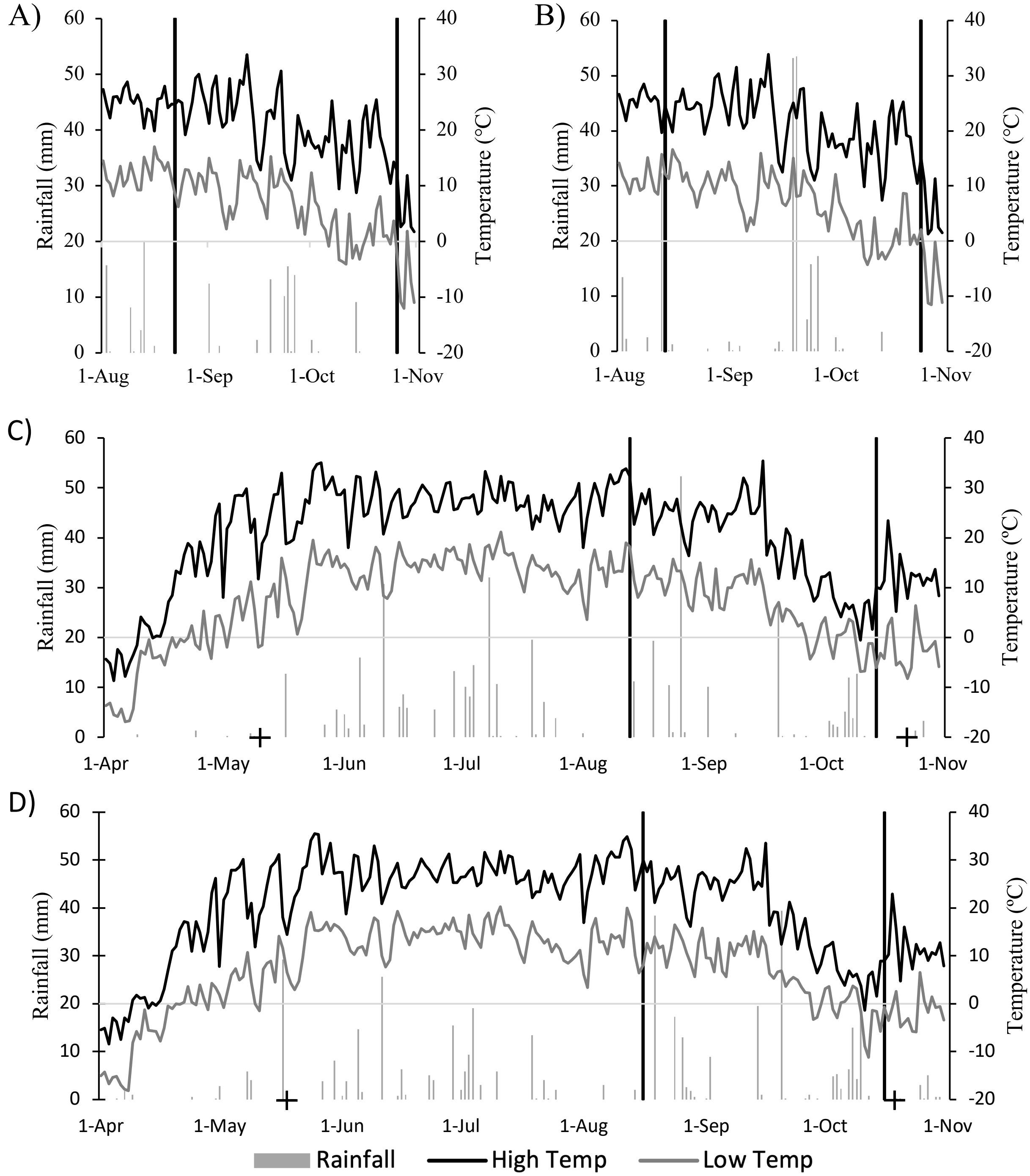

Figure 2. Temperature (recorded every 60 s) and rainfall in each environment, vertical black lines are cover crop sowing and harvesting dates, grey lines are individual rainfall events, and + symbols are maize sowing and harvesting dates in 2018.
A) Hickson 2017, B) Prosper 2017, C) Hickson 2018, and D) Prosper 2018.

Table 4. Total monthly rainfall, temperature, and difference from the 30-yr average for four environments at Hickson and Prosper, ND, in 2017 and 2018.

		Rainfall		Temperature			
Environment	Month	Total	±30-yr.†	Max	Min	Avg	±30-yr
		------- mm -------		----------------- ºC -----------------			
Hickson 2017	July	37	-46	29	14	21	0
	Aug	50	-13	25	12	18	-2
	Sept	69	6	22	9	15	0
	Oct	12	-41	15	0	8	0
Hickson 2018	Apr	2	-37	6	-5	1	-6
	May	22	-55	25	9	17	+3
	June	95	2	27	14	21	+2
	July	107	25	27	14	21	-1
	Aug	96	33	26	12	19	-1
	Sept	39	-25	21	7	14	-1
	Oct	46	-7	10	-2	4	-4
Prosper 2017	July	50	-38	28	14	21	0
	Aug	53	-14	25	11	18	-2
	Sept	152	86	22	8	15	0
	Oct	7	-55	15	0	8	0
Prosper 2018	Apr	4	-33	6	-6	0	-6
	May	54	-24	25	9	17	+3
	June	79	-21	27	14	20	+2
	July	65	-23	27	14	20	-1
	Aug	79	12	27	12	19	-1
	Sept	71	5	21	7	14	-1
	Oct	67	5	9	-1	4	-3

Weather data obtained from: https://ndawn.ndsu.nodak.edu/weather-data-monthly.html.
† 30-yr average temperatures based on 1981-2010 long-term averages (NDAWN, 2019).

Both 2018 environments also started with drier-than-average rainfall (Fig. 2C, 2D). Hickson 2018 received slightly above average rainfall in June through August, whereas Prosper 2018 received below average rainfall until August, where it received 12 mm above average, followed by 5 mm above average in both September and October. Along with a dry spring, both 2018 environments were 6ºC below average throughout April. In May and June, both environments had slightly above average temperatures, followed by slightly below average temperatures for the rest of the season.

Cover crop growth

Stand count of both pea cultivars averaged across environments was significantly higher than the faba bean cultivars ($P \leq 0.05$) (Table 5). There was no difference ($P > 0.05$) among any of the faba bean cultivars, showing that they all had equal emergence and growth; the same was true between the two pea cultivars. There was a significant ground coverage by environment interaction ($P \leq 0.05$) across three environments, data was not available for ground coverage in the Hickson 2017 environment. Forage pea cv. Arvika significantly ($P \leq 0.05$) covered the ground more than any other treatment across each of the three environments (Table 6). Field pea cv. Nette had the next most coverage but was always significantly less than 'Arvika'.

Table 5. Sources of variation (SOV), degrees of freedom (df), and trait mean squares for the combined analyses of cover crops (CC) of four environments (Env) for cover crop stand count, biomass, leaf:stem ratio, biomass chemical composition, N accumulation and ground cover in Hickson and Prosper, ND, in 2017 and 2018.

SOV	df	Stand count	Biomass	Leaf:stem ratio	Crude protein	P	Ash	N accumulation‡	df	Ground cover
Env	3	1236*	3542605*	3.76*	160.76*	0.0082*	21.45*	4908*	2	1233.38*
Rep(env)	12	395*	251304	0.06	15.23*	0.0002*	1.72	718	9	40.09*
CC	6	1442*	780830	3.99*	27.79*	0.0058*	36.72*	2019*	7	1539.07*
Env x CC	18	82	384383	0.17*	3.71	0.0001	3.72*	871*	14	273.18*
Error	72	58	233373	0.04	2.67	0.0001	1.41	454	63	7.27
CV%		28	40	12.72	5.66	2.08	18.42	39		13.45

* Significantly different ($P \leq 0.05$).
‡ N accumulated in cover crop shoot biomass.

Prostrate growth along with the higher sowing density of the pea cultivars led to their higher ground coverage. Faba bean cv. Snowdrop and Boxer had consistently low ground coverage (Table 6). The check plots had some weeds, explaining the coverage observed in check plots in both 2018 environments. In 2017, there was a large amount of uncontrolled volunteer wheat in the plots explaining the 14.1% average coverage in the check plot. This volunteer wheat, along with the pictures being taken later, and faba beans beginning to turn a darker color, led to the skewed coverage readings of cover crops in that environment. The ground cover from these cover crops could help decrease soil losses due to wind erosion, which according to Fryrear

(1985), can be reduced by 58% with just 20% ground cover. Though no-till management can greatly reduce soil erosion, there is still chance for interrill erosion which can be reduced by adding cover crops (Kaspar et al., 2001).

Table 6. Cover crop stand count for five faba bean and two pea cultivars averaged across four environments and ground coverage for each cultivar in three environments in Hickson and Prosper, ND, in 2017 and 2018.

