Government of Saskatchewan
Ministry of Agriculture

ADF Project Progress Report Format

1. Project title, ADF file number and reporting period.

Title: **Intercropping pea with canola or oat: impact on nitrogen, disease and economics**

ADF file number: 2020093

Reporting period: April 1, 2021 – March 31, 2022

2. Name of the Principal Investigator and contact information.

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4. **Abstract (Not more than 250 words). Describe in lay language the progress towards the project objectives over the last reporting period. Include any key findings and any interim conclusions. Include any deviations from the original methodology.**

The main objective of this 3-year (2021-2024) project is to assess the impacts of pea-based intercrops on grain yield, grain quality, N cycling, disease, and economic returns. In 2021, field studies were conducted at Melfort, Redvers, and Swift Current, Saskatchewan. For the first year's report (2021), we focus on agronomic results as chemical lab analysis of soil and plant samples are underway. We found that agronomic responses to cropping (e.g., intercrops vs monocrops) varied among the three sites, with similar responses at the two moist sites, Melfort and Redvers. The land equivalent ratio indicated that intercropping slightly (1-3%) increased yields at Melfort and Redvers (moist ecozones) compared to the monocrops; however, it was unexpected that intercropping decreased yields at Swift Current (semi-arid ecozone). Similarly, straw biomass and pea equivalent yield (PEY), which was calculated based on grain yield and price, were not different between intercrops and pea monocrops at the moist sites of Melfort and Redvers; however, at Swift Current, straw biomass and PEY was significantly lower in pea-oat intercrops than in the pea monocrop. Increasing N rates in intercrops from 0 to ½ of recommended rate for the companion monocrops had no effects on PEY for both pea-oat and pea-canola intercrops. Intercropping oat with pea increased the percentage of plump seed but decreased the protein content of oat compared to the oat monocrop. Increasing N rates for pea-oat intercrops had no effect on oat grain quality as indicated by percentage of plump, beta-glucan content, and protein content.

5. **Introduction: Brief project background and rationale (Maximum of 1500 words or 1.5-3 pages).**

Field pea has been successfully adapted to Saskatchewan and seeded in over 1.5 million acres per year since 2011. Pea plays an important role in diversifying and stabilizing the dominant cereal-oilseed cropping systems in Saskatchewan (Liu et al., 2020, Knight, 2012). Most importantly, growing a pea crop substantially reduces the fertilizer N input in subsequent crops as a result of biological N_2-fixation (Liu et al., 2019b, Hossain et al., 2016, St. Luce et al., 2015). The yield benefits of growing pea to the following cereals and oilseeds are well documented in Saskatchewan (Liu et al., 2019a, Liu et al., 2020, O'Donovan et al., 2014, St. Luce et al., 2015). Pea is also widely used in intercropping (Chapagain and Riseman, 2014, Strydhorst et al., 2008, Kontturi et al., 2011, Holzapfel and Chalmers, 2011). Intercropping pea with relatively rigid and upright crops, such as oat or canola, can minimize pea lodging (Kontturi et al., 2011, Shaw et al., 2020) while pea can provide nitrogen (N) to intercropped oat or canola, creating mutual benefits between crops.

Mutual benefits of intercropping can lead to increased grain yield and quality compared to mono-cropping (Holzapfel and Chalmers, 2011, Strydhorst et al., 2008, Pelzer et al., 2012). In a study conducted in North Dakota, grain protein of oat increased by 1.8% in pea-oat intercrop compared with oat monocrop (Zwinger et al., 2018). Similarly, in a pea-oat intercrop demonstration trial in Saskatchewan, pea-oat intercropping showed potential to increase oat quality compared with oat monocrop (Shaw et al., 2020). May et al. (2004) found that fertilizer N rates were an important factor affecting oat quality indicators such as groat percentage, plump seed, and protein content. Holzapfel and Chalmers (2011) reported that applying fertilizer N did not benefit pea yield but had a positive effect on canola yield, to a certain extent in a pea-canola intercrop study. In addition, N application rates in pea-based intercrops affected not only the yield and quality of the non-legume crop, but also nodule formation, N fixation, and N transfer from pea to the non-legume crop (Chapagain and Riseman, 2014). Therefore, further studies are needed to determine N rate effects on grain yield and N transfer in pea-based intercrops.

Nitrogen transfer from pea to the non-legume crop during growing seasons can reduce fertilizer N application rates in intercrops. In a pea-barley intercrop, intercropped pea displayed increased nodulation (27–45%) and biological N_2 fixation (9–17%) compared with pea monocrop (Chapagain and Riseman, 2014). The enhanced N fixation by the intercropped pea likely increases N transfer from pea to the non-legume companion crop, thus improving N use efficiency and possibly grain quality. Oat is a mycorrhizal crop, while canola is a non-mycorrhizal crop. When pea is intercropped with oat or canola, the extent of N transfer from pea might be different because mycorrhizae play an essential role in N acquisition and transfer (He et al., 2009). To enhance N use efficiency and improve grain quality, it is important to quantify the difference in N transfer from pea to oat and from pea to canola.

In addition to well-known N benefits, pea-based intercrops likely increase carbon sequestration through greater plant biomass production and residue carbon returns. Chapagain and Riseman (2014) reported that pea-barley intercrops increased straw biomass carbon by 10% compared to barley monocrop. High biomass returns to soils from intercropping practices alter soil carbon and N pools, affecting soil health and the subsequent crop performance. However, most intercropping studies only assessed the intercropping year, without further exploring the "carry over" effects to the following crops. This carry-over function affects soil N supply, crop yield, grain quality (e.g. protein content), and disease in the subsequent year of rotations. Knowledge of the carry-over effects of pea-based intercropping is required to better understand the role of intercropping at the cropping system level.

In addition to crop yield and soil health, intercropping may affect disease as a result of the alternation of host plants densities, soil biochemistry and/or micro-climates. Root rot can have a devastating impact on pea crops. This disease can be caused by a range of organisms, including Fusarium species and the oomycete *Aphanomyces euteiches* (Gossen et al., 2016). Intercropping with oat may also influence Aphanomyces root rot severity in pea by means of oat root exudates that could potentially either induce germination of *A. eutieches* long-lived, tough oospores (Shang et al., 2000), making them more vulnerable, and/or directly kill oomycete zoospores (Deacon and Mitchell, 1985).

Sclerotinia, caused by the fungus *Sclerotinia sclerotiorum*, can lead to significant damage in canola crops. Relative humidity is an important factor in the development of this disease (Derbyshire and Denton-Giles, 2016). It is possible that intercropping pea and canola could alter the humidity level in the crop canopy, thereby influencing disease. Blackleg, caused by the fungus *Leptosphaeria maculans*, is one of the most serious diseases of canola in western Canada. The impacts of pea-canola intercrops remain unknown for this disease. Thus, exploring how intercropping with pea impacts this disease has value.

