AAFC RESEARCH BRANCH
Research Project Final Report – 2012-2013

Note: If the project ended during fiscal year 2011-2012, you must use the following form: AAFC RESEARCH BRANCH – Research Project Final Report – 2011-2012

RBPI Number:	1925
RBPI Project Title:	3.6.4 - Legume crops to improve soil fertility for enhanced canola production
Cluster Name (if applicable):	Canola
Start Date (yyyy-mm-dd):	2010-04-01
Expected End Date (yyyy-mm-dd):	2013-03-31
Principal Investigator (PI):	John O'Donovan
Alignment with Action Plan Expected Key Result(s): e.g. 3.3 or if does not apply, indicate N/A	4.3 Develop crop production systems to enhance producer profitability by decreasing risk, decreasing cost of production and improving overall economic and environmental sustainability 4.3.1 Develop management practices and standards to promote plant health
Fund Source (name and number) and Functional Area: e.g. SAGES, Fund 0253, FA 5294	Canola cluster Year Functional Area **Functional Area** 2010-2011 5232 - Agri-Science Clusters 2011-2012 5232 - Agri-Science Clusters 2012-2013 5232 - Agri-Science Clusters

Short Executive Summary of report:

Hybrid canola is a strong consumer of nitrogen fertilizer. Legume crops fix nitrogen from the atmosphere. The objectives were to investigate the effects of growing legumes in rotation on hybrid canola and barley productivity, gravimetric soil moisture levels, soil microbial biomass and diversity, sclerotinia risk, inorganic and mineralizable nitrogen and overall economics. Experiments were established at seven locations across western Canada in 2009. Crops seeded were field pea, lentil, fababean, canola and wheat taken for seed, and fababean as a green manure. The legumes received no fertilizer nitrogen while canola and wheat were fertilized according to the soil test recommendation. Hybrid Canola was seeded in 2010 and 2012 and malting barley in 2011 and nitrogen was applied at 0, 30, 60, 90 and 120 kg/ha. Since canola would normally be rotated with a cereal crop such as wheat, canola and barley yields on wheat residue were compared to yields on all other residues.

In 2010, canola yields were consistently higher when canola was grown on fababean green manure residue compared to wheat and all other crop residues. When fababean was grown for seed, canola yield increases occurred at only three of the seven locations. Significant increases in canola yield occurred on pea and lentil residue at four of the seven locations, but the increases were not generally as high as when canola was grown on fababean green manure. Growing canola on canola residue resulted in significant canola yield reductions at three of the seven locations. This was unexpected since there

was no evidence of increased disease incidence after only two years of canola. In most cases, there was a general increase in yield with increasing nitrogen rate regardless of crop residue. In general, % canola oil tended to be lower when canola was grown on the legume residues (especially fababean green manure) compared to wheat or canola residues but there were some exceptions. Decreases in % oil relative to wheat residue occurred with fababean green manure residue at all locations except Lethbridge and Scott, and with fababean grown for seed at all locations except Beaverlodge and Scott. Reductions in % oil with lentil residue occurred only at Beaverlodge and did not occur with pea residue at any location suggesting that pea and lentil residues may be less likely to result in lower canola oil content than fababean residues. The impact on canola oil is presently less important than impacts on yield since growers are not paid based on oil content. However, this may change in the future. At most locations, % canola oil decreased with increasing nitrogen rate. This was expected since protein content usually increases with increasing nitrogen rate and there is a reciprocal relationship between oil and protein.

The beneficial effects of the legume residues in enhancing barley yield compared to wheat residue were evident at most locations in 2011. Again, the fababean green manure residue tended to be most consistent and effective in enhancing barley yield. Barley yield significantly increased at all locations except Swift Current. As with canola, fababean grown for seed residue was less effective and consistent in increasing yield of barley, and beneficial effects were evident only at three of the seven locations. Beneficial effects of pea and lentil residue also carried over to 2011. Pea and lentil residue increased yield at three and four of the seven locations, respectively. Canola residue (2009) resulted in increased barley yield at three of the locations. In most cases, there was a general increase in barley yield with increasing nitrogen rate. However, the significant interaction between residue and nitrogen rate at Beaverlodge and Lacombe suggests that the nitrogen rate required to optimize yield varied with crop residue at these locations. At Lacombe, barley yield decreased with most of the residues at nitrogen rates above 30 kg/ha. This was most likely due to severe lodging at the higher nitrogen rates, especially with the fababean green manure residue. This suggests that legumes grown in rotation may increase barley lodging at high nitrogen rates and result in reduced yield. The effect of crop residue on % barley protein (as determined by NIRS) was significant at five of the seven locations while the effect of nitrogen rate was significant at all locations. In some cases, % protein tended to be higher when barley was grown on the legume residues compared to wheat or canola residues but there were some exceptions and results tended to be variable. Increases in % protein relative to wheat residue occurred with fababean green manure residue at three of the seven locations. Pea or fababean grown for seed residues did not result in protein increases. Overall, legume residues established in 2009 rarely resulted in unacceptable protein level. As expected, at most locations, % protein increased with increasing nitrogen rate, sometimes to unacceptable levels (> 12.5%) for malting; and increasing seed protein levels resulted in lower levels of malt extract. Overall, high protein barley tended to modify more poorly resulting in higher beta glucan, and lower friability. The effect of crop residue on quality was not consistent across locations. At Lacombe, barley planted on lentil and fababean green manure had significantly higher protein, accompanied by smaller kernels. This resulted in malts with lower extract and poorer friability. At Swift Current and Brandon, crop residue had no significant effect on barley protein content, or other related malt quality factors.