		Hickson	Prosper	
Cultivar	Stand count	2018	2017	2018
	plants m^{-2}	------------ ground coverage (%) ------------		
Fanfare	19	23.0	12.1	19.1
Boxer	23	19.3	13.2	15.0
Laura	22	21.4	12.5	17.4
Snowdrop	21	19.4	12.3	12.0
Tabasco	22	26.1	14.2	15.3
Nette	40	40.9	15.2	23.7
Arvika	41	61.9	21.1	49.4
No cover check	0	1.1	14.1	1.3
LSD (*P* = 0.05)	7	---------------------- 3.8 ----------------------		

† Coverage in the no cover check corresponds to volunteer wheat in 2017 and weeds in 2018.

Cover crop biomass yield averaged across four environments was similar among all cultivars (Table 7). This shows that faba bean has the ability to produce similar amounts of above ground biomass as forage and field pea. This is in contrast to Iglesias and Lloveras (1998) who reported significantly greater biomass production with faba bean than forage pea. This is likely because of the short growing period of the cover crops in this study, whereas in Iglesias' study, cover crops were grown to maturity through a mild winter. Biomass yields averaged 1210 kg ha^{-1} and ranged from 957 to 1630 kg ha^{-1} (Table 7) across cultivars, but were not significantly different. 'Arvika' averaged 1630 kg ha^{-1}, which was similar to biomass yield reported from Iglesias and Lloveras (1998) and Wichmann et al. (2005). These researchers also indicated that at an earlier harvest, pea had higher biomass yield than other cool-season legumes such as lupin (*Lupinus angustifolius* L.), faba bean, and hairy vetch (*Vicia villosa* Roth). The differences in forage and field pea biomass align with findings from Uzun et al. (2005) and Turk and Albayrak

(2012) who reported leaved pea cultivars averaged higher dry matter yield than semi-leafless cultivars. The carrying capacity per hectare of the average biomass produced by cover crops in this study (1210 kg ha^{-1}) resulted in 1.5 animal unit months (AUM) ha^{-1} for a 450 kg cow and calf.

Table 7. Cover crop biomass yield and leaf:stem ratio averaged across four environments, Hickson and Prosper, ND, in 2017 and 2018.

Cultivar	Biomass yield	Leaf:stem ratio
	kg ha^{-1}	
Fanfare	1021	1.69
Boxer	1184	1.85
Laura	1190	1.82
Snowdrop	957	1.71
Tabasco	1320	1.69
Nette	1149	0.49
Arvika	1630	1.12
LSD (P = 0.05)	NS	0.31

All faba bean cultivars averaged across environments showed significantly higher ($P \leq$ 0.05) leaf:stem ratio than forage pea which had a significantly higher ratio than field pea (Table 7). This shows that the faba bean cultivars had a greater leaf:stem ratio than either pea cultivar. Alkhtib et al. (2016) found that faba bean has higher concentration of CP in the leaves than in stems, meaning that the higher leaf:stem ratio of faba bean would make them a high nutritive value forage. Forage pea had a greater number of leaves and stipules, but they were much smaller in size than faba bean leaves, giving it a lower leaf:stem ratio. Field pea is largely a vine plant and had only stipules that were counted as leaves contributing to its significantly lower leaf:stem ratio.

Leaf:stem ratio analysis also indicated a significant cover crop by environment interaction ($P \leq 0.05$) (Table 5). Faba bean in both 2018 environments generally attained a significantly higher leaf:stem ratio than faba bean from the 2017 environments (Table 8). Both field pea and forage pea also achieved greater leaf:stem ratio in 2018 than in 2017, although not always significant. Temperatures were slightly lower at both environments in 2018 than in 2017, with 2018 environments accruing less GDD throughout the life of the cover crop (Table 1). Cover crops were also harvested earlier in each environment in 2018 than in 2017. Rainfall, however, was higher at each 2018 environment than in was in 2017 environments (Fig. 2). This leads to the conclusion that rainfall may have been the limiting factor for producing leaves in this experiment.

Table 8. Environment by cover crop interaction of leaf:stem ratio in Hickson and Prosper, ND, in 2017 and 2018.

	Hickson		Prosper	
Cultivar	2017	2018	2017	2018
Fanfare	1.34	1.98	1.23	2.20
Boxer	1.59	2.29	1.27	2.23
Laura	1.73	2.19	1.20	2.16
Snowdrop	1.29	2.03	1.35	2.18
Tabasco	1.36	1.94	1.17	2.28
Nette	0.45	0.48	0.43	0.59
Arvika	0.97	1.13	1.02	1.38
LSD (P = 0.05)	-------------------------------- 0.26 --------------------------------			

Cover crop biomass chemical composition

All biomass chemical composition parameters evaluated were significantly different among cultivars ($P \leq 0.05$) (Table 5). ‘Boxer’ had the highest CP concentrations, but ‘Laura’ faba bean and ‘Arvika’ forage pea cultivars also had similar concentrations of CP (Table 9). ‘Nette’ field pea had significantly lower CP concentrations than any other cover crop treatment with 264 g kg^{-1}. Wichmann et al. (2005) also reported that faba bean contained more CP than pea. Faba bean cv. Fanfare, Tabasco, and Snowdrop all had significantly less CP than ‘Boxer’. Uzun et al. (2005), Strydhorst et al. (2008), and Soto-Navarro et al. (2012) reported that forage pea averaged higher CP forage yield than semi-leafless pea, and that faba bean had significantly more CP than field pea. This could be related to the leaf:stem ratio of the plants because Alkhtib et al. (2016) shows that leaves have a higher concentration of CP than stems. Legumes in this study were in vegetative stage at harvest, which explains their high CP concentration. Younger plants have been shown to have higher CP content than more mature plants (Turk and Albayrak, 2012). Crude protein concentration of typical legume forages, such as alfalfa (*Medicago sativa* L.), averaged 212 g kg^{-1} when cut at early bud stage (Lloveras et al., 1998).

Table 9. Cover crop biomass chemical composition averaged across four environments, Hickson and Prosper, ND, in 2017 and 2018.

Cultivar	Crude protein	Phosphorus	Ash
	---------------------------	g kg^{-1}	---------------------------
Fanfare	289	4.73	74
Boxer	304	4.83	77
Laura	297	4.76	75
Snowdrop	284	4.66	73
Tabasco	285	4.63	67
Nette	264	4.24	44
Arvika	298	4.57	42
LSD (P = 0.05)	14	0.08	14

Pea harvested in vegetative stages had better forage nutritive value than more mature plants (seed fill), with earlier harvests having higher CP, total digestible nutrients, and relative feed value (Turk and Albayrak, 2012). Crude protein concentration in all cover crops in this study were much above that needed by beef and dairy cattle (*Bos taurus* L.). A gestating beef cow in the mid-1/3 of pregnancy, weighing 540 kg requires about 10 kg of dry matter intake with 71 g kg^{-1} of crude protein (Lalman, 2017), so it is important to graze these legume cover crops along with an alternative source of fiber to increase the amount of dry matter, reduce CP concentration of cattle intake to maintain rumen stability, and avoid bloating (Lalman, 2017). This could be provided by wheat stubble and regrowth in the fall, along with supplying other low-CP dry hay.

Amiri and Shariff (2012) found that combining legumes and grass species provided proper nutrition requirements for grazing livestock. Pea grain and forage are known to cause bloat in ruminant animals because of their high protein content (Radostits et al., 2006). Faba bean contains condensed tannins, which are attributed to reduce bloating typical of other legume forages (Lees, 1992), meaning faba bean is more bloating-safe than pea. However, there are tannin-free faba bean cultivars available (Strydhorst et al., 2008) to increase digestibility of the grain for feed, which could lead to bloating issues in ruminant livestock.

Phosphorus concentration in the biomass was different among cultivars ($P \leq 0.05$), especially between faba bean and pea cultivars, with the greatest being 'Boxer' with 4.83 g kg^{-1} and the least being 'Nette' with 4.24 g kg^{-1}. Forage pea had significantly lower P concentration than all faba bean cultivars except for 'Tabasco', and field pea had significantly lower P than forage pea. These legume cover crops provided more than enough P for cattle, which need 1.4 g P kg^{-1} of feed (Lalman, 2017).

Ash was significantly greater ($P \leq 0.05$) in all faba bean cultivars than that of the pea cultivars (Table 9). This was likely due to the higher leaf:stem ratio of faba bean and the fact that leaves have higher ash content than the stem (Alkhtib et al., 2016). Overall, these ash concentrations (42-77 g kg^{-1}) are relatively low compared with the average ash concentration of a grass-legume mixture (90 g kg^{-1}), though the average ash in maize silage is only 50 g kg^{-1} (Hoffman, 2005).