Economically, including pulse crops in wheat-canola cropping systems has the potential to be profitable and enhance input use efficiencies (Khakbazan et al., 2018, Khakbazan et al., 2009). Intercropping pea with oat or canola will significantly reduce fertilizer N inputs. Fertilizer N, in combination with on-farm fuel use, can comprise over 80% of the total energy input in traditional production systems (Zentner et al., 2004). In addition, intercropping affects pesticide inputs, field operations, yield, grain separation, all of which affect economic returns. However, limited information is available on the economic evaluation of pea-oat or pea-canola intercrops at the whole farm level. With the growing popularity and importance of pea in Saskatchewan, it is important to evaluate the economic returns and risks of pea-based intercropping for a healthy cropping system.

In Saskatchewan, intercropping is gradually gaining more attention as indicated by insured acreages increasing from 29,000 acres in 2018 to over 70,000 acres in 2019 (SCIC data). Growers are interested in intercropping as a means of reducing fertilizer use and increasing profitability. Therefore, we proposed a pea-based intercrop project to meet the grower's demands and adapt intercropping practices more efficiently.

6. Objectives and the progress towards meeting each objective

Objectives (Please list the original objectives and/or revised objectives if Ministry-approved revisions have been made to original objective. A justification is needed for any deviation from original objectives)	Progress (e.g. completed/in progress)
a) Determine effects of intercropping pea with oat or canola on grain yield, quality, and soil health	**In progress.** Field studies were conducted at all three proposed sites in the 2021 growing season. Yield and quality data were collected and reported in this report. Soil samples were collected and soluble soil carbon are

	being analyzed in the lab and will be reported when available.
b) Quantify N transfer from pea to oat (mycorrhizal crop) or canola (non-mycorrhizal crop) and N recovery at different N rates	**In progress.** A master's degree student, Kennedy Choo-Foo, started on May 2, 2022. Soil and plant samples for N uptake and ^{15}N analyses were collected at all sites for the 2021 growing season. N analyses are being analyzed in the lab.
c) Assess effects of intercropping on disease	**In progress.** Common diseases such as root rot and mycosphaerella blight of pea, blackleg and sclerotinia of canola and crown rust of oats were monitored and rated for both intercrops and monocrops in 2021-2022.
d) Evaluate economic returns of intercropping	**In progress.** All input data were collected for the 2021 growing season. As planned, a comprehensive economic analysis will be conducted in the last year (2024) of this study.

7. Changes in the work plan, or budget: Briefly explain new challenges found during the work completed in this reporting period and the impact on the work plan or the budget (Maximum of 1 page)

No changes in work plan or budget.

8. Methodology: Specify project activities undertaken during this reporting period. Include approaches, experimental design, tests, materials, sites, etc. Please note that any significant changes from the original work plan will require written approval from the Ministry. (Maximum of 5 pages)

8.1 Experimental design:

The study was conducted at three SK sites including Swift Current, Melfort, and Redvers. Soil properties are given in ***Table 1***.

Table 1. Baseline soil properties at three experimental sites, 2021.

Site	Sand (%)	Silt (%)	Clay (%)	Soil texture	pH	EC (mS/cm)	Organic C (ugC/g)	Organic N (ugN/g)
Melfort	17.1	46.3	36.6	Silty Clay Loam	6.7	0.6	100.0±8.1	13.2±0.9
Redvers	51	25	24	Sandy Clay Loam	7.4	1.6	61.6±4.5	9.0±0.5
Swift Current	31	26.3	42.8	Clay	7.1	0.9	47.6±2.2	6.4±0.4

This study includes two phases (i.e., phase I and II) and each phase is a 2-year crop sequence. Phase I crops grow in 2021 and 2022, while phase II crops grow in 2022 and 2023. In the second study year (2022), both the second year of phase I and the first year of phase II are seeded at each site but in different fields. In order to have a similar preceding crop background, both phases I and II are established on a previous cereal crop. Two intercrops are evaluated: pea-oat and pea-canola, with oat representing a mycorrhizal crop and canola representing a non-mycorrhizal crop. Pea is the main crop and seeded at 2/3 seeding rate of pea monocrop, while oat (or canola) is the support crop and seeded at ½ seeding rate of oat (or canola) monocrop. The intercrops are arranged in mixed rows, since mixed-row intercropping resulted in higher yield than alternate-row intercropping (Holzapfel and Chalmers, 2011). In addition, three N rates are applied to each intercrop: no fertilizer N control,

¼ of recommended N rate of the non-legume monocrop, and ½ of recommended N rate of the non-legume monocrop. In 2021, there were nine treatments, including six intercrops and three monocrops:

- Pea + oat (0 N)
- Pea + oat (1/4 of recommended N rate for oat monocrop)
- Pea + oat (1/2 of recommended N rate for oat monocrop)
- Pea + canola (0 N)
- Pea + canola (1/4 of recommended N rate for canola monocrop)
- Pea + canola (1/2 of recommended N rate for canola monocrop)
- Pea monocrop
- Oat monocrop
- Canola monocrop

No synthetic chemical N fertilizer are applied to the pea monocrop, which is inoculated with commercial Rhizobium inoculants (e.g., TagTeam) that contains a P solubilizing fungi *P. bilaii* at seeding. Fertilizer N rates for oat and canola monocrop are determined based on soil test recommendations.

In the second year of each phase, all plots will be seeded to wheat. A flat N rate will be applied to wheat crop, based on soil test recommendations.

All treatments are arranged in a randomized complete block design with 4 blocks, with a total of 36 plots.

8.2 Data collection

8.2.1 Baseline soil properties

Prior to establishing the experiment in the spring of 2021, at each site, two composite soil samples per block were collected to determine soil texture, pH, EC, soil total N, soil organic C (OC) and organic N, soil mineral N, soil test P, and soil test K.

8.2.2 Grain yield and quality

Crop growth stages (e.g. emergence, flowering, and maturity dates) were recorded. Plant lodging was rated on a scale of 1 (upright) to 10 (flat). Crops were harvested at physiological maturity using a plot combine. The grains from the intercrops were cleaned and separated, then the land equivalent ratio (LER) was used to assess yield performance of the intercrops. For grain quality, all grains were analyzed for total carbon and N content at Swift Current Centre. Oat milling quality (e.g., % plump kernels, soluble fiber (beta-glucan content), and protein content) was analyzed at General Mills laboratory through in-kind support to this project.

Pea was the most common crop in this study. When analysis requires comparing different crop yields at the same site, all crop yields were expressed as pea equivalent yield (PEY) on a plot basis. The PEY, which allows for comparison between monocrops and intercrops, was calculated as:

$$PEY = \frac{P_{non-pea}}{P_{pea}} \times Y_{non-pea}$$

Where $P_{non-pea}$ is the price of non-pea crops, P_{pea} is the price of pea, and $Y_{non-pea}$ is the yield of non-pea crops. Based on the calculation, the PEY for the pea crop was exactly the same as the pea grain yield.