The effects of the crop residues established in 2009 had very variable, unexplainable and somewhat unexpected effects on canola yield in 2012. Improved canola yield due to the fababean green manure residue were evident only at Lacombe and Lethbridge, while improved yield due to pea and lentil residue occurred only at Lethbridge. Unexpectedly, there were several instances of canola yield decreases where legume crops were grown in 2009 compared to where wheat residues were grown. This occurred with pea residue at Indian Head and Brandon, with lentil residue at Brandon, and with fababean green manure residue at Swift Current and Brandon. At Brandon, almost all residues resulted in reduced canola yield relative to wheat residue. These results are difficult to explain. There was no evidence of increased disease incidence with the legume residues. Responses to nitrogen rate were variable among locations but in most cases there was little or no advantage to increasing the nitrogen rate above 60 kg/ha.

In 2010, there were no differences in soil microbial biomass, diversity or enzyme activity between treatments at Lethbridge. In canola rhizosphere at Beaverlodge, microbial biomass was highest where canola was grown after pea, and lowest where canola followed lentil. In bulk soil at the same site, β-glucosidase enzyme activity was lower where canola followed lentil and fababean green manure than in the other treatments. At Lacombe, there were no differences between treatments in bulk soil. In canola rhizosphere, microbial diversity was lower in canola following lentil and in continuous canola than in other treatments. The low soil microbial biomass, diversity or enzyme activity when canola was grown after lentil may be related to poor adaptability of lentil to the northern climates of Beaverlodge and Lacombe. In barley rhizosphere at Beaverlodge, microbial biomass was highest where fababean for seed and canola had been grown in 2009 and lowest where lentil, fababean green manure and wheat had been grown. At Lethbridge, microbial biomass was in the order: fababean green manure > wheat = lentil ≥ fababean = canola ≥ pea. The order of microbial biomass at Lethbridge is more reflective of the effect that fababean green manure had on canola yields in 2010 than the order at Beaverlodge. There were no differences in soil microbial biomass, diversity or enzyme activity between treatments in bulk soil at either site in 2011. Similarly, there were no significant differences among treatments in MBC, β-glucosidase enzyme activity, or diversity of bacteria in canola rhizosphere or bulk soil at any site. Overall, effects of crop residues on soil microbial biomass and diversity were variable and likely of little significance over the long-term.

Crop residues had few significant effects on gravimetric soil moisture. Some significant differences occurred at three of the locations. These were relatively minor but the most important may have been at Beaverlodge which was relatively dry compared to the other locations. At 60-90 cm depth, plots with fababean green manure residue had 6% more soil moisture than plots with canola and wheat residue; and plots with lentil residue had 5% more moisture than plots with canola and wheat residue.

Total soil nitrate-N in the upper 60 cm in the fall of 2009 was highest after fababean green manure in half of the sites, but soil nitrate-N was not consistently higher after pulse crops than after canola or wheat. However, when averaged across locations, fall nitrate levels were highest after Fababean Green manure and lowest after wheat. This effect of the preceding crop on nitrate N persisted through the following season of canola production to the fall of 2010. Nitrate content in the fall was higher after the fababean green manure than after the other crops at all sites but Swift Current, with the difference not being statistically significant at Scott. Nitrate was also high after lentil at Beaverlodge, Brandon, and Swift Current with a similar tendency occurring at Scott. Lowest residual N levels normally occurred after wheat.

By 2011, after the production of a second crop, barley, significant effects of the crop residue grown in the first year of the study only occurred at Beaverlodge, where the fababean green manure still had higher soil nitrate levels than the other crops. Numerically, the nitrate levels after fababean green manure were also higher than after the other crops at Scott, but the effect was not significant due to high field variability. In fall of 2010, residual nitrogen was affected by N application on all sites. The increase was relatively low at low rates of application up to approximately 60 kg N ha^{-1} where N fertilizer rate was well-matched with crop demand. When rates of application increased beyond approximately 60 kg N ha^{-1}, depending on the site, residual nitrogen began to increase significantly. Residual N levels in 2011 showed a similar pattern to that observed in 2010, with large increases occurring primarily above the 60 kg N ha^{-1} application rate . At Brandon in particular, residual N levels were high at the highest rate of N application, indicating over-fertilization. Based solely on residual nitrate levels, it appears that the optimum N application rate would have been between 60 and 90 kg N ha^{-1} at most locations.

Seed yield of canola and the yield response to N application was related to soil nitrate-N concentration to some extent, but there were discrepancies. For example, soil nitrate-N at Beaverlodge and Lacombe was low compared to that at Brandon, yet the canola seed yield was as high or higher in the unfertilized check and response to fertilizer application lower at these two sites than at Brandon. This may indicate high levels of mineralizable N at the Beaverlodge and Lacombe sites. This aspect of the study is continuing for another two years and several mineralization tests are being evaluated for their ability to more accurately predict plant-available N and potential response to N fertilization at these field locations. An economic analysis is also currently underway.

In conclusion, the results indicate that growing legume crops in rotation with canola and barley can provide a viable alternative to inorganic nitrogen. The fababean green manure resulted in the highest yields but it is doubtful if this would be economically viable since growers would not accrue any monetary returns during the year the green manure was grown. However, growing pea or lentil for yield would be a more viable and economic alternative. The legumes provided little or no advantage in terms of conserving soil gravimetric moisture. The soil mineralization aspect of the study is continuing for another two years and several mineralization tests are being evaluated for their ability to more accurately predict plant-available N and potential response to N fertilization. An economic analysis is also currently underway.

A. Research Progress and Accomplishments (to date in relation to expected milestones and deliverables / outputs)

- Include brief summary of:
  - Introduction, literature review, objectives, milestones and deliverables / outputs.
  - Approach / methodology (summary by objectives).
- Include results and discussion (overview by objectives and milestones), next steps and references.