Ash analysis also showed a significant ($P \leq 0.05$) cover crop by environment interaction (Table 5). The greatest concentration of ash was seen in 'Laura' faba bean in the Prosper 2018 environment, although it was not different than all other faba bean cultivars in that same environment. The least ash concentration was seen in 'Arvika' forage pea in the Hickson 2018 environment, but not different than pea cultivars at all other environments with exception of 'Nette' in Prosper 2017 (Table 10). Cover crops grown in the Prosper environments typically had higher ash concentrations than cover crops grown in the Hickson environments. Ash concentration was the same among most faba bean cultivars, with the exception of 'Tabasco' in 2018, which was significantly lower than many faba bean cultivars at all environments.

Table 10. Environment by cover crop interaction of ash content in Hickson and Prosper, ND, in 2017 and 2018.

	Hickson		Prosper	
Cultivar	2017	2018	2017	2018
	---------------------------------- g kg^{-1}	--------------------------------		
Fanfare	71.6	65.0	69.8	88.2
Boxer	76.2	66.9	79.7	86.9
Laura	63.7	62.3	75.0	97.4
Snowdrop	62.7	65.1	76.1	88.4
Tabasco	61.4	50.7	69.7	84.4
Nette	67.6	32.8	40.3	34.6
Arvika	48.5	30.6	44.4	43.4
LSD (P = 0.05)	-------------------------------- 16.7	--------------------------------		

No significant differences ($P \leq 0.05$) in N accumulation were found between cover crops averaged across environments (Table 5). 'Arvika' forage pea accumulated the greatest amount of N in its biomass with 76.8 kg N ha^{-1}, but was not significantly different than 'Snowdrop' faba bean which accumulated the least with 43.4 kg N ha^{-1} (Table 11).

Table 11. Environment by cover crop interaction and combined average across four environments of N accumulation in the shoot biomass of each cultivar in Hickson and Prosper, ND, in 2017 and 2018.

	Hickson		Prosper		
Cultivar	2017	2018	2017	2018	Combined
	--------------------------------- kg ha^{-1}	---------------------------------			
Fanfare	34.0	41.7	64.5	47.6	46.9
Boxer	55.1	42.8	90.2	39.2	56.9
Laura	38.8	49.7	91.2	49.1	57.2
Snowdrop	38.2	50.2	55.4	29.6	43.4
Tabasco	73.0	47.4	84.6	29.0	58.5
Nette	57.3	46.4	55.8	29.7	47.3
Arvika	105.1	71.3	66.1	64.8	76.8
LSD (P = 0.05)	------------------------- 30.0	-------------------------			NS

Analysis indicated that there was a significant ($P \leq 0.05$) N accumulation by environment interaction (Table 5). Nitrogen accumulation follows the same trend as biomass by environment (data not shown) with Prosper 2017 averaging the greatest, followed by Hickson 2017 and 2018, and Prosper 2018 averaging the least. These biomass and N accumulation averages follow the trend of the available NO_3-N in the soil at cover crop sowing in each environment. The lack of cover crop biomass by environment interaction suggest that available NO_3-N in the soil is not essential for biomass production, but that these cover crops are able to accumulate excess NO_3-N when it is available. The Prosper 2017 environment likely had the highest average N accumulation since it had the most growing degree days accumulated between cover crop sowing and harvest (Table 1), along with having the most NO_3-N in the soil at cover crop sowing (Table 3) allowing for the most crop growth. The greatest amount of N was accumulated by ‘Arvika’ forage pea with 105.1 kg ha^{-1} in Hickson in 2017 (Table 11), largely due to this environment having the highest ‘Arvika’ biomass yield although it was not significantly different from ‘Boxer’, ‘Laura’, and ‘Tabasco’ grown in Prosper in 2017. In general, the least N accumulation was seen in most cultivars at Prosper in 2018 (Table 11).

Soil residual NO_3-N

Soil residual NO_3-N was not significantly different among treatments at the end of the fall (Table 12), this was likely due to the short time they had to take NO_3-N up, but could also be due to the N_2 fixation of the legumes. No-cover crop check plots did average slightly, but not significantly, higher residual NO_3-N in the soil than that of cover crop plots (Table 13). Hauggaard-Nielsen et al. (2009) found that excess nutrients accumulate in cover crop biomass and can reduce nutrient leaching or loss through erosion throughout the fall, winter, and spring. Couedel et al. (2018) found that decrease in soil NO_3-N from legume cover crops grown during a fallow period ranged from 25 to 56%, with pea causing the most reduction.

Change in soil NO_3-N during the life of the cover crops was not significantly different between treatments (Table 12). Soil NO_3-N changes are mainly due to mineralization, leaching, and immobilization and the legume cover crops fixing some of the N that they accumulate. The least amount of change was seen in the check plot due to the lack of cover crop taking up soil nutrients.

Table 12. Sources of variation (SOV), degrees of freedom (df), and trait mean squares for the combined analyses of four environments (Env) for soil NO_3-N in the fall and change in soil NO_3-N in cover crops (CC) in Hickson and Prosper, ND, in 2017 and 2018.

SOV	df	Fall soil N	Change in soil N†
Env	3	6570*	16596*
Rep(env)	12	216	6714*
CC	7	34	34
Env x CC	21	193	193
Error	84	153	153
CV%		51	58

* Significantly different ($P \leq 0.05$).
† Change in soil NO_3-N from cover crop sowing to the first killing frost.

Table 13. End of season soil NO_3-N and change in soil NO_3-N throughout the life of the cover crop averaged across four environments, Hickson and Prosper, ND, in 2017 and 2018.

Cultivar	Soil NO_3-N	Change in NO_3-N†
	------------------ kg ha^{-1}------------------	
Fanfare	24.0	21.6
Boxer	23.8	21.7
Laura	22.1	23.4
Snowdrop	22.7	22.8
Tabasco	23.7	21.8
Nette	25.9	19.7
Arvika	24.7	20.9
Check	26.4	19.1
LSD (P = 0.05)	NS	NS

† Change in soil NO_3-N at 0- to 60-cm from cover crop sowing to biomass harvest.

Maize parameters in the growing season following legume cover crops

Grain water content at harvest was the only maize parameter that showed significant differences ($P \leq 0.05$) from cover crop treatments in the previous fall (Table 14). The no cover check plot had the greatest grain water content in the following year with 17.8 g kg^{-1} water at harvest. The lowest maize grain water content was after the 'Laura' faba bean cultivar (Table 15). There was no indication faba bean or pea cultivars had any other effect on maize in the season following the fall cover crops. Similarly, Hauggaard-Nielsen et al. (2009) reported that production of wheat in the spring was unaffected after fall-sown grass/clover mixture. However, when analyzing the maize grain yield response to residual soil NO_3-N after each cover crop in the spring, there was a slight response (r^2=0.30) (Fig. 3) where pea cultivars and the check plot had lower maize grain yield compared with the faba bean cultivars. This low response may also be due to low spring rainfall in 2018 (Fig. 2) which may have decreased the N mineralization rate in the soil.

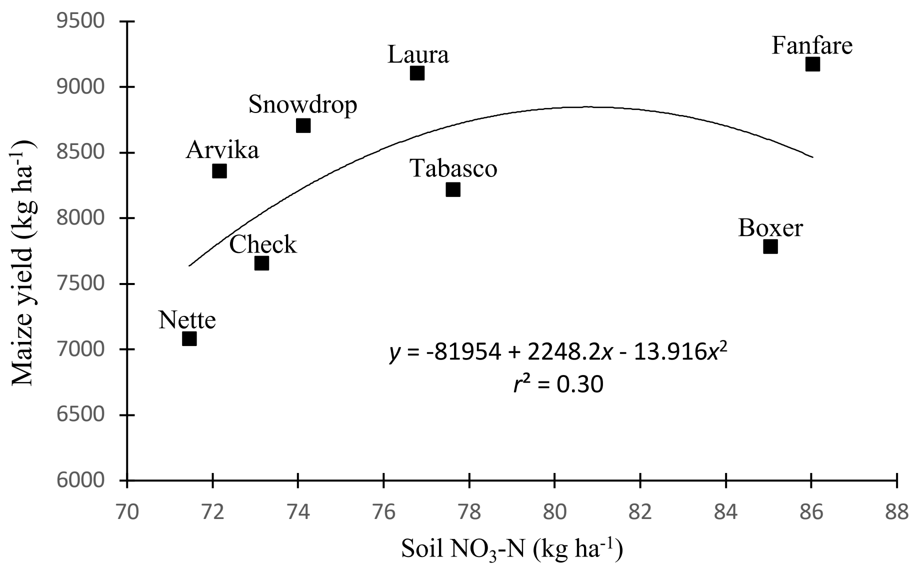

Figure 3. Interaction between soil NO_3-N from 0-60 cm in depth available in the spring following cover crops and maize grain yield averaged across two environments, Hickson and Prosper, ND, in 2018; interaction is not significant.