8.2.3 Plant biomass

At crop physiological maturity, all plants in 1 m length of 2 rows were hand harvested at two locations in each plot for biomass measurement. Biomass samples were separated into weed biomass and plant biomass, which were further separated into straw and grains. The biomass of grain and straw was determined after being oven-dried at 45°C. Straw and grain samples were ground and are currently being analyzed for carbon and nitrogen in a chemical lab.

8.2.4 Nitrogen transfer from pea to mycorrhizal crop oat and non-mycorrhizal crop canola

In 2021, two micro-plots, 2 meters apart, were established in each of the (20) selected plots. The 1 square meter micro-plots were centered amongst the rows. One micro-plot (test plot) receives ^{15}N enriched 98 atom% urea and another (control) receives non- ^{15}N enriched urea. The N rate for each micro-plot was equivalent to 5 kg N per ha, ensuring that plants would be sufficiently enriched with ^{15}N. The ^{15}N enriched urea was dissolved in 4 L of water and evenly applied to each test micro-plot using a water can, and an additional 2L water was applied to ensure that urea enters into soil. The control micro-plot was applied with non-^{15}N enriched urea. Just prior to crop physiological maturity stage, the aboveground biomass of each crop (e.g. two crops in the intercrop plots) was collected from each micro-plot, a subsample was oven-dried at 45°C, and ground into fine-powder, and the remaining crop residue was returned to field to determine N recovery. Total N content and the atom percentage of ^{15}N are currently being analyzed in a lab using an automated CN analyzer coupled with an isotope ratio mass spectrometer. We will report the results when the lab analysis is completed.

In 2021, at crop maturity, plant biomass in the micro-plots was harvested and weighed. The straw was chopped into 10 cm pieces (to simulate crop residue after harvest) and returned to the fields, swapping residue between test and control micro-plots in each plot. The straw exchange allows us to determine N recovery from ^{15}N enriched above-ground crop residue and from the soil (Taveira et al., 2020). The straw was covered by 1-cm mesh net during the non-growing season to prevent losses by wind. In 2022, wheat samples will be collected from the micro-plots to determine biomass, ^{15}N atom%, and N recovery.

8.2.5 Disease assessment

The severity of mycosphaerella blight of pea was rated at early flowering on a 0-5 scale shown in Table 2 based on 5 randomly selected plants in each plot. Root rot of pea was assessed on 5 randomly selected plants per plot. It was assessed at early flowering. However, roots were dug on July 23, 2021 in Redvers. Root rot severity was scored on a 0-5 scale (Willsey et al., 2018) (Table 3).

Table 2. Rating scale (0-5) for assessment of Ascochyta / Mycosphaerella blight on peas.

Rating	Description
0	No visible necrosis on leaf and/or stem
1	Under 5% of plant area covered by necrosis. A few flecks on leaves and a few streaks on stems
2	5-25% of plant area covered by necrosis. Numerous flecks on leaves and streaks on stems
3	25 to 50% of plant area covered by necrosis, with coalescent streaks forming 3- to 5-mm lesions on stems
4	50 to 75% of plant area covered by necrosis, with a necrotic zone up to 3 mm wide encircling the stem
5	More than 75% of plant area covered by necrosis, necrotic zone wider than 3 mm encircling the stem

Table 3. Pea root rot scale (0-5)

Rating	Description
0	Healthy, no disease
1	1-25% of root area discolored
2	26-50% of root area discolored
3	51-75% of root area discolored
4	76-100% of root area discolored
5	Plant dead

Sclerotinia and blackleg of canola were both assessed at maturity with 50 plants, 10 plants were selected from 5 randomly selected locations in each plot. The blackleg and Sclerotinia rating scales are summarized in ***Table 4*** and ***Table 5***.

Table 4. Rating of blackleg of canola

Rating	Description
0	No disease visible in the cross section
1	Diseased tissue occupies up to 25% cross-section
2	Diseased tissue occupies 26 to 50% cross-section
3	Diseased tissue occupies 51 to 75% cross-section
4	Diseased tissue occupies > 75% cross-section with little constriction of affected tissues
5	Diseased tissue occupies 100% cross-section with significant constriction; tissue dried and plant dead

Table 5. Rating of Sclerotinia of canola

Rating	Description
0	No symptoms of disease on plant
1	A few pods affected
2	One major branch girdled; ¼ of the plant affected
3	Two major branches girdled; ½ of the plant affected
4	Three or more major branches girdled; ¾ of the plant affected
5	Main stem lesion affecting entire plant

8.2.6 Data analysis

Statistical analyses were conducted using PROC MIXED of SAS, considering treatment as fixed factor and block as random factor. Data were analyzed at each site separately. The data were transformed to meet the assumptions of normality and homoscedasticity if necessary. Least square means were compared at the 0.05 significance level.

9. Results and discussion: Describe research accomplishments during the reporting period under relevant objectives listed under section 6. The results need to be accompanied with tables, graphs and/or other illustrations. Provide discussion necessary to the full understanding of the results. Where applicable, results should be discussed in the context of existing knowledge and relevant literature. Detail any major concerns or project setbacks. (Maximum of 20 pages of text not including figures or tables).

9.1 Effects of intercropping pea with oat or canola on grain yield

The land equivalent ratio (LER), an index of intercropping yield performance, varied among the three experimental sites (***Figure 1***). The average LERs at Melfort and Redvers were greater than 1, with a value of 1.01 and 1.03, respectively. This indicates an average increase of 1 and 3% yield per unit of land in intercrops compared to monocrops at Melfort and Redvers, respectively. It was unexpected that the LER at Swift Current was lower than 1 with an average value of 0.83 (***Figure 1***). The extreme drought weather might partially explain this unexpected result but more data are needed to confirm this.