INTRODUCTION

The unpredictability of fertilizer costs has resulted in increased interest in the investigation of alternatives to inorganic nitrogen e.g. the cost of a tonne of urea increased 31% between 2006 and 2008. Farmers are interested in cost-effective options that would reduce fertilizer input costs while maintaining soil nutrient levels for optimum crop production. Pulse crops, with their ability to fix nitrogen, have the potential to reduce the requirement for inorganic N in subsequent crops. Our knowledge of the rotational effects of pulse crops throughout the different soil and climatic zones in the Northern Great Plains remains imprecise and inadequate (Miller et al. 2002). Previous research (mainly with cereal crops) suggests that pulse crops that can achieve high levels of N2 fixation (e.g. field pea, fababean and lentil) contribute positively to the overall N economy (Walley et al. 2007). However, virtually no research of a similar kind has been conducted with canola. Studies conducted on the Northern Great Plains to quantify pulse crop N benefits have resulted in highly variable estimates (Walley et al. 2007). It is possible that if a common protocol was used across multiple locations our knowledge of the reasons for the variability may become clearer. Using grain legumes in rotation was also shown to offer interesting options for reducing environmental burdens and promoting greater energy efficiencies (Nemecek et al. 2008).

Excess N application is a major cause of poor N use efficiency (NUE), contributing to negative environmental impacts and reduced economic benefit. Soil nitrate is used in western Canada to predict soil N supply and N fertilizer recommendations, but its effectiveness may have decreased due to changing crop production practices. Higher yielding cultivars, reduced tillage, cropping intensification, and higher fertilizer input over time may have increased the return of high N crop residues to the soil and increased the contribution of in-season N mineralization to the crop N supply (Grant et al., 2002). A more accurate estimate of the total supply of both inorganic and mineralizable N is needed to predict N requirements and avoid over- or under-fertilization.

This experiment also provided the opportunity to assess the effects of the crop residues, especially the pulse residues on yield and quality of malting barley seeded two years after establishment of the pulses. Quality requirements for malting barley are strict, including a requirement for low protein. As a result, producers can be reluctant to grow malting barley on pulse crop residues due to the perceived negative effect on grain protein. Previous studies have found that growing malting barley the year following peas did not have a major impact on protein levels, but may have other negative effects on quality such as reduced friability (Turkington et al. 2012). This study investigated the effect of the legume residues two years after theirestablishment.

OBJECTIVES

To determine:

1) the effect of different crop residues established in 2009 on yield and quality of subsequent hybrid canola in 2010 and 2012 and barley in 2011.

2) the effect of different crop residues on gravimetric moisture at various depths.

3) the impact of the relatively slow release nitrogen provided by the pulse residues on soil health as measured by microbial biomass and diversity.

4) the relative risk of sclerotania when canola is seeded on pulse crop residues.

5) the effect of the residues on inorganic and mineralizable nitrogen.

6) the economics of growing a pulse to supplement nitrogen requirements of canola and possibly reduce the amount of inorganic nitrogen required to optimize yield.

METHODOLOGY

General

Experiments were established at 7 AAFC locations (Beaverlodge, Lacombe, Lethbridge, AB; Scott, Indian Head, Swift Current, SK; Brandon, MB) across western Canada in 2009. Crops seeded were field pea, lentil, faba bean, canola and wheat taken for seed, and fababean as a green manure. For the green manure treatment, fababean was sprayed with glyphosate at the early pod stage and mowed and the residue left on the soil surface. The legumes received no fertilizer nitrogen while canola and wheat were fertilized according to the soil test recommendation. In the fall of 2009, soil moisture was sampled to depths of 0-30, 30-60 and 60-90 cm. In 2010, hybrid canola was seeded and nitrogen was applied at 0, 30, 60, 90 and 120 kg/ha. The experiment was a randomized complete block with a split-plot feature. Crop residues were assigned to main plots and nitrogen rates to sub-plots. All crops were direct seeded using zero tillage seeders with knife openers. In 2011 and 2102, malting barley and canola, respectively, were seeded and nitrogen was again applied at 0, 30, 60, 90 and 120 kg/ha.

Accumulation of Nitrate and Ammonium

Soil samples were taken in the fall after crop harvest and analysed for nitrate, ammonium and for mineralizable N using several techniques. A split-plot design with four replicates was used with preceding crop as the main plot and N rates as sub-plots. Crops were harvested at maturity and analyzed for seed and tissue N. The ability of the various soil tests to predict plant-available N and the yield response to N application is currently being assessed. Results of the plant portion of the study and N mineralization are reported in different sections of this report. This portion deals with the impact of treatment factors on Nitrate and ammonium nitrogen in the soil to 60 cm after harvest, the portion of nitrogen that would be available for crop utilization the following year in the absence of over-winter or early spring losses prior to crop uptake.

Assessment of Malting Barley Quality

In 2011, protein concentration was determined with a near infrared reflectance spectrometer. Malt analyses included; 1) Malt extract (fine grind), a measurement of the solubility of malt which indicates a malt's beer production potential; 2) Kolbach index, the ratio of soluble malt to total malt protein that indicates how well modified the protein was as soluble protein is required for adequate foam stability in beer but too much soluble protein can result in beer hazes and darker coloured beers; 3) ß-glucan, an indicator of the extent to which the barley endosperm was degraded during malting; 4) Diastatic power and α-amylase, enzymes that produce fermentable sugars from malt starch during the first phase of brewing. Analyses were performed according to the standard methods of the American Society of Brewing Chemists. Malt modification and homogeneity of modification, were assayed with both the friability method.

Assessment of Soil Microbial Biomass and Diversity

Soil samples were collected in canola rhizosphere and bulk soil (0-7.5 cm depth) at flowering stage of canola growth at Beaverlodge, Lacombe and Lethbridge. The samples were analysed for a) Microbial biomass C (MBC), using the substrate-induced respiration (SIR) method, b) Functional diversity of bacteria, using the Biolog® method, which tests the ability of a microbial community to utilize different C substrates contained in a microplate (Eco-plate®), c) β-glucosidase enzyme activity, by colorimetrically determining p-nitrophenol released by the enzyme after incubating the soil with buffered (pH 6.0) p-nitrophenyl-β-D-glucoside.

RESULTS

Effect of Crop Residues on Canola and Barley Yield and Quality

Since canola would normally be rotated with a cereal crop such as wheat, canola and barley yields on wheat residue were compared to yields on all other residues.