Higher maize yield in the year following forage pea, compared with the field pea was likely due to its higher leaf:stem ratio and greater N concentration; a response also reported by Lupwayi and Soon (2015). A higher N concentration, and likely reduced C:N ratio would allow faster mineralization of the nutrients in the faba bean biomass, leading to a slight boost in maize yield. This trial was not fertilized with N; thus, a slightly greater availability of soil NO_3-N could have made a difference in grain yield. Lupwayi and Soon (2015) indicated that forage pea released more N in the first year of decomposition than both field pea and faba bean.

Table 14. Sources of variation (SOV), degrees of freedom (df), and trait mean squares for the combined analyses of four environments of maize parameters following cover crops (CC) in Hickson and Prosper, ND, in 2018.

SOV	df	Harvest index	Spring soil NO_3-N	Fall soil NO_3-N	Change in soil NO_3-N	Stand count	Biomass yield	Test weight	Grain yield	Grain water content
Env	1	303.2*	297	465.5*	1506	0.39	165357096	29.40*	34546476*	182.93*
Rep(env)	6	54.9	2079*	88.8*	1929*	0.33	172877662*	5.53	12881421*	4.72*
CC	7	23.2	256	21.9	277	0.55	114880169	1.80	4276481	0.47*
Env x CC	7	11.2	552	56.6	694	0.25	71932004	2.02	4932007	0.09
Error	42	27.9	356	28.5	441	0.44	54408338	3.14	2806057	0.28
CV%		10.2	24	41.9	33	12.91	24	2.58	20	3.04

* Significantly different ($P \leq 0.05$).

Table 15. Parameters tested in maize for each cover crop treatment averaged across two environments, Hickson and Prosper, ND, in 2018.

Cultivar	Harvest index	Spring soil NO_3-N†	Fall soil NO_3-N	Change in soil NO_3-N	Stand count	Biomass yield	Test weight	Grain yield	Grain water content
	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	Plants m^{-1}	Mg ha^{-1}	kg hL^{-1}	Mg ha^{-1}	g kg^{-1}
Fanfare	54.1	86.0	11.8	74.3	5.1	33.6	68.6	9.1	171.5
Boxer	50.7	85.0	12.3	72.7	5.4	31.9	68.9	7.8	176.6
Laura	52.0	76.8	15.4	61.4	5.4	37.1	68.3	9.1	170.9
Snowdrop	52.1	74.1	14.2	60.0	5.3	28.3	69.6	8.7	174.3
Tabasco	54.6	77.6	13.9	63.8	4.6	25.1	68.4	8.2	173.4
Nette	51.1	71.5	12.9	58.6	5.0	28.0	68.7	7.1	172.1
Arvika	49.6	72.2	10.6	61.5	4.9	29.1	68.7	8.4	174.3
Check	50.9	73.1	10.9	62.2	5.3	32.4	68.0	7.7	177.8
LSD (P = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	3.5

† NO_3-N sampled from 0-60 cm depth

Conclusion

Faba bean, forage pea, and field pea all show potential as late-season cover crops and forage grazing due to their ability to produce biomass when sown after wheat harvest, and their high CP content. All cover crop treatments tested attained similar biomass accumulation and enough ground coverage to potentially reduce erosion. Peas provided more ground coverage though increasing faba bean sowing rate would likely increase biomass production and ground coverage more than increasing pea sowing rate due to the lower rate of the faba beans. On just these cover crops alone 1.5 AUM would be able to graze per hectare. Forage pea and faba bean provide better nutritive value than field pea because of their higher leaf:stem ratio and CP concentration, with faba bean having significantly better results than forage pea for each also. Faba bean cultivars had greater leaf:stem ratio than peas. This would likely lead to higher intake of faba bean than peas for grazing cattle. Condensed tannins in faba bean decrease risk of bloat in ruminants, whereas peas are a bloat risk. The cover crops did not lead to any significant differences in maize yield parameters in the following year. No differences were observed in grain yield in maize following cover crops. Faba bean residue turns black, which could lead to soils with faba bean heating faster in spring, compared with soils covered in light brown pea residue. There are multiple advantages to using these leguminous cover crops after wheat, with pea and faba bean having different advantages and disadvantages, though more research is needed on their residual nutrient effect on following crops.

CHAPTER 3: INTERSOWING COVER CROP INTO STANDING MAIZE

Abstract

Faba bean (*Vicia faba* Roth) is grown worldwide, but uncommon in Midwest farming systems. This study was conducted to determine growth and forage quality when intersown into maize (*Zea mays* L.). Faba bean, forage pea (*Pisum sativum* L.), balansa clover (*Trifolium michelianum* Savi), red clover (*Trifolium pratense* L.), and rye (*Secale cereale* L.) were evaluated when intersown into maize. Below average rainfall led to poor establishment of intercrops. Rye had the greatest biomass yield (374 kg ha^{-1}) followed by faba bean (319 kg ha^{-1}), forage pea (179 kg ha^{-1}), and red clover (123 kg ha^{-1}). Balansa clover had low survivability at all environments. The R4 sowing date averaged higher yields than V7 sowing date. Intercrops did not affect maize yield. Though intersowing offers many challenges difficult to overcome, faba bean is a potential option as an intersown cover crop.

Materials and Methods

Field establishment and experimental design

This experiment was conducted in 2017 and 2018 at two North Dakota State University (NDSU) research sites at Prosper, ND (-97°1143’ W, 46°9997’ N; 281-m elevation), and Hickson, ND (-96°8259’ W, 46°6335’ N; 281-m elevation). The soil type in Prosper is a Kindred-Bearden silty clay loam (Fine-silty, mixed, superactive frigid Typic Endoaquolls; Bearden: Fine-silty, mixed, superactive, frigid Aeric Calciaquolls), and the soil type in Hickson is a Hagne-Fargo silty clay loam (Hagne: Fine, smectitic, frigid Typic Calciaquerts; Fargo: Fine, smectitic, frigid Typic Epiaquerts) (Web Soil Survey, 2017). Daily temperature and rainfall were monitored by the North Dakota Agricultural Weather Network (NDAWN) stations nearest to each site.

The experiment was a split-plot randomized complete-block design with four replicates. The main plots were two different intersowing dates, V8 and R4 stages of maize (*Zea mays* L.), and sub-plots were five different cover crops: faba bean (*Vicia faba* Roth), forage pea (*Pisum sativum* L.), balansa clover (*Trifolium michelianum* Savi), red clover (*T. pratense* L.), and rye (*Secale cereale* L.). Peterson farm seed 72A91 VT2PRO (91-day maturity) maize was sown in 56-cm rows and at a population of 79,262 plants ha^{-1} (MaxEmerge XP, John Deere, Moline, IL). Maize sowing was done on 9 May 2017 and 4 May 2018 in Hickson, as well as on 11 May 2017 and 15 May 2018 in Prosper. In Hickson, maize was fertilized with 135 kg N ha^{-1} and 22 kg P_2O_5 ha^{-1} in 2017 and 2018. In Prosper, maize was fertilized with 180 kg N ha^{-1} and 18 kg P_2O_5 ha^{-1} in 2017 and 2018.

'Tabasco' Faba bean was intersown at 150,000 PLS ha^{-1}, 'Arvika' forage pea at 67 kg PLS ha^{-1}, 'Fixation' balansa clover at 9 kg PLS ha^{-1}, 'Dynamite' red clover at 13 kg PLS ha^{-1}, and 'Dylan' rye at 45 kg PLS ha^{-1} at two maize growth stages (V8 and R4); along with a check plot with no cover crop. Faba bean and forage pea were sown at 4-cm deep, rye and both clovers were sown at 1.5-cm. The V8 sowing date was on 27 June 2017 and 22 June 2018 in Hickson, and on 29 June 2017 and 28 June 2018 in Prosper. The R4 sowing date was on 21 August 2017 and 15 August 2018 in Hickson, and on 18 August 2017 and 22 August 2018 in Prosper.

Table 16. Growth cycle, 1000 seed weight, and seeding rate for each intercrop

Cultivar	Growth cycle†	1000 seed weight	Sowing rate
		g	PLS ha^{-1}
Faba bean	A	472.50	150,000
Forage pea	A	157.90	424,000
Balansa clover	A	2.09	4,310,000
Red clover	A/P	2.39	5,440,000
Rye	WA	17.37	2,590,000

† A – annual, P – perennial, WA – winter annual

Cover crops were sown by hand using a harrow with two blades 15-cm apart. Two furrows were made between the maize rows, 15-cm apart; seeds were spread by hand into the furrows which were closed after sowing with either a foot or a rake. This was done to mimic the use of a high-clearance intersowing drill developed by Amity Technologies (Fargo, ND) for the intersowing research in our project. Each experimental unit was four 56-cm wide rows of maize 7.6-m long, with two cover crop rows being sown between three sets of corn rows, and only being sown in 6.1-m in length to avoid the border effect. Each plot was separated by a pair of corn rows with no cover crops intersown in between.

Plant sampling and analysis

Stand was recorded once emergence was determined to be finished, typically two weeks or more depending on weather, after intersowing by counting two 1-m lengths in the center cover crop twin-row of each plot.