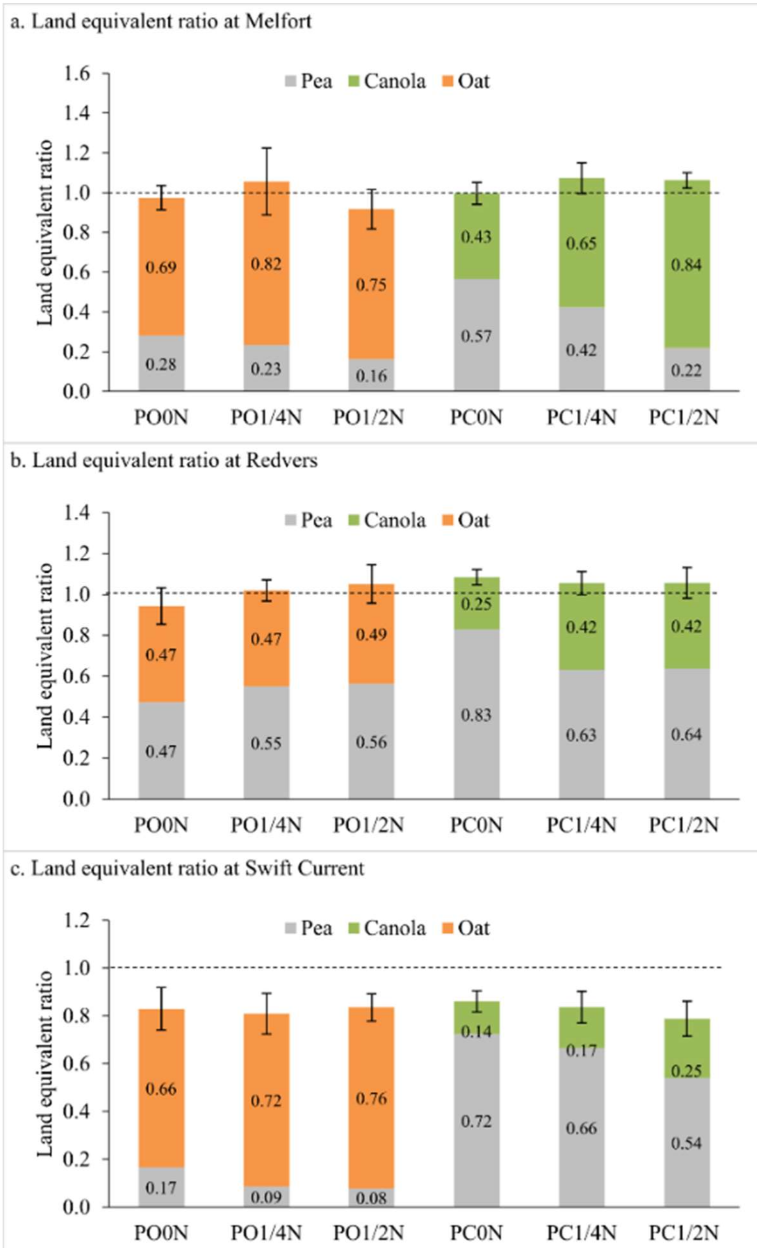

Figure 1. Land equivalent ratio for all intercropping treatments at (a) Melfort, (b) Redvers, and (c) Swift Current in 2021. The error bars correspond to standard errors. Dashed line represents a land equivalent ratio of one. PO0N = pea and oat intercrop without N fertilizer, PO1/4N = pea and oat intercrop with 1/4 of recommended N rate for oat monocrop, PO1/2N = pea and oat intercrop with 1/2 of recommended N rate for oat monocrop, PC0N = pea and canola intercrop without N fertilizer, PC1/4N = pea and canola intercrop with 1/4 of recommended N rate for oat monocrop, and PC1/2N = pea and canola intercrop with 1/2 of recommended N rate for oat monocrop.

The contribution of pea and non-pea crops (i.e., canola, oat) to the LER varied at the three sites (***Figure 1***). For the pea-oat intercrops, oat was the dominant contributor to the LER at Melfort and Swift Current, whilst pea and oat contributed almost equally at Redvers. For the pea-canola intercropping, pea was dominant at Redvers and Swift Current while canola was dominant at Melfort, except for the treatment receiving no N fertilizer. The different responses of intercropping across different sites suggested a site-specific intercrop be required in order to maximize yield benefits at each site.

The pea equivalent yield (PEY) varied among the three experimental sites (***Figure 2***). For pea-oat intercrops, the highest average PEY across all treatments was found at Melfort with a value of 2105.5 kg ha^{-1} yr^{-1}, followed by 2076.6 and 828.6 kg ha^{-1} yr^{-1} at Redvers and Swift Current, respectively. For pea-canola intercrops, the highest average PEY across all treatments was found at Redvers with a value of 2623.6 kg ha^{-1} yr^{-1}, followed by 1756.4 and 1113.5 kg ha^{-1} yr^{-1} at Melfort and Swift Current, respectively.

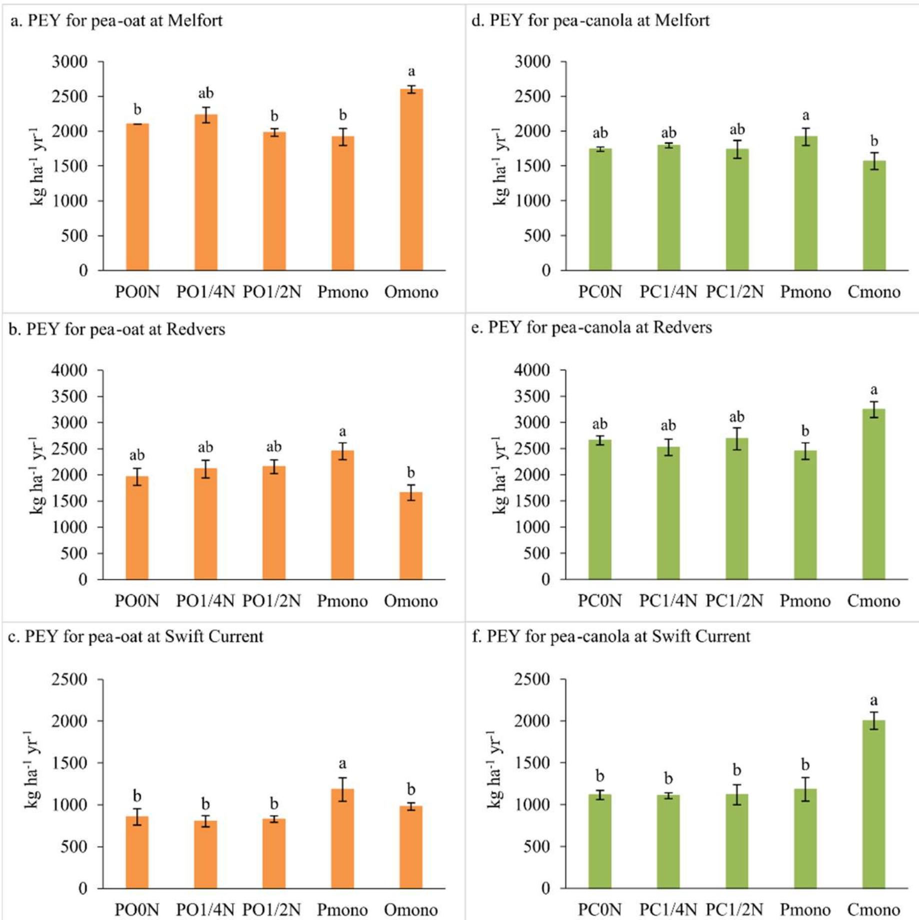

Figure 2. Pea equivalent yield (PEY) for (a-c) pea-oat and (d-f) pea-canola intercropping at Melfort, Redvers and Swift Current in 2021. The error bars correspond to standard errors. Different letters indicate significant differences among treatments (P < 0.05). PO0N = pea and oat intercrop without N fertilizer, PO1/4N = pea and oat intercrop with 1/4 of recommended N rate for oat monocrop, PO1/2N = pea and oat intercrop with 1/2 of recommended N rate for oat monocrop, PC0N = pea and canola intercrop without N fertilizer, PC1/4N = pea and canola intercrop with 1/4 of recommended N rate for oat monocrop, PC1/2N = pea and canola intercrop with 1/2 of recommended N rate for oat monocrop, Pmono = pea monocrop, Omono = oat monocrop, and Cmono = canola monocrop.