Canola 2010: The mixed analysis of variance indicated significant ($p<0.001$) effects of crop residue on canola yield at all locations (Table 1). The effect of nitrogen rate was also significant at all locations except Lacombe. None of the interactions between crop residue and nitrogen rate were significant. Results for Lacombe are omitted for pea and lentil residue due to extensive flooding of most plots in 2010, and some cutworm damage to these plots.

At all locations, canola yields were consistently higher ($p < 0.001$) when canola was grown on fababean green manure residue compared to wheat and all other crop residues (Table 2). The increase in yield varied from 251 kg/ha at Swift Current to 1028 kg/ha at Lacombe (Table 2; Figs. 1A to 7A). When fababean was grown for seed, canola yield increases occurred at only three of the seven locations (Figs. A to 7A; Table 2). Compared to wheat residue, fababean grown for seed residue resulted in increases in yield at Lacombe, Swift Current and Brandon while a significant yield loss occurred at Lethbridge. Significant increases in canola yield occurred on pea and lentil residue at Beaverlodge, Indian Head, Swift Current and Brandon, but the increases were not generally as high as when canola was grown on fababean green manure, and ranged from 158 to 320 kg/ha with pea residue and 173 to 606 with Lentil residue (Figs.1A to 7A; Table 2). The lack of a significant response on pea and lentil residue compared to wheat residue at Lethbridge may have been influenced by a serious outbreak of stripe rust on the wheat crop seeded for residue in 2009. This likely resulted in little soil nitrogen use by the wheat crop in 2009 with higher levels of residual nitrogen in 2010. Growing canola on canola residue resulted in significant canola yield reductions at Beaverlodge, Lethbridge and Brandon (Table 2). This was unexpected since there was no evidence of increased disease incidence after only two years of canola.

Canola yield responses to nitrogen for each crop residue type at each location are presented in Figs. 1A to 7A. In most cases, there was a general increase in yield with increasing nitrogen rate regardless of crop residue. The exception was Lacombe where the response to nitrogen rate was not significant (Table 1; Fig. 2A).

The effect of crop residue on % canola oil was significant at all locations except Scott while the effect of nitrogen rate was significant at all locations except Lethbridge (Table 3). None of the interactions between crop residue and nitrogen rate were significant. In general, % oil tended to be lower when canola was grown on the legume residues (especially fababean green manure) compared to wheat or canola residues but there were some exceptions (Table 4). Decreases in % oil relative to wheat residue occurred with fababean green manure residue at all locations except Lethbridge and Scott, and with fababean grown for seed at all locations except Beaverlodge and Scott (Table 5). Reductions in % oil with lentil residue occurred only at Beaverlodge and did not occur with pea residue at any location (Table 5) suggesting that pea and lentil residues may be less likely to result in lower canola oil content than fababean residues. The impact on canola oil is presently less important than impacts on yield since growers are not paid based on oil content. However, this may change in the future.

At most locations, % canola oil decreased with increasing nitrogen rate (Table 6). This was expected since protein content usually increases with increasing nitrogen rate and there is a reciprocal relationship between oil and protein.

Barley 2011: The mixed analysis of variance indicated significant ($p<0.01$) effects of crop residue (established in 2009) on barley yield at all locations except Scott where residue had no effect (Table 1). The effect of nitrogen rate was significant ($p < 0.001$) at all locations, and there was a significant residue x nitrogen rate interaction only at Beaverlodge and Lacombe.

The beneficial effects of the legume residues in enhancing barley yield compared to wheat residue were again evident at most locations in 2011. Again, the fababean green manure residue tended to be most consistent and effective in enhancing barley yield (Figs.1 B to 7B; Table 2). Barley yield significantly increased at all locations except Swift Current, and ranged from 263 kg/ha at Scott to 972 kg/ha at Beaverlodge. As with canola, fababean grown for seed residue was less effective and consistent in increasing yield, and beneficial effects were evident only at Beaverlodge, Lacombe and Indian Head (Figs.1 B to 7B; Table 2). Beneficial effects of pea and lentil residue also carried over to 2011. Pea residue increased yield at Beaverlodge, Lethbridge and Brandon while lentil residue increased yield at Beaverlodge, Lacombe, Indian Head and Brandon (Figs.1 B to 7B; Table 2). Canola residue (2009) resulted in increased barley yield at Scott, Swift Current and Brandon with no effects at the other four locations (Figs.1B to 7B; Table 2).

Barley yield responses to nitrogen for each crop residue type at each location are presented in Figs. 1B to 7B. In most cases, there was a general increase in yield with increasing nitrogen rate. However, the significant interaction between residue and nitrogen rate at Beaverlodge and Lacombe suggests that the nitrogen rate required to optimize yield varied with crop residue at these locations. At Beaverlodge, yield tended to be optimized at 60 kg/ha nitrogen with most of the crop residues (Fig. 1 B). However, with pea and canola residues, yield was optimized at 120 and 90 kg/ha, respectively. At Lacombe, yield decreased with most of the residues at nitrogen rates above 30 kg/ha. This was most likely due to severe lodging at the higher nitrogen rates, especially with the fababean green manure residue (Fig. 8). Optimum barley yields tended to occur at 60 kg/ha at Scott (Fig. 4B) and Lethbridge (Fig. 3B), 90 kg/ha at Indian Head (Fig. 5B) and Swift Current (Fig. 6B), and 120 kg/ha at Brandon (Fig. 7B).

The effect of crop residue on % barley protein (as determined by NIRS) was significant at all locations except Scott and Swift Current while the effect of nitrogen rate was significant at all locations (Table 3). Interactions between crop residue and nitrogen rate were non-significant at all locations except Scott (Table 3). In some cases, % protein tended to be higher when barley was grown on the legume residues compared to wheat or canola residues but there were some exceptions and results tended to be variable among locations (Table 4). Increases in % protein relative to wheat residue occurred with fababean green manure residue at Beaverlodge, Lacombe and Lethbridge and with lentil residue at Beaverlodge, Lacombe and Swift Current (Table 5). Pea or fababean grown for seed residues did not result in protein increases. Overall, legume residues established in 2009 rarely resulted in unacceptable protein levels (> 12.5%) for malting (Table 6).