Photosynthetically active radiation (PAR) under the maize canopy and leaf area index (LAI) was measured every two weeks, as weather allowed, after intersowing using a light ceptometer (AccuPAR LP-80, METER Group Inc, Pullman, WA). The average of three readings was recorded from each plot. The readings were taken at approximately the same time of day from 12:00 to 4:00 PM at solar zenith, with sunlight unimpeded by clouds. Each reading was recorded by holding one light sensor above the maize canopy, and another sensor was held below the maize canopy, above the cover crop canopy. Readings were taken on 7 and 20 July, and 4, 17, and 30 August in both environments, along with one on 20 September in Hickson, and one on 17 October in 2017. In 2018, readings were taken on 31 July, 17 August, 6 September, and 5 October, along with an earlier reading taken on 15 July in Prosper.

Shortly before the first expected killing frost, intercrop biomass samples were collected by hand clipping all aboveground biomass in 0.2-m^2 from each plot. This was done on 30 and 31 October in Hickson in 2017, no intercrop biomass was collected in Prosper in 2017. In 2018, intercrop biomass was harvested on 16 October in both environments. Biomass samples were dried at 70°C until constant weight, and then dry weight was recorded. Carrying capacity of the cover crop and maize biomass was calculated assuming 50% harvest efficiency using the NDSU Grazing Calculator Application (NDSU Grazing Calculator, North Dakota State University, Fargo, ND). Dried samples were ground with a mill to pass through a 1-mm sieve (E3703.00, Eberbach Corporation, Bellville, MI).

Ground cover crop samples were analyzed using near-infrared reflectance spectroscopy (NIRS) with an XDS analyzer (Foss, Denmark) for N, P, and ash. Crude protein was calculated by multiplying N content by 6.25. Biomass N accumulation was calculated by multiplying the dry matter biomass yield by the total N concentration of each cover crop.

Plant height of maize was measured at the time harvest in 2017 by averaging three measurements from each plot. Height was not taken in 2018 due to a majority of maize plants having the tops broken off from late-season wind and rainfall. Maize grain and biomass yield were determined by harvesting the center-two rows of mature maize in each plot. Biomass yield and stand count were determined by cutting, counting, and weighing 1-m of maize row, 10-cm above ground from one of the two-center rows. After weighing, two whole maize plants were saved from each plot to determine harvest index. These samples were dried at 70°C until constant weight. Maize cobs were removed from the plant by hand and shelled (SCS-2, Agriculex, Ontario, Canada). Dry grain and stover were then weighed separately. Harvest index was calculated using the equation:

$$Harvest\ index = \frac{dry\ grain\ weight}{total\ biomass\ weight}\ x\ 100$$

Maize from the other center row of each plot was harvested for grain yield (HP 5 combine, Almaco, Nevada, IA). Grain from each plot was tested for water content and test weight (Mini GAC 2500, Dickey-John, Auburn, IL). Maize was harvested on 20 October in Hickson and 24 October in Prosper in 2017, and on 30 October in Hickson and 31 October in Prosper in 2018. Maize grain and biomass were not analyzed for chemical composition since no significant differences were found in the other yield parameters tested.

Soil sampling and analysis

Composite samples of each replicate were taken before each sowing date. Soil samples taken at the 0- to 15-cm depth were tested for soil pH, organic matter, P (Olsen, 1954), and K with the ammonium acetate method (Warncke and Brown, 1998) with a Buck Scientific Model 210 VGP Atomic Absorption Spectrophotometer (Buck Scientific, East Norwalk, CT). Soil samples were analyzed for NO_3-N from 0- to 60-cm using the Vendrell and Zupancic (1990) method (Table 17). Composite soil samples for the first sowing date were taken on 12 July in Hickson and Prosper in 2017, and 13 July at in Hickson and 10 August in Prosper in 2018. The second sowing date composite samples were taken on 29 August in Hickson and Prosper in 2017, and 17 August in Hickson and 4 September in Prosper in 2018.

Shortly following cover crop harvest, each experimental unit with harvestable intercrop biomass, along with check plots without cover crops, were sampled separately from 0- to 60-cm for only NO_3-N. This was done at both 2017 environments on 3 November, along with 14 November in Hickson, and 13 November in Prosper in 2018. The difference between the soil NO_3-N in the composite samples before each intersowing and soil NO_3-N after cover crop harvest samples was considered the change in NO_3-N.

Table 17. Soil sample results for each block and sowing date (SD) taken before intersowing in Hickson and Prosper, ND, in 2017 and 2018.

Environment	SD	pH†	Organic Matter	Phosphorus	Potassium	NO_3-N‡
			g kg^{-1}	------ mg kg^{-1} ------		kg ha^{-1}
Hickson 2017	V8	7.2	64	21	291	240
	R4	7.1	58	24	332	178
Hickson 2018	V8	8.0	53	10	281	14
	R4	7.7	53	11	344	15
Prosper 2017	V8	6.4	40	47	334	127
	R4	6.4	35	40	300	59
Prosper 2018	V8	6.7	46	45	304	97
	R4	6.3	39	36	278	66

† pH, organic matter, P, and K, all sampled from 0-15 cm depth.
‡ NO_3-N sampled from 0-60 cm depth.

In 2017, soil samples were taken in the first sowing date from 0- to 7-cm in depth to determine gravimetric water content of the soil. These samples were taken on 12 July and 3 August in both environments. Wet weight of these samples was recorded and then the samples were oven dried at 105ºC until constant weight (24-48 h). The oven dry weight was recorded, and gravimetric soil water content was calculated with the equation:

$$Gravimentric\ water = \frac{wet\ soil\ with\ tin - dry\ soil\ with\ tin}{dry\ soil\ with\ tin - tin\ weight} x100$$

Statistical analysis

Statistical analysis was conducted using standard procedures for a split-plot randomized complete-block design. Data was analyzed using analysis of variance with the MIXED procedure of SAS (version 9.4, SAS Institute Inc., 2005) by each location and year, and homogeneity of variances was tested before combining them. Each location-year combination was considered an environment and a random effect, while cover crops and grain crops are considered fixed effects in the analysis. All interactions of fixed effects with environment were considered random in the analysis. The mean separation test used was an *F*-protected least significant differences (LSD) ($P \leq 0.05$).

Results and Discaussion

Weather

Both 2017 environments received lower rainfall than the 30-yr long-term average throughout the whole growing season except the month of September (Table 18). The Hickson 2017 environment received 213-mm less rainfall than the 30-yr average from April through October, and the Prosper 2017 environment received 114-mm less rainfall than the 30-yr average from April through October. Prosper 2017 received 86-mm more rainfall than the 30-yr average in September relieving some possible water deficiency, but not enough to save many of the already dead intercrops. Hickson 2017 only received 6-mm of rainfall more than average in September, making its total rainfall deficit to be much greater than that of Prosper 2017. Despite their low rainfall, both of these environments had close to 30 yr-average temperatures throughout the growing season. This low rainfall is likely the reason for the loss of all intercrops at the Prosper 2017 environment.

Both 2018 environments also started with drier-than-average springs (Fig. 2C, 2D, Table 18). Hickson 2018 received slightly above average rainfall in June through August, whereas Prosper 2018 received below average rainfall until August where it received 12-mm above average, followed by 5-mm above average in both September and October. Along with a dry spring, both 2018 environments were 6ºC below average throughout April. In May and June both environments had slightly above average temperatures, followed by slightly below average temperatures for the rest of the season.

Table 18. Total monthly rainfall, temperature, and deviation from the 30-yr average for four environments at Hickson and Prosper, ND, in 2017 and 2018.

		Rainfall		Temperature			
Environment	Month	Total	±30-yr.†	Max	Min	Avg	±30-yr.
		------- mm -------		----------------- ºC -----------------			
Hickson 2017	Apr	28	-10	14	0	7	-1
	May	22	-55	21	6	13	-1
	June	39	-54	27	11	19	0
	July	37	-46	29	14	21	0
	Aug	50	-13	25	12	18	-2
	Sept	69	6	22	9	15	0
	Oct	12	-41	15	0	8	0
Hickson 2018	Apr	2	-37	6	-5	1	-6
	May	22	-55	25	9	17	+3
	June	95	2	27	14	21	+2
	July	107	25	27	14	21	-1
	Aug	96	33	26	12	19	-1
	Sept	39	-25	21	7	14	-1
	Oct	46	-7	10	-2	4	-4
Prosper 2017	Apr	17	-20	13	0	7	0
	May	17	-61	21	6	13	0
	June	88	-12	26	12	19	0
	July	50	-38	28	14	21	0
	Aug	53	-14	25	11	18	-2
	Sept	152	86	22	8	15	0
	Oct	7	-55	15	0	8	0
Prosper 2018	Apr	4	-33	6	-6	0	-6
	May	54	-24	25	9	17	+3
	June	79	-21	27	14	20	+2
	July	65	-23	27	14	20	-1
	Aug	79	12	27	12	19	-1
	Sept	71	5	21	7	14	-1
	Oct	67	5	9	-1	4	-3

Weather data obtained from: https://ndawn.ndsu.nodak.edu/weather-data-monthly.html.
† 30-yr average temperatures based on 1981-2010 long-term averages (NDAWN, 2019).