For the pea-oat intercrops, PEY in the pea monocrop was either similar to or higher than in the pea-oat intercrops at all three sites (***Figure 2***). However, there was no consistent pattern of PEY between the oat monocrop and the pea-oat intercrop across the three experimental sites.

For the pea-canola intercrops, the pea monocrop had similar PEY to intercrops at all sites, while the canola monocrop had significantly higher PEY than intercrop at Swift Current, although PEY was similar between intercrops and the canola monocrop at Melfort and Redvers (***Figure 2***). The higher PEY in the canola monocrop at Swift Current is unexpected and more data were needed to confirm such results.

For both pea-oat intercrop and pea-canola intercrop, increasing N fertilizer rates had no effects on PEY (***Figure 2***).

9.2 Effects of intercropping pea with oat on oat grain quality

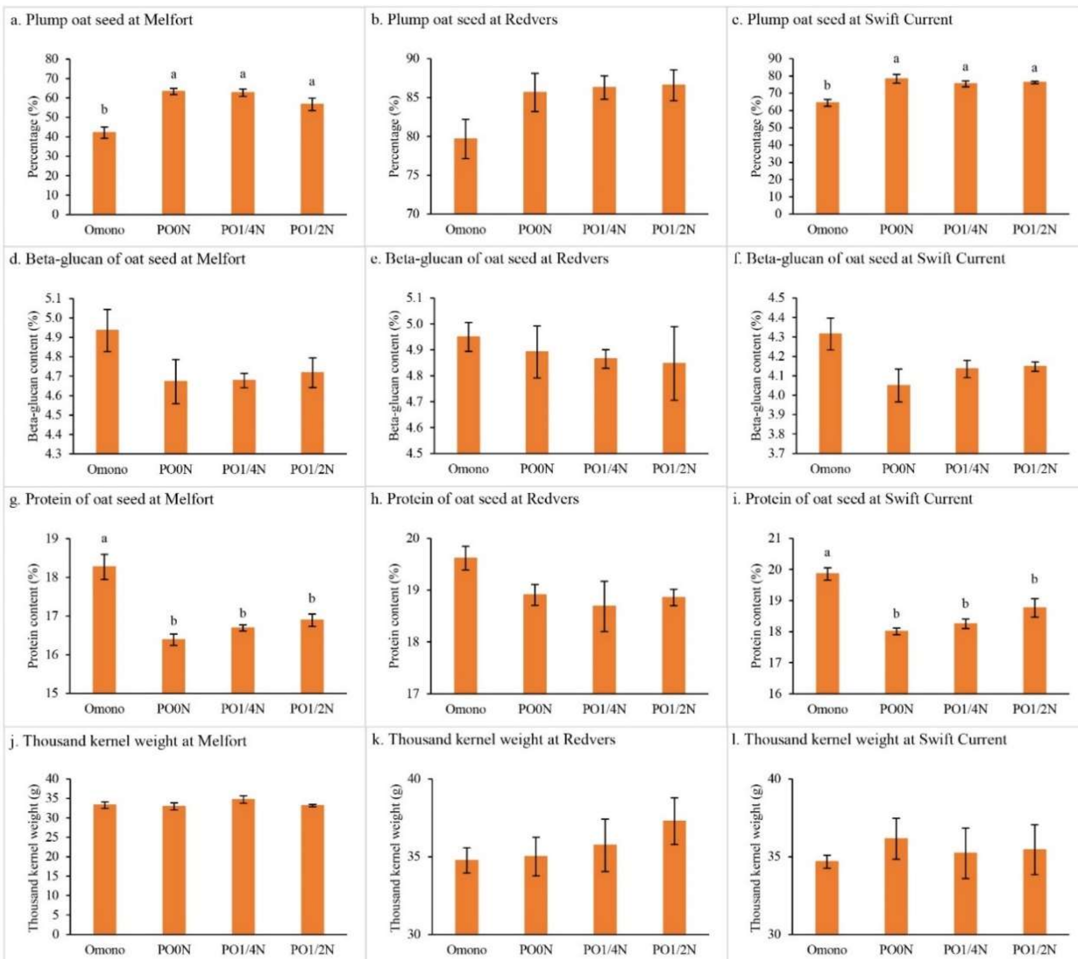

Figure 3. (a-c) Percentage of plump oat seed, (d-f) beta-glucan content, (g-i) protein content, and (j-l) thousand kernel weight of oat seed at Melfort, Redvers and Swift Current in 2021. Different letters indicate significant difference among treatments (P < 0.05). The error bars correspond to standard errors. PO0N = pea and oat intercrop without N fertilizer, PO1/4N = pea and oat intercrop with 1/4 of recommended N rate for oat monocrop, PO1/2N = pea and oat intercrop with 1/2 of recommended N rate for oat monocrop, and Omono = oat monocrop.

The response of oat grain quality varied among the three sites (***Figure 3***). Compared to the oat monocrop, intercropping oat with pea increased the percentage of plump seeds, particularly at the Melfort and Swift Current sites. Averaged across the three pea-oat intercrops, the percentage of plump seeds increased by 44, 8, and 19% at Melfort, Redvers, and Swift Current, respectively. The N fertilizer application rate had no effects on the percentage of plump seeds.

Intercropping of oat with pea resulted in slightly lower beta-glucan content of oat at all three sites, but the reduction was not significant (***Figure 3***).

Intercropping oat with pea had no effect on protein content of oat at Redvers but significantly reduced the protein content of oat at Melfort and Swift Current (***Figure 3***). The N fertilizer application rates in intercrops had no effects on oat protein content. Averaged across all three N rates in intercrops, intercropping oat with pea reduced the protein content of oat by 9, 4, and 8% compared with the oat monocrop at Melfort, Redvers, and Swift Current, respectively. The reduction in oat protein content was likely related to reduced N fertilizer rates in pea-oat intercrops relative to the oat monocrop.

Intercropping oat with pea had no effect on the 1000-kernel weight at all three sites (***Figure 3***).