As expected, at most locations, % protein increased with increasing nitrogen rate, sometimes to unacceptable levels (> 12.5%) for malting (Table 6).

Barley from each of three locations (Brandon, Lacombe, and Swift Current) was selected for micromalting and quality analysis. Barley from Swift Current was moderately plump, had good germination and vigour, low water sensitivity, and relatively low protein. Barley from Lacombe was similarly plump, with moderate protein, good germination and moderate water sensitivity. Barley from Brandon was of lower plumpness, moderate protein, and had good germination characteristics with no water sensitivity.

Increasing rates of nitrogen fertilization had the expected effect of increasing seed protein levels (Table 7), resulting in lower levels of malt extract (Table 8). Higher protein content also resulted in higher levels of starch-degrading enzymes (Table 8). Overall, high protein barley tended to modify more poorly resulting in higher beta glucan, and lower friability (Table 8).

The effect of crop residue on quality was not consistent across locations (Tables 9 and 10). At Lacombe, barley planted on lentil and fababean green manure had significantly higher protein, accompanied by smaller kernels (Table 9). This resulted in malts with lower extract and poorer friability (Table 10). At Swift Current and Brandon, crop residue had no significant effect on barley protein content, or other related malt quality factors (Tables 9 and 10).

Canola 2012: The mixed analysis of variance indicated significant ($p<0.05$) effects of crop residue on canola yield at all locations except Indian Head while the effect of nitrogen rate was significant ($p<0.001$) at all locations (Table 1). However, none of the interactions between crop residue and nitrogen rate were significant. Results for Scott are omitted due to severe wind damage to the swath canola which compromised the integrity of the results.

Overall, the effects of the crop residues established in 2009 had very variable, unexplainable and somewhat unexpected effects on canola yield in 2012 (Figs.1C to 7C; Table 2). Improved canola yield due to the fababean green manure residue were evident only at Lacombe and Lethbridge, while improved yield due to pea and lentil residue occurred only at Lethbridge (Table 2). Unexpectedly, there were several instances of canola yield decreases where legume crops were grown in 2009 compared to where wheat residues were grown (Figs.1C to 7C; Table 2). This occurred with pea residue at Beaverlodge, Lacombe, Indian Head and Brandon, with lentil residue at Brandon, and with fababean green manure residue at Swift Current and Brandon (Table 2). At Brandon, all residues (with the exception of fababean grown for seed) resulted in reduced canola yield relative to wheat residue. These results are difficult to explain. There was no evidence of increased disease incidence with the legume residues.

Responses to nitrogen rate were variable among locations but in most cases there was little or no advantage to increasing the nitrogen rate above 60 kg/ha (Figs.1C to 7C).

Effect of Crop Residues on Soil Microbial Biomass and Diversity

Canola 2010: There were no differences in soil microbial biomass, diversity or enzyme activity between treatments at Lethbridge. In canola rhizosphere at Beaverlodge, microbial biomass was highest where canola was grown after field pea, and lowest where canola followed lentil. In bulk soil at the same site, β-glucosidase enzyme activity was lower where canola followed lentil and faba bean green manure than in the other treatments. At Lacombe, there were no differences between treatments in bulk soil. In canola rhizosphere, microbial diversity was lower in canola following lentil and in continuous canola than in other treatments. The low soil microbial biomass, diversity or enzyme activity when canola was grown after lentil may be related to poor adaptability of lentil to the northern climates of Beaverlodge and Lacombe.

Barley 2011: In barley rhizosphere at Beaverlodge, microbial biomass was highest where fababean for seed and canola had been grown in 2009 and lowest where lentil, fababean green manure and wheat had been grown (Fig. 9a). At Lethbridge, also in barley rhizosphere, microbial biomass was in the order: fababean green manure > wheat = lentil ≥ faba bean = canola ≥ pea (Fig. 9b). The order of microbial biomass at Lethbridge is more reflective of the effect that faba bean green manure had on canola yields in 2010 than the order at Beaverlodge. There were no differences in soil microbial biomass, diversity or enzyme activity between treatments in bulk soil at either site in

2011.

Site-by-site statistical analysis showed no significant differences amongst treatments in MBC, β-glucosidase enzyme activity, or diversity of bacteria in canola rhizosphere or bulk soil at any site. Therefore, the effects of the legumes grown in 2009 on soil microbial characteristics did not extend to the third subsequent crop. At Beaverlodge in canola rhizosphere, the grand mean for MBC was 841 mg kg^{-1} soil, β-glucosidase enzyme activity was 464 mg nitrophenol kg^{-1} soil h^{-1}, and Shannon index (H') of diversity was 2.20. In bulk soil, MBC was 825 mg kg^{-1} soil, enzyme activity was 483 mg nitrophenol kg^{-1} soil h^{-1}, and H' was 2.07. At Lacombe in canola rhizosphere, the grand mean for MBC was 943 mg kg^{-1} soil, enzyme activity was 427 mg nitrophenol kg^{-1} soil h^{-1}, and H' was 2.48. In bulk soil, MBC was 939 mg kg^{-1} soil, enzyme activity was 378 mg nitrophenol kg^{-1} soil h^{-1}, and H' was 2.05. At Lethbridge in canola rhizosphere, the grand mean for MBC was 816 mg kg^{-1} soil, enzyme activity was 286 mg nitrophenol kg^{-1} soil h^{-1}, and H' was 2.62. In bulk soil, MBC was 859 mg kg^{-1} soil, enzyme activity was 299 mg nitrophenol kg^{-1} soil h^{-1}, and H' was 2.25.