Photosynthetically active radiation (PAR)

Photosynthetically active radiation intercepted by the maize canopy seemed to plateau in late July at around 90% across all environments (Fig. 4A). Gallo et al. (1985) also reported that maize canopies can intercept more than 80% of PAR. Maize PAR interception began to decline in mid- to late-September but was still greater than 80% in early October. Leaf area index of the maize peaked in early August when it ranged from 5 to 7 across environments (Fig. 4B). Maize LAI consistently decreased after this peak across environments. This shows that intercrops sown at both dates received less than 20% PAR throughout the season, leading to slow growth.

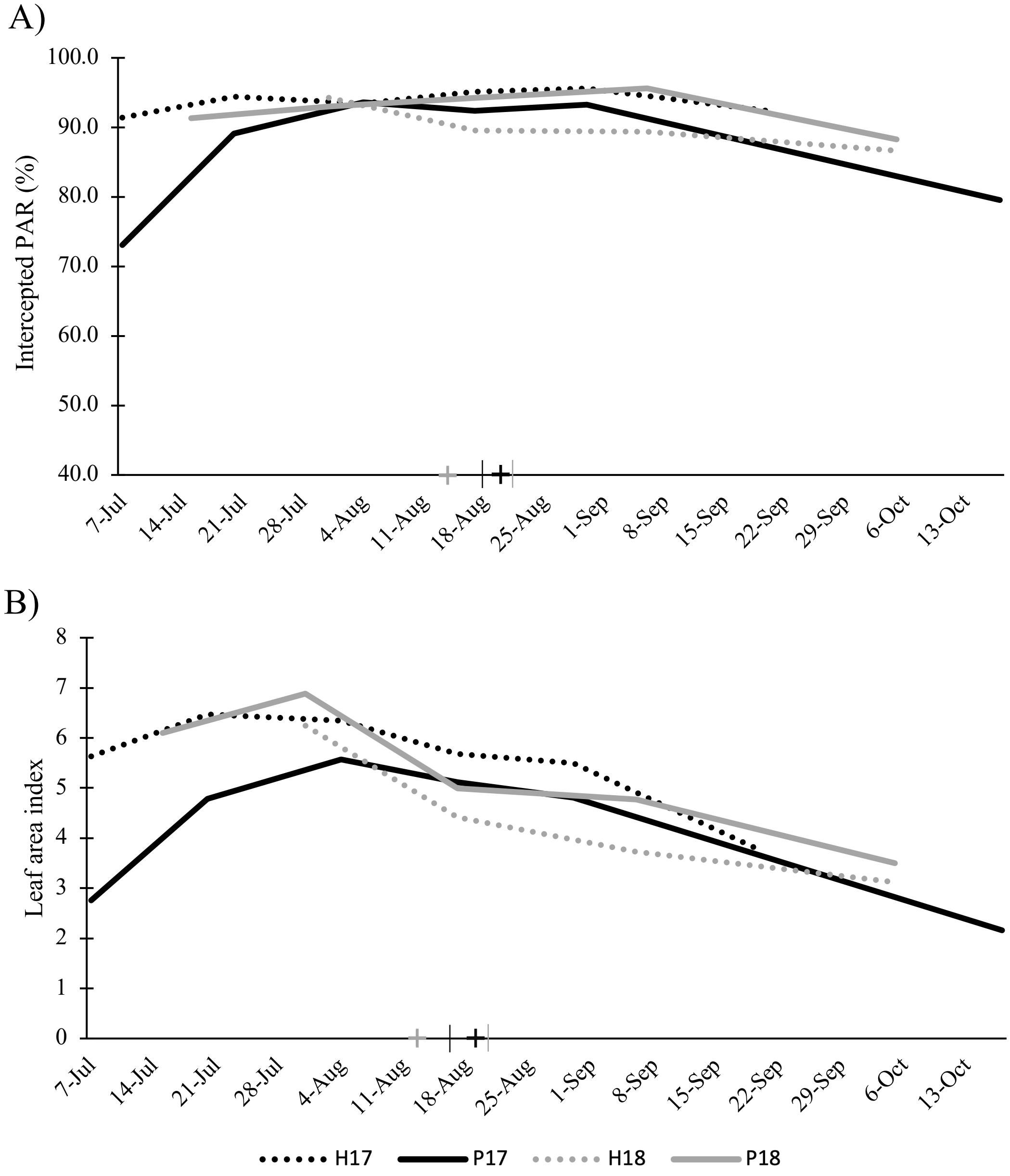

Figure 4. A) PAR intercepted by maize canopy and B) LAI of maize measurements at each environment throughout the life of the intercrop in Hickson (H) and Prosper (P), ND, in 2017 (17) and 2018 (18).
Symbols represent cover crop intersowing R4 dates:
+ Hickson 2017 + Hickson 2018 │ Prosper 2017 │ Prosper 2018.

Maize stand count, biomass yield, harvest index, grain water content, grain yield and plant height

Maize stand count and biomass both showed significance between sowing dates ($P \leq 0.05$) (Table 19). No other parameters tested in maize indicated significant differences for main fixed effects. This includes plant height, harvest index, grain water content, test weight, and grain yield, showing that intersowing cover crops at the V8 and R4 stages of maize does not affect any yield parameters of the crop.

Table 19. Sources of variation (SOV), degrees of freedom (df), and trait mean squares for the combined analyses of sowing dates (SD), cover crops (CC), and four environments (Env) of maize parameters when intersown with cover crops in Hickson and Prosper, ND, in 2017 and 2018.

SOV	df	Stand count	Biomass yield	Harvest index	Grain water	Test weight	Grain yield	df	Plant height†
Env	3	5.50*	950969108*	70.50*	96.98*	124.1*	98871499*	1	0.347*
Rep(env)	12	1.01	40553806*	11.07*	4.72*	14.2	3822640*	6	0.031*
SD	1	1.60*	93727822*	0.56	0.19	18.4	2234689	1	0.013
Env x SD	3	0.15	4705515	0.81	0.86	15.0	840144	1	0.006
Env x rep x SD	12	2.30*	65479103*	10.69*	2.08*	19.9	1559457	6	0.054*
CC	5	1.41	5136092	5.93	0.64	7.3	1318674	5	0.003
Env x CC	15	0.93	10614519	5.39	0.51	8.6	1787098	5	0.008
CC x SD	4	1.83	15220211	3.94	0.37	13.0	3064889	4	0.008
Env x CC x SD	12	1.49	9253765	2.17	0.56	8.7	2494360	4	0.010
Error	108	1.22	13936371	5.50	1.06	11.9	2062961	54	0.005
CV%		11.17	11	4.16	5.63	5.2	12		3.143

* Significantly different ($P \leq 0.05$).

† Height only taken in Hickson and Prosper 2017 environments.

Stand count was significantly higher in the late sowing date (9.98 plants m^{-1}) than the early sowing date (9.74 plants m^{-1}) (data not shown). Since these two stand counts are so similar overall it is unlikely that it was truly a consequence of the intercrops. Maize biomass yield averaged 33.7 Mg ha^{-1} in the late sowing date and significantly less in the early sowing date at 32.4 Mg ha^{-1} (data not shown). This could be due to intercrops sown early may have competed with maize for water and nutrients, enough to reduce the biomass yield, but not enough to affect overall grain yield. Maize grain yield average was 11.7 Mg ha^{-1} with test weight averaging 67 kg hL^{-1} (Table 20).

Table 20. Maize parameter means when intersown with cover crops averaged across four environments in Hickson and Prosper, ND, in 2017 and 2018.

Cover crop	Stand count	Biomass yield	Harvest index	Grain water†	Test weight	Grain yield	Plant height
	Plants m^{-1}	Mg ha^{-1}	%	g kg^{-1}	kg hL^{-1}	Mg ha^{-1}	m
Faba bean	5.1	32.84	56.2	184	67.24	11.56	2.19
Forage pea	4.9	33.54	56.8	184	66.86	11.76	2.17
Balansa clover	4.8	32.88	57.0	182	66.03	11.76	2.17
Red clover	4.8	33.13	56.1	183	67.11	11.81	2.17
Rye	5.1	33.49	56.4	181	67.36	11.44	2.20
Check	5.0	33.00	55.7	182	67.10	12.05	2.16
LSD (P = 0.05)	NS	NS	NS	NS	NS	NS	NS

† Grain water content was measured at harvest.

Intercropped cover crops biomass yield

Combined analysis across three environments showed significance between cover crops along with significant environment by sowing date, environment by cover crop, cover crop by sowing date, and environment by cover crop by sowing date interactions ($P \leq 0.05$) (Table 21). The significant environment related interactions were likely due to differences in cover crop biomass yield caused by dissimilar rainfall after sowing.