9.3 Effects of intercropping pea with oat or canola on straw biomass

The effect of intercropping on the straw biomass varied among the three experimental sites (***Figure 4***). There was no significant difference in straw biomass between the intercrops and monocrops at Melfort and Redvers; however, at Swift Current, the straw biomass in the pea monocrop was 20-35% higher than that in the pea-oat intercrops. The N fertilizer rate had no effects on straw biomass for all intercrops except for the pea-canola at Swift Current, where an increased N rate resulted in greater straw biomass. In addition to straw quantity, the difference in straw quality might affect soil carbon sequestration and soil health. In addition, regardless of N fertilizer levels, the average straw biomass in the pea-canola intercrops were consistently greater than in the pea-oat intercrops at all sites (i.e., 3046 vs 2297 at Melfort, 4152 vs 3823 at Redvers, 2485 vs 2088 at Swift Current; ***Figure 4***). Greater straw biomass might lead to a higher soil soluble carbon concentration, which is currently being analyzed in the lab.

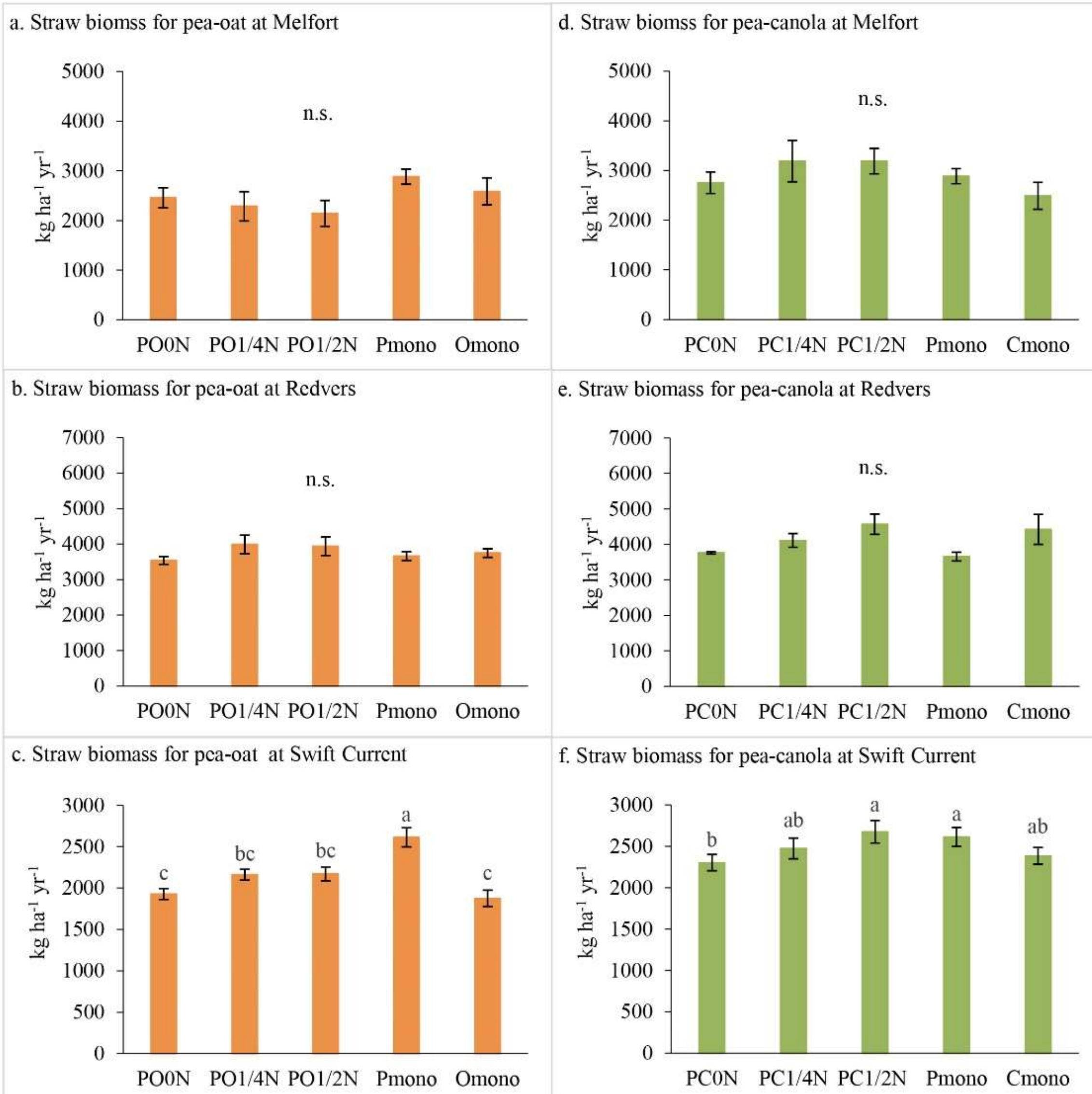

Figure 4. Straw biomass returns for (a-c) pea-oat and (d-f) pea-canola intercrops at Melfort, Redvers and Swift Current in 2021. The error bars correspond to standard errors. Different letters indicate significant difference among treatments ($P < 0.05$). n.s. = non-significance. PO0N = pea and oat intercrop without N fertilizer, PO1/4N = pea and oat intercrop with 1/4 of recommended N rate for oat monocrop, PO1/2N = pea and oat intercrop with 1/2 of recommended N rate for oat monocrop, PC0N = pea and canola intercrop without N fertilizer, PC1/4N = pea and canola intercrop with 1/4 of recommended N rate for oat monocrop, PC1/2N = pea and canola intercrop with 1/2 of recommended N rate for oat monocrop, Pmono = pea monocrop, Omono = oat monocrop, and Cmono = canola monocrop.

9.4 Effects of intercropping pea with oat or canola on disease

At Swift Current, in 2021, no disease was observed in any crop or treatment. This was unsurprising, given the hot dry conditions and the use of a preventative fungicide (Priaxor) application.

Melfort had no disease symptoms in pea, oat or canola in 2021. It is surprising that no root rot symptoms were present. However, dry conditions and site-to-site variability likely explain this.

Redvers had disease in pea, but not oat or canola. Although, both mycosphaerella blight and root rot severity were quite low. The heat and drought in 2021 likely contributed to this. The late planting date probably added to this impact because the plants were maturing later in the season and thus exposed to even higher temperatures. There were no differences between treatments for either disease (***Figure 5***). Later rating of root rot also potentially reduced the likelihood for treatments being different because, as roots get older, senescence can make root rot symptoms harder to rate. In addition, saprophytic organisms can colonize the roots later in the season.

The 2021 results showed that intercropping pea with oat or canola did not impact disease under low disease pressure. If wetting conditions occur in 2022 or 2023, it will be interesting to compare the results to those from 2021.