Effect of Crop Residues on Gravimetric Soil Moisture at Various Depths

Crop residues had few significant effects on gravimetric soil moisture (Table 11). Some significant differences occurred at three of the locations but these were relatively minor. At Beaverlodge at 60-90 cm depth, plots with fababean green manure residue had 6% more soil moisture than plots with canola ($p = 0.007$) and wheat ($p = 0.008$) residue; and plots with lentil residue had 5% more moisture than plots with canola ($p = 0.011$) and wheat ($p = 0.014$) residue. At Scott at 15-30 cm depth, plots with pea ($p = 0.014$), fababean grown for seed ($p = 0.006$) and fababean green manure ($p = 0.004$) residues had 4, 5 and 5% higher gravimetric moisture levels, respectively, than plots with canola residues. At Swift Current at 90-120 cm soil depth some differences occurred but these were very minor (< 2% soil moisture). Otherwise, there were no significant differences in soil moisture levels between residues at any of the depths.

Effect of Crop Residues on Sclerotinia Risk

Sclerotinia levels were very low or non-existent at the different locations each year suggesting that there was low risk of sclerotinia infestations when canola was grown after pulse crops.

Impact of Preceding Crop and Nitrogen Management on Accumulation of Nitrate and Ammonium in the Soil Profile

Soil nitrate was measured in the fall after crop production annually to provide information on the available nitrogen that would be present at the end growing season and potentially available for crop production the following year. The fall nitrate test is commonly used to predict available N for the following season's crop production in the Prairie Provinces because nitrogen transformations are normally relatively low from the fall to spring period due to the cold, dry conditions. In this environment, fall nitrate-N is a good predictor of available N and fertilizer requirements for the subsequent year's crop. Fall soil nitrate content will be affected by removal of nitrogen by the crop in the previous growing season, by nitrification-immobilization reactions, by nitrogen fixation of legume crops, by carry-over of unused fertilizer applications and by nitrogen losses by denitrification, leaching, and possibly volatilization. These reactions will all be affected by crop type, management practices, soil characteristics and environmental conditions.

Total soil nitrate-N in the upper 60 cm in the fall of 2009 was highest after fababean green manure in half of the sites, but soil nitrate-N was not consistently higher after pulse crops than after canola or wheat (Table 12). However, when averaged across locations, fall nitrate levels were highest after Fababean Green manure and lowest after wheat.

Effects of preceding crop on nitrate N persisted through the following season of canola production to the fall of 2010 (Table 13). Nitrate content in the fall was higher after the fababean green manure than after the other crops at all sites but Swift Current, with the difference not being statistically significant at Scott. Nitrate was also high after lentil at Beaverlodge, Brandon, and Swift Current with a similar tendency occurring at Scott. Lowest residual N levels normally occurred after wheat.

By 2011, after the production of a second crop, barley, significant effects of the crop grown in the first year of the study only occurred at Beaverlodge, where the fababean green manure still had higher soil nitrate levels than the other crops (Table 14). Numerically, the nitrate levels after fababean green manure were also higher than after the other crops at Scott, but the effect was not significant due to high field variability.

Fertilizer rates were not incorporated in the study until the 2010 crop year, so there were no measured effects of fertilizers in the fall of 2009 sampling. Interaction between nitrogen fertilizer and the preceding crop were only rarely significant, so the discussion will focus on the main effect of the nitrogen.

In fall of 2010, residual nitrogen was affected by N application on all sites (Table 15). The increase was relatively low at low rates of application up to approximately 60 kg N ha^{-1} where N fertilizer rate was well-matched with crop demand. When rates of application increased beyond approximately 60 kg N ha^{-1}, depending on the site, residual nitrogen began to increase significantly. This residual N will remain available for crop use the following year if conditions are dry, but could be lost via denitrification or leaching under wet conditions.

Residual N levels in 2011 showed a similar pattern to that observed in 2010, with large increases occurring primarily above the 60 kg N ha^{-1} application rate (Table 16). At Brandon in particular, residual N levels were high at the highest rate of N application, indicating over-fertilization. Based solely on residual nitrate levels, it appears that the optimum N application rate would have been between 60 and 90 kg N ha^{-1} at most locations.

Total canola seed yield and the yield increase with N application varied substantially with location and preceding crop (Figs. 1 to 7). Seed yield was consistently higher after fababean green manure than wheat or canola, regardless of N fertilizer input or effect on soil nitrate, indicating both a nitrate-based and a non-nitrate-based benefit. Seed yield of canola and the yield response to N application was related to soil nitrate-N concentration to some extent, but there were discrepancies. For example, soil nitrate-N at Beaverlodge and Lacombe was low compared to that at Brandon, yet the canola seed yield was as high or higher in the unfertilized check and response to fertilizer application lower at these two sites than at Brandon. This may indicate high levels of mineralizable N at the Beaverlodge and Lacombe sites. Several mineralization tests are currently being evaluated for their ability to more accurately predict plant-available N and potential response to N fertilization at these field locations.