There were significant differences ($P \leq 0.05$) in the stand count of intersown cover crops (Table 21), due to their different sowing densities. Red and balansa clover were sown at the highest densities due to their small seed size. Red clover had higher stand count than any other cover crop and was sown at the highest density. Balansa clover was sown at the second highest density, but had significantly less stand than red clover and similar emergence to rye. This shows that balansa clover may not be as well suited as red clover for intersowing as it showed low emergence in this study. Forage pea and faba bean had similar stand counts and had lower stand than all other intercrops due to their lower sowing density.

Table 21. Sources of variation (SOV), degrees of freedom (df), and trait mean squares for the combined analyses of sowing dates (SD), cover crops (CC), and three environments (Env) for stand count, biomass yield, N accumulation, and biomass chemical composition of cover crops in Hickson and Prosper, ND, in 2017 and 2018.

SOV	df	Stand count	df	Biomass yield	N accumulation	df	P	Ash	Crude protein
Env	3	15476*	2	480176*	789*	2	0.0032*	95.7	21.28*
Rep(env)	12	167	9	9393	11	9	0.0040*	1.0	1.01
SD	1	4917	1	258960	1164	1	0.0032	24.5	52.13*
Env x SD	3	8014*	2	91745*	122*	2	0.0097*	10.0	1.16
Env x rep x SD	12	241	9	7976	11	6	0.0010	2.8	0.86
CC	4	49132*	3	325887*	869*	3	0.1697	2456.9	358.62*
Env x CC	12	3919*	6	55784*	90*	6	0.0512*	277.2*	36.93*
CC x SD	4	1570	3	287283*	622*	2	0.0028	20.0	34.78
Env x CC x SD	12	2042*	6	40431*	74*	1	0.0207*	57.2*	27.27*
Error	96	270	54	10310	13	30	0.0009	3.2	0.86
CV%		32		41	33		5.4803	8.4	3.41

* Significantly different ($P \leq 0.05$).

Analysis of cover crop biomass showed significant differences between cover crop treatments, and also a significant cover crop by sowing date interaction. When cover crops were combined across environments and sowing dates, rye had the greatest biomass production with 374 kg ha^{-1}, but not significantly different than that of faba bean (319 kg ha^{-1}) (Table 22). Forage pea produced significantly less biomass than rye with 179 kg ha^{-1} and was similar to faba bean. Red clover produced significantly less biomass than faba bean and was similar to forage pea. Balansa clover never produced enough biomass to be harvested and was not included in the analysis. These cover crop biomass yields only have a carrying capacity of 0.5 AUM ha^{-1} or less for a 450 kg cow with a calf. With the average of maize biomass left in the field, however, carrying capacity can increase to 40 AUM ha^{-1}, and this addition of higher protein forage with the intercrops could help the cattle (*Bos taurus* L.) maintain a more stable rumen than grazing just the corn biomass. Although, another higher protein hay source would still be necessary for the cattle.

At the V8 sowing date, rye, faba bean, and red clover had significantly higher biomass production than pea (Table 22), which produced no living biomass at the end of the season when sown at the V8 stage. When sown at the R4 stage of maize growth, faba bean (412 kg ha^{-1}), rye (385 kg ha^{-1}), and forage pea (359 kg ha^{-1}) had similar biomass yield. Red clover produced significantly less biomass with just 49 kg ha^{-1} (Table 22).

Table 22. Sowing date by cover crop interaction for biomass yield, along with cover crop stand count averaged across three environments, Hickson and Prosper, ND, in 2017 and 2018.

	Sowing date			
Cover crop	V8	R4	Mean	Stand count
	--------------------kg ha^{-1}		--------------------	Plants m^{-2}
Faba bean	226	412	319	8
Forage pea	-	359	179	20
Balansa clover	-	-	-	58
Red clover	201	49	125	108
Rye	363	385	374	60
LSD_1 (P = 0.05)†	219			
LSD_2 (0.05)‡	231			
LSD_3 (0.05)§	247			
LSD_4 (0.05)¶			167	34

† LSD_1 to compare between cover crop means within the same sowing date.
‡ LSD_2 to compare means between different sowing dates within a same cover crop.
§ LSD_3 to compare between different cover crops and sowing dates.
¶ LSD_4 to compare cover crop means averaged across sowing dates and environments.

When comparing how a single cover crop performed between each sowing date, the largest biomass difference was seen in forage pea, which produced significantly more biomass at the later sowing date (359 kg ha^{-1}) than at the earlier date (no living biomass). This shows that pea can produce biomass quickly when intersown but has low long-term survivability. It is likely that pea water requirements were not met when intersown early, or it is highly susceptible to prolonged reduced light. Faba bean followed a similar trend with having nearly double the living biomass when sown at the later sowing date, but without significant difference. Red clover and rye also did not show significant differences in biomass between sowing dates. These findings are in contrast with Scott et al. (1987) in New York, which found intersowing in mid-June produced more intercrop biomass than intersowing in early August. This is likely due to the unusually dry summer conditions encountered in this study (Fig. 2, Table 18). Red clover was the only cover crop with higher accumulated biomass when sown at V8, although not a significant difference. This is likely because red clover plants have relatively slow growth, so more time is needed to produce biomass, but also shows that it has some tolerance to shade (USDA-NRCS, 2002) allowing it to survive when intersown. Rye produced quite similar biomass at both sowing dates. Rye biomass was considerably higher (374 kg ha^{-1}) than the results found by Noland et al. (2018) (61 kg ha^{-1}), and more similar to results found by Wilson et al. (2013) (up to 506 kg ha^{-1}).

When comparing cover crop biomass between treatments and sowing dates, faba bean and rye sown at both V8 and R4, along with and forage pea sown at R4, and red clover sown at V8 were statistically similar. Red clover sown at R4 produced significantly less biomass than all other treatments except for red clover and faba bean sown at V8 (Table 22).

Cover crop biomass chemical composition

Crude protein concentration was quite high in all of the cover crops, since they were in vegetative stage at collection. Younger plants have been shown to have higher CP content (Turk and Albayrak, 2012). Forage pea had the highest CP content with 317 g kg^{-1}, but was not significantly different than rye and faba bean (Table 23). This is in contrast to findings from Wichmann et al. (2005) who found faba bean had higher CP content than pea. This is likely because the pea biomass was only from the later sowing date, so they would have a higher CP content than faba bean that had been living under the maize canopy longer and had few leaves left. Red clover had significantly less CP content than the other intercrops harvested at 155 g kg^{-1}. This is similar to reported research on red clover CP content when intersown with triticale (*Triticosecale* Witt.) (Kunelius et al., 2006). Crude protein was significantly different between sowing dates ($P \leq 0.05$). The CP concentration in cover crops sown at R4 was 292 g kg^{-1}, (data not shown) compared with the V8 sowing date which had 234 g CP kg^{-1}. This is likely due to the plants from the later sowing date being younger and having higher leaf:stem ratio than the plants from the earlier sowing date.

Wilson et al. (2004) and Fernandez-Rivera and Klopfenstein (1989) indicate the intake of maize residues by cattle would average 57 g CP kg^{-1}. The addition of these cover crops would only improve the diet of grazing cattle by 1.3 g CP kg^{-1} with rye, 1.1 g CP kg^{-1} with faba bean, 0.7 g CP kg^{-1} with forage pea, and 0.2 g CP kg^{-1} with red clover at 50% grazing efficiency using the average biomass and CP across sowing dates.

Table 23. Cover crops biomass chemical composition averaged across sowing dates and three environments, Hickson and Prosper, ND, in 2017 and 2018.

Cover crop	Crude protein	P	Ash
	-------------------------	g kg^{-1}	-------------------------
Faba bean	294	4.7	139
Forage pea	317	5.2	119
Red clover	155	4.1	498
Rye	284	6.7	179
LSD (*P* = 0.05)	55	NS	NS

All cover crops biomass had similar P concentration (Table 23). These intercrops provide more than enough P for cattle, which need 1.4 g P kg^{-1} of feed (Lalman, 2017). Analysis of ash content also found no significant differences between cover crops (Table 23). Red clover ash content averaged 498 g kg^{-1}, with the three other cover crops averaging lower, each having less than 200 g kg^{-1}. This large difference is nonetheless non-significant. This may have been because at biomass harvest, red clover plants were quite a bit smaller than the other intercrop treatments. This most likely caused more soil to end up in these samples which could have skewed the results to show much higher ash content

Nitrogen accumulated by cover crops biomass showed the same significant effects and interactions as biomass yield (Table 21, 24). This is largely due to N accumulation being calculated using biomass and the N content of the biomass. Rye accumulated the most N in the V8 sowing date with 15.4 kg ha^{-1} but was not different than that of faba bean (9 kg ha^{-1}) (Table 24). Red clover (5.8 kg ha^{-1}) was similar to faba bean, but significantly less than rye. Forage pea did not survive to the end of the season when sown at the V8 stage. Balansa clover never produced enough biomass for content analysis. Faba bean accumulated the most N in the R4 sowing date with 21 kg ha^{-1}. Forage pea and rye both also accumulated similar amounts of N to that of faba bean with 18.3 and 17.8 kg ha^{-1}, respectively. Red clover accumulated significantly less N than the other surviving intercrops with just 1 kg ha^{-1} when sown at the R4 stage.