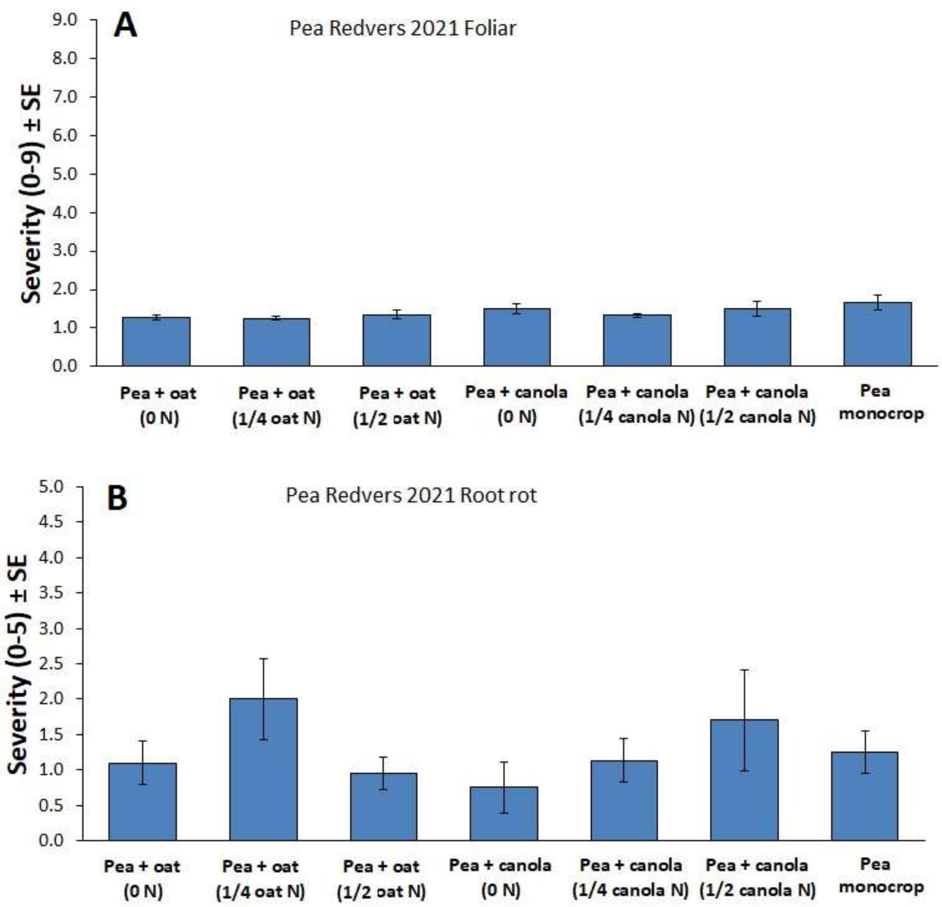

Figure 5. Mycosphaerella blight (A) and root rot (B) in pea in Redvers in 2021. There were no differences between treatments (P-value ≤ 0.05).

9.5 Lodging and maturity days

The average rates of crop lodging in all treatments were close to 1 at all sites (***Table 6***), indicating no lodging in the 2021 growing season due to drought related poor crop growth. The days to maturity of oat were similar among the three sites (75-77 days), while the days to maturity of pea and canola were quite different among the sites (***Table 6***). Across the three sites, the days to maturity of pea range from 72-74 days at the Melfort site to 79-86 days at the Swift Current site, while the days to maturity of canola range from 81-83 days at the Melfort site to 95-96 days at the Redvers site. The maturity dates of oat and canola were less affected by intercrop and N fertilizer rate compared with pea. The N fertilizer rates had no effects on the days of maturity as a result of the relatively low N rate applied. There was no significant difference in days to maturity between intercrops and monocrop at Melfort and Redvers sites, but pea-oat intercrops required more days for the pea to mature compared with pea monocrop at Swift Current.

Table 6. Lodging and day to maturity across all treatments at Melfort, Redvers and Swift Current in 2021.

Location	Treatments	Lodging* (1-10)	Days to maturity (day)		
			Pea	Canola	Oat
Melfort	PO0N†	1.0	71.8		77.5
	PO1/4N	1.0	72.3		77.5
	PO1/2N	1.0	71.8		77.0
	PC0N	1.0	71.5	81.0	
	PC1/4N	1.0	71.8	81.5	
	PC1/2N	1.0	74.0	83.0	
	Pmono	1.0	72.3		
	Omono	1.0			76.0
	Cmono	1.0		83.0	
Redvers	PO0N	1.0	74.0		75.8
	PO1/4N	1.0	74.5		76.0
	PO1/2N	1.0	74.0		75.3
	PC0N	1.0	75.0	95.0	
	PC1/4N	1.0	74.0	95.0	
	PC1/2N	1.0	73.8	95.3	
	Pmono	2.0	75.8		
	Omono	1.3			73.3
	Cmono	1.0		95.5	
Swift Current	PO0N	1.5	85.5		77.3
	PO1/4N	1.3	84.3		77.0
	PO1/2N	1.3	85.0		77.3
	PC0N	1.0	78.5	86.8	
	PC1/4N	1.3	78.8	87.3	
	PC1/2N	1.8	79.0	87.3	
	Pmono	1.0	79.0		
	Omono	1.0			78.0
	Cmono	1.0		86.3	

* Plant lodging was rated on scale of 1 (upright) to 10 (flat).
† PO0N = pea and oat intercrop without N fertilizer, PO1/4N = pea and oat intercrop with 1/4 of recommended N rate for oat monocrop, PO1/2N = pea and oat intercrop with 1/2 of recommended N rate for oat monocrop, PC0N = pea and canola intercrop without N fertilizer, PC1/4N = pea and canola intercrop with 1/4 of recommended N rate for oat monocrop, PC1/2N = pea and canola intercrop with 1/2 of recommended N rate for oat monocrop, Pmono = pea monocrop, Omono = oat monocrop, and Cmono = canola monocrop.