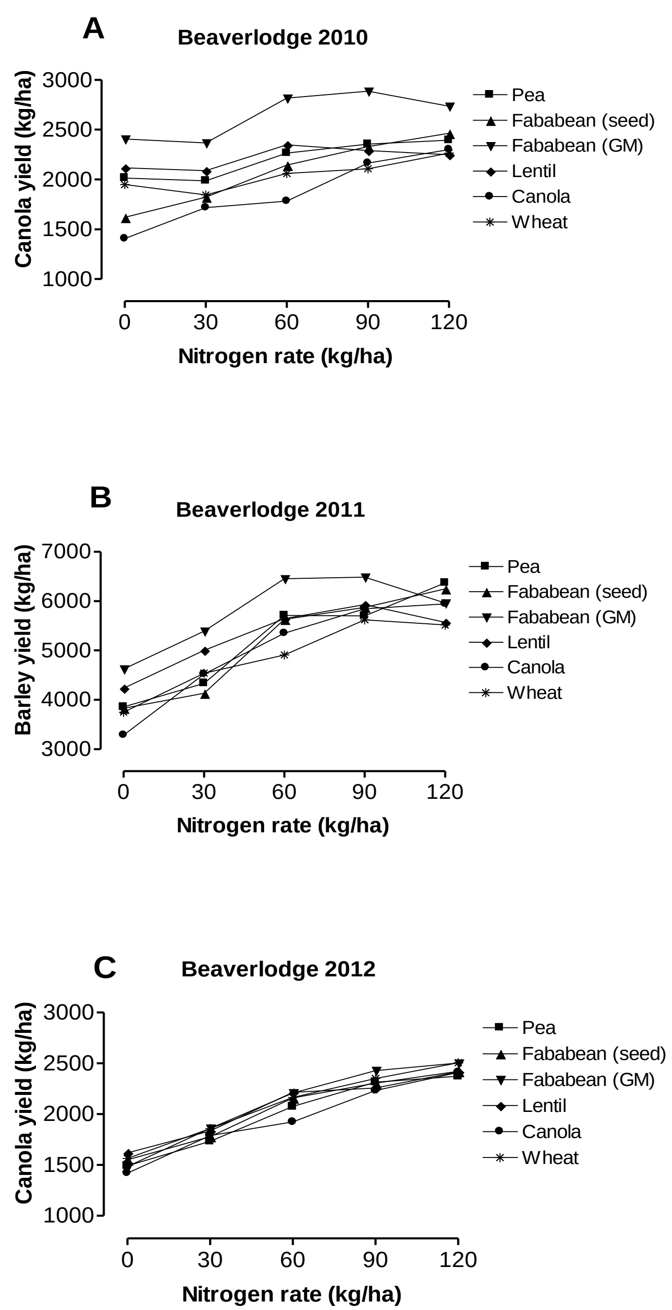


Fig. 1. Canola (2010, 2012) and barley (2011) yield at Beaverlodge as affected by nitrogen rate and various crop residues established in 2009. See Tables 1 and 2 for statistical analyses.

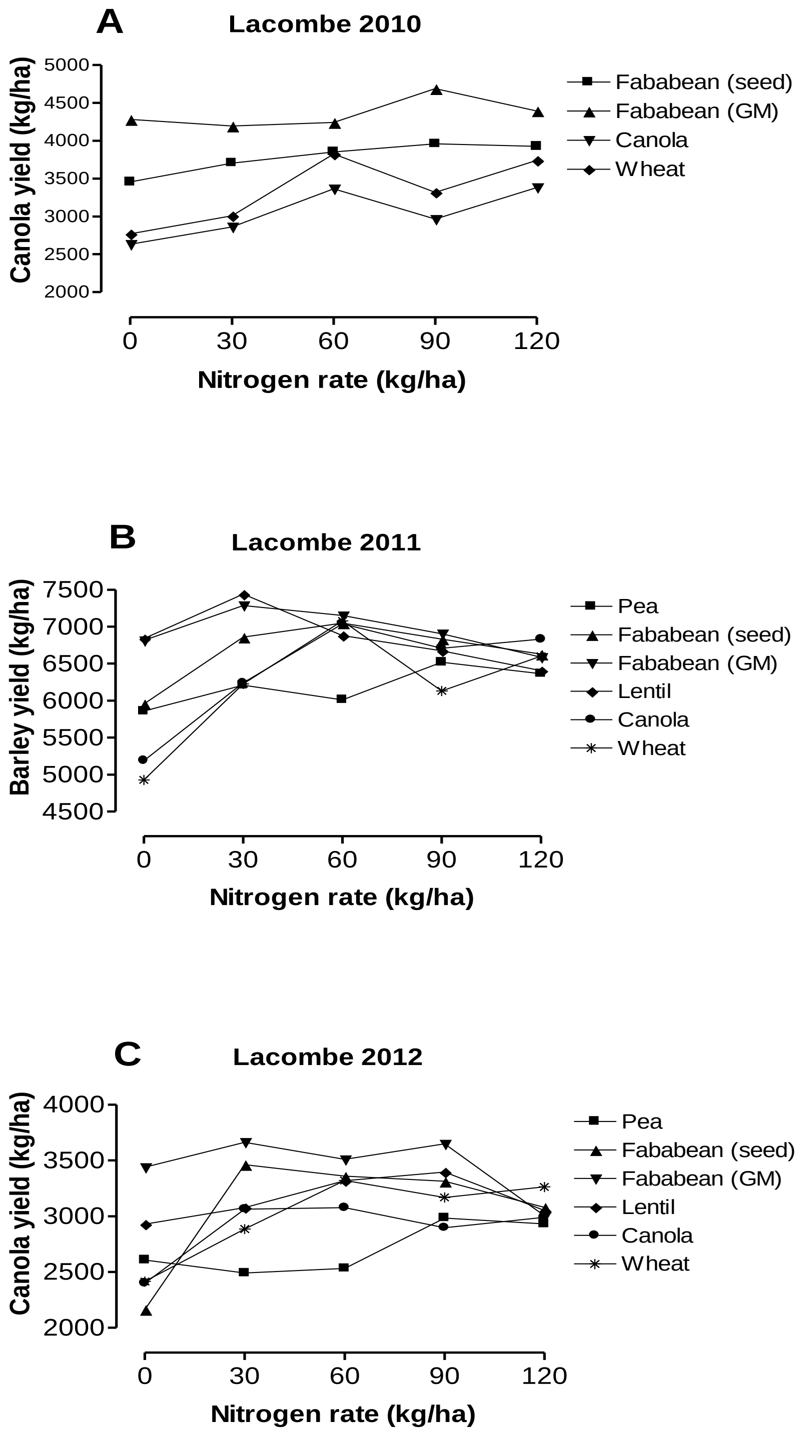


Fig. 2. Canola (2010, 2012) and barley (2011) yield at Lacombe as affected by nitrogen rate and various crop residues established in 2009. See Tables 1 and 2 for statistical analyses.