Table 24. Cover crop N accumulation at each sowing date, and averaged across sowing dates and three environments, Hickson and Prosper, ND, in 2017 and 2018.

	Sowing date		
Cover crop	V8	R4	Combined
	---------------------------- kg ha^{-1} ----------------------------		
Faba bean	9.0	21.0	15.0
Forage pea	0.0	18.3	9.1
Balansa clover	-	-	-
Red clover	5.8	1.0	3.4
Rye	15.4	17.8	16.6
LSD_1 (*P* = 0.05)†	9.1		
LSD_2 (0.05)‡	9.3		
LSD_3 (0.05)§	9.7		
LSD_4 (0.05)¶			6.7

† LSD_1 to compare between cover crop means within the same sowing date.
‡ LSD_2 to compare means between different sowing dates within for a same cover crop.
§ LSD_3 to compare between different cover crops and sowing dates.
¶ LSD_4 to compare cover crop means averaged across sowing dates and environments

Faba bean and forage pea both achieved significantly higher N accumulation at the R4 sowing date than they did at the earlier, V8, sowing date. Rye also accumulated more N when sown at the R4 stage but was not significantly different. Faba bean intersown at the R4 maize stage accumulated the most N of any other cover crop at either sowing dates with 21 kg ha^{-1}. When comparing treatments across both sowing dates, R4 faba bean and forage pea, along with rye from both sowing dates all have similar amounts of N accumulation ranging from 15.4 to 21 kg ha^{-1}. Faba bean sown at V8 accumulated similar amounts of N (9 kg ha^{-1}) as R4 pea and rye from both sowing dates, but accumulated significantly less than faba bean sown at R4. Red clover sown at V8 accumulated 5.8 kg N ha^{-1}, similar to rye and faba bean sown at V8, but significantly less than rye, forage pea, and faba bean from the R4 sowing date. Red clover sown at R4 and forage pea sown at V8 accumulated significantly less N than Rye sown at V8 and were similar to red clover and faba bean sown at V8.

Rye had the greatest N accumulation (16.6 kg ha^{-1}) when averaged across environments and sowing dates. This is similar to N accumulation amounts found (11-27.5 kg ha^{-1}) in intersown rye by Ruffatti et al. (2019). Faba bean accumulated 15 kg N ha^{-1}, which is statistically the same as rye. Forage pea accumulated significantly less N (9.1 kg ha^{-1}) than rye but was similar to faba bean. Red clover accumulated 3.4 kg N ha^{-1} overall which is similar to forage pea, but significantly less than faba bean. All treatments except balansa clover averaged higher than intercrops from Noland et al. (2018) which had an overall average of 1.3 kg N ha^{-1}.

Soil NO_3-N and gravimetric water content

Soil NO_3-N after biomass harvest and the change of soil NO_3-N from intersowing to harvest were not different between cover crops and the no cover crop check at any sowing date or environment (Table 25). Check plots without cover crops did tend to have slightly more soil NO_3-N at the end of the year. The no-cover check plot also had the least change in NO_3-N throughout the life of the intercrops. This shows that cover crops did take up a small amount of soil NO_3-N available and prone to run-off or leaching. These cover crops did not have the effect of the rye intersown by Noland et al. (2018), who saw reductions of up to 53 kg NO_3-N ha^{-1} compared with the no cover check plot.

Table 25. Sources of variation (SOV), degrees of freedom (df), and trait mean squares for fall soil NO_3-N, change in NO_3-N, gravimetric water content in July and August combined analyses of sowing dates (SD), cover crops (CC), and three environments (Env) in Hickson and Prosper, ND, in 2017 and 2018.

SOV	df	Soil NO_3-N†	Change in NO_3-N‡	df	July water content§	August water content¶
Env	2	24508*	89602*	1	449.87*	271.19*
Rep(env)	9	2626*	4503*	6	2.40	4.82
SD	1	283	3835	-	.	.
Env x SD	2	548	3495	-	.	.
Env x rep x SD	6	185	6361*	-	.	.
CC	5	92	92	4	1.29	10.73*
Env x CC	8	342	342	4	2.88	0.74
CC x SD	2	348	348	-	.	.
Env x CC x SD	1	588	588	-	.	.
Error	36	549	549	24	1.43	5.62
CV%		65	41		6.55	15.39

* Significantly different ($P \leq 0.05$).
† Soil NO_3-N and change in NO_3-N are combined across three environments.
‡ Change in soil NO_3-N from cover crop sowing to biomass harvest.
§ July water content was taken on 12 July 2017 in the first sowing date.
¶ August water content was taken on 3 August 2017 in the first sowing date.

Soil water content taken in the first intercrop sowing date from 0- to 7-cm in July showed no significant differences with treatments ranging from 179 g kg^{-1} to 188 g kg^{-1} (Table 25, 26). Samples taken in August at the same depth had a significant difference between balansa clover and the rest of the cover crops. Balansa clover plots had the most soil water content at 174 g kg^{-1}. All other cover crop plots had significantly less soil water and were not different from each other, averaging 149 g kg^{-1}. This is because balansa clover had poor growth, so almost no water was taken up. Although cover crops were relatively small under the maize canopy, they still reduced soil water slightly more than if there were no cover crops, which agrees with Noland et al. (2018) who found intersown rye reduced volumetric water at 30-cm soil depth more than the no cover crop check plot. This can be a negative in a season with less than average rainfall.

Table 26. End of season soil NO_3-N, change in soil NO_3-N throughout the life of the cover crop averaged across three environments, and July and August soil gravimetric water content in the first sowing date of intercrops averaged across environments, in Hickson and Prosper, ND, in 2017.

Cover crop	Soil NO_3-N†	Change in NO_3-N‡	July water content§	August water content
	---------------- kg ha^{-1} ----------------		------------ g kg^{-1} ------------	
Faba bean	38.2	70.08	186	150
Forage pea	36.6	47.45	179	145
Balansa clover¶	-	-	188	174
Red clover	32.7	65.35	180	152
Rye	35.0	66.88	182	148
Check	38.9	47.17	-	-
LSD (*P* = 0.05)	NS	NS	NS	12

† Soil NO_3-N and change in NO_3-N were measured from 0- to 60-cm.
‡ Change in soil NO_3-N from cover crop sowing to biomass harvest.
§ July and August water content were measured from 0- to 7-cm.
¶ Soil NO_3-N was not measured on balansa clover plots since there was no crop.

Conclusion

Intersown cover crops at earlier sowing dates reduced stand count and biomass production of maize. However, maize grain yield was unaffected by intersowing. Faba bean and forage pea produced significantly more biomass when intersown at R4 compared with V8. Red clover and rye produced similar biomass regardless of intersowing date. Balansa clover had insignificant biomass production at either intersowing date. Averaged across sowing dates rye and faba bean produced the most biomass. Forage pea produced significantly less biomass than rye but was similar to faba bean. Red clover produced significantly less biomass than faba bean but was similar to forage pea. Faba bean, forage pea, and rye all contained similar concentrations of CP, and had significantly more than red clover. With the biomass produced and CP content of these cover crops, more supplementation would still be necessary to reach cattle CP requirements when grazing with maize residue.

CHAPTER 4: GENERAL CONCLUSIONS

Faba bean showed comparable or superior biomass production and CP content with other cover crops tested, making it a good option as a cover crop; especially if in need of late-season grazing options. Increased sowing rate would likely improve biomass production and ground coverage of faba bean. Nitrogen accumulation varied depending on biomass production and amount of NO_3-N in the soil at cover crop sowing. High concentration of CP in cover crop biomass may lead to digestion issues and bloat in ruminants, leading to a need for supplementation with a low CP hay source. This is less likely to be a problem in faba bean than in pea because of the condensed tannins in faba bean reducing bloat risk. Legume cover crops sown after wheat did not lead to any significant differences in yield of the following maize crop.

Biomass production of intersown cover crops was much less than that of cover crops sown after wheat. Faba bean and rye were the most reliable intercrops producing similar biomass amounts at both sowing dates. Forage pea did produce biomass when intersown at R4, but never had living biomass after maize harvest when intersown at V8. Intercrops did not affect maize yield and also did not provide enough biomass to sufficiently amend a grazing ruminant's diet with enough CP, leaving need for more supplementation. Faba bean is a legume that can fit into upper Midwest farming systems and produce as much biomass as a cover crop or intercrop as other commonly used cover crop options in the area, while providing a healthier grazing option than these other cover crops.

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