10. **Interim conclusions (*Maximum of 500 words)*.**

- The preliminary results in 2021 showed that the impact of intercropping on grain yield, grain quality, and straw biomass varied among three different ecozones. The land equivalent ratio (LER) and pea equivalent yield (PEY), which was calculated based on grain yield and price, were used to examine the effect of intercropping on grain yield. The LER results showed that, compared to monocrops, intercrops slightly increased grain yield by 1% and 3% per unit of land at Melfort and Redvers (moist ecozones), respectively. However, the intercropping decreased the yield by up to 17% at Swift Current (dry ecozone), which was unexpected. The reduced crop production in intercrops at Swift Current can be due to the extreme drought but needs to be verified with more data collected in the coming two years.
- The PEY was not different between intercrops and pea monocrops at moist sites of Melfort and Redvers; however, at Swift Current, PEY was significantly lower in pea-oat intercrops than in the pea monocrop. Increasing N rates in intercrops from 0 to ½ of recommended rate for the companion non-pea monocrops had no effects on PEY for both pea-oat and pea-canola intercrops.
- Pea-canola intercrop produced higher straw biomass than pea-oat intercrop, which might help increase soil carbon sequestration. There was no difference in straw biomass between intercrops and monocrops at Melfort and Redvers, but the pea monocrop produced similar or higher straw biomass than intercrops at Swift Current.
- For pea-oat intercrop, increasing N rate had no effect on oat grain quality as indicated by the percentage of plump, beta-glucan content, and protein content. Compared with the oat monocrop, intercropping oat with pea increased the percentage of plump seed by 44, 8, 19% at Melfort, Redvers, and Swift Current, respectively; while intercropping oat with pea reduced the protein content of oat by 9, 4, and 8% at Melfort, Redvers, and Swift Current, respectively.
- There was no significant difference in straw biomass between intercrops and monocrops at Melfort and Redvers; however, straw biomass was 20-35% greater in the pea monocrop than in the pea-oat intercrops at Swift Current.
- Regarding the diseases, intercropping pea with oat or canola did not impact diseases under low disease pressure in the dry year of 2021.
- Biological N fixation and N transfer from pea to oat (or canola) will be reported once the data from chemical lab become available
- As planned, economic analysis will be performed in the last year of this project when all input and output data are available.
- The year of 2021 was extremely dry; therefore, cautions should be taken when extrapolating these preliminary findings from 2021 to a normal weather year. The results generated from the remaining two years, together with the 2021 results, will provide more solid information regarding intercrops compared with monocrops.

11. **List any technology transfer activities undertaken in relation to this project: *Include conference presentations, talks, papers published etc.***

- Hubbard M, Shaw L, May W, Chatterton S, Ostlie M, Keene C. 2022. Intercropping and Disease. Intercropping webinar- Lakeland Agricultural Research Association, North Peace Applied Research Association and Peace Country Beef & Forage Association Applied Research. Feb 8, 2022. Virtual

12. **Identify any changes expected to industry contributions, in-kind support, collaborations or other resources.**

No change is required.

12.1 Reference

CHAPAGAIN, T. and RISEMAN, A. (2014) Barley–pea intercropping: Effects on land productivity, carbon and nitrogen transformations. *Field Crops Research,* **166**, 18-25.

DEACON, J. W. and MITCHELL, R. T. (1985) Toxicity of oat roots, oat root extracts, and saponins to zoospores of Pythium spp. and other fungi. *Transactions of the British Mycological Society,* **84** (3), 479-487.

DERBYSHIRE, M. C. and DENTON-GILES, M. (2016) The control of sclerotinia stem rot on oilseed rape (Brassica napus): current practices and future opportunities. **65** (6), 859-877.

GOSSEN, B. D., et al. (2016) Identifying and managing root rot of pulses on the Northern Great Plains. **100** (10), 1965-1978.

HE, X., et al. (2009) Use of 15N stable isotope to quantify nitrogen transfer between mycorrhizal plants. *Journal of Plant Ecology,* **2** (3), 107-118.

HOLZAPFEL, C. and CHALMERS, S. (2011) Exploring the merits of field pea-canola intercrops for improved yield and profit. *2011 IHARF annual report*.

HOSSAIN, Z., et al. (2016) Biological nitrogen fixation by pulse crops on semiarid Canadian prairies. *Canadian Journal of Plant Science,* **97** (1), 119-131.

KHAKBAZAN, M., et al. (2018) Economic Impact of Residual Nitrogen and Preceding Crops on Wheat and Canola. **110** (1), 339-348.

KHAKBAZAN, M., et al. (2009) Effects of alternative management practices on the economics, energy and GHG emissions of a wheat-pea cropping system in the Canadian prairies. *Soil and Tillage Research,* **104** (1), 30-38.

KNIGHT, J. D. (2012) Frequency of field pea in rotations impacts biological nitrogen fixation. *Canadian Journal of Plant Science,* **92** (6), 1005-1011.

KONTTURI, M., et al. (2011) Pea–oat intercrops to sustain lodging resistance and yield formation in northern European conditions. *Acta Agriculturae Scandinavica, Section B — Soil & Plant Science,* **61** (7), 612-621.

LIU, K., et al. (2020) Intensifying crop rotations with pulse crops enhances system productivity and soil organic carbon in semi-arid environments. *Field Crops Research,* **248**, 107657.

LIU, K., et al. (2019a) Lentil enhances the productivity and stability of oilseed-cereal cropping systems across different environments. *European Journal of Agronomy,* **105**, 24-31.

LIU, L., et al. (2019b) A side-by-side comparison of biological nitrogen fixation and yield of four legume crops. *Plant and Soil,* **442** (1), 169-182.

MAY, W. E., et al. (2004) Effect of nitrogen, seeding date and cultivar on oat quality and yield in the eastern canadain prairies. *Canadian Journal of Plant Science,* **84**, 1025-0336.

O'DONOVAN, J. T., et al. (2014) Rotational effects of legumes and non-legumes on hybrid canola and malting barley. **106** (6), 1921-1932.

PELZER, E., et al. (2012) Pea–wheat intercrops in low-input conditions combine high economic performances and low environmental impacts. *European Journal of Agronomy,* **40**, 39-53.

SHANG, H., et al. (2000) Oospore Germination of Aphanomyces euteiches in Root Exudates and on the Rhizoplanes of Crop Plants. **84** (9), 994-998.

SHAW, L., et al. (2020) Final report for pea oat intercrop demonstration.

ST. LUCE, M., et al. (2015) Legumes can reduce economic optimum nitrogen rates and increase yields in a wheat-canola cropping sequence in western canada. *Field Crops Research,* **179**, 12-25.

STRYDHORST, S. M., et al. (2008) Forage Potential of Intercropping Barley with Faba Bean, Lupin, or Field Pea. **100** (1), 182-190.

TAVEIRA, C. J., et al. (2020) Tracing crop residue N into subsequent crops: Insight from long-term crop rotations that vary in diversity. *Field Crops Research,* **255**.

WILLSEY, T., et al. (2018) Detection of interactions between the pea root rot pathogens Aphanomyces euteiches and Fusarium spp. using a multiplex qPCR assay. *Plant Pathology,* **67** (9), 1912-1923.

ZENTNER, R. P., et al. (2004) Effects of tillage method and crop rotation on non-renewable energy use efficiency for a thin Black Chernozem in the Canadian Prairies. *Soil and Tillage Research,* **77** (2), 125-136.

ZWINGER, S., et al. (2018) Intercropping oats and filed pea in organic production system. https://www.ag.ndsu.edu/CarringtonREC/staff/steve-zwinger.