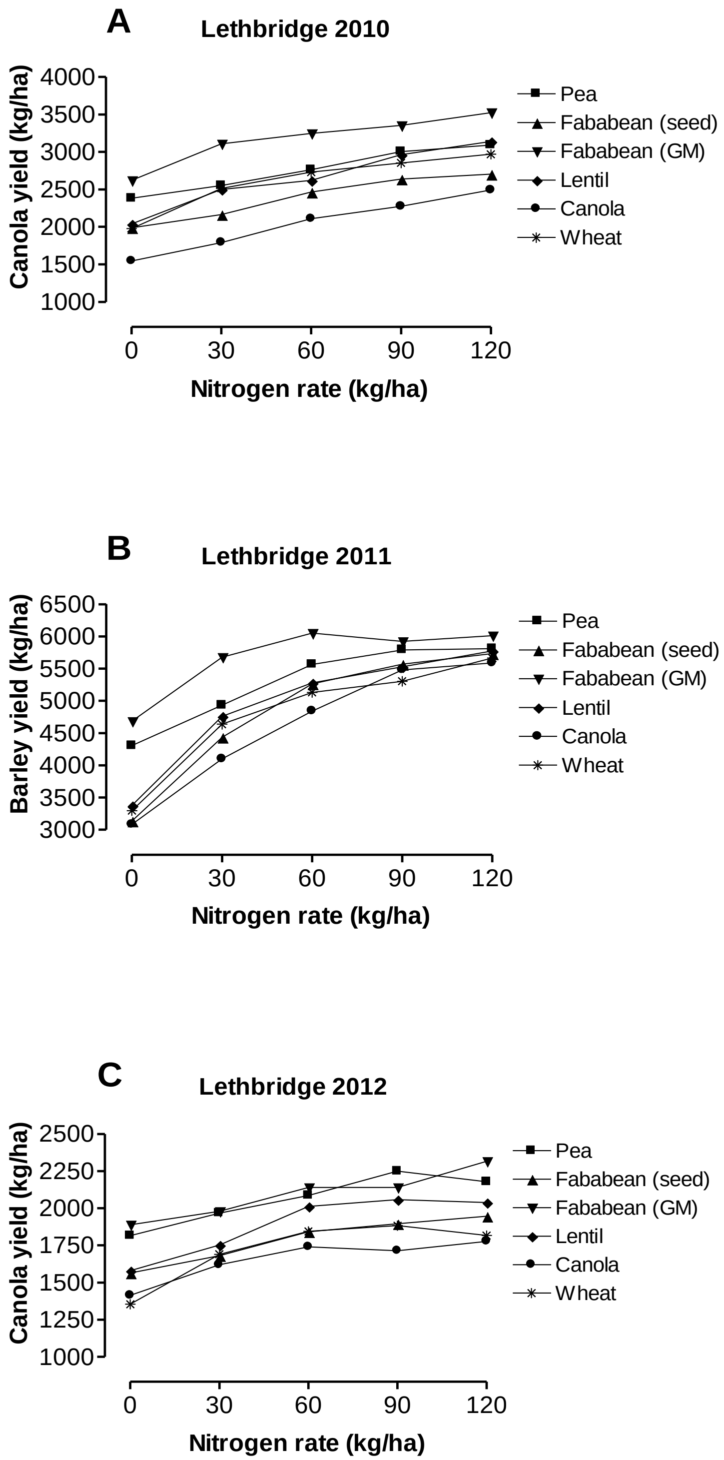
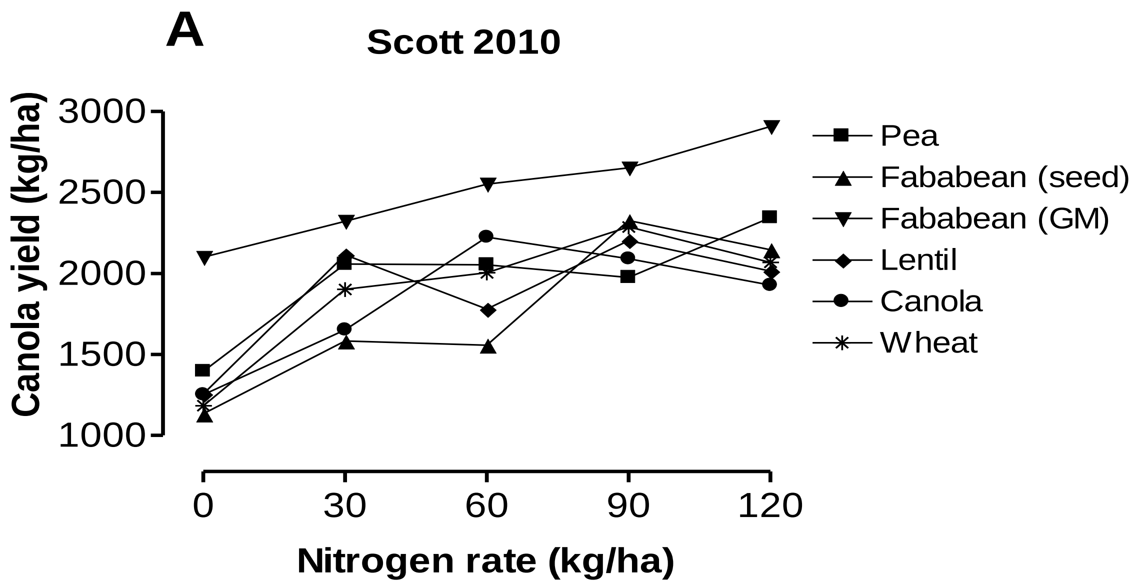


Fig. 3. Canola (2010, 2012) and barley (2011) yield at Lethbridge as affected by nitrogen rate and various crop residues established in 2009. See Tables 1 and 2 for statistical analyses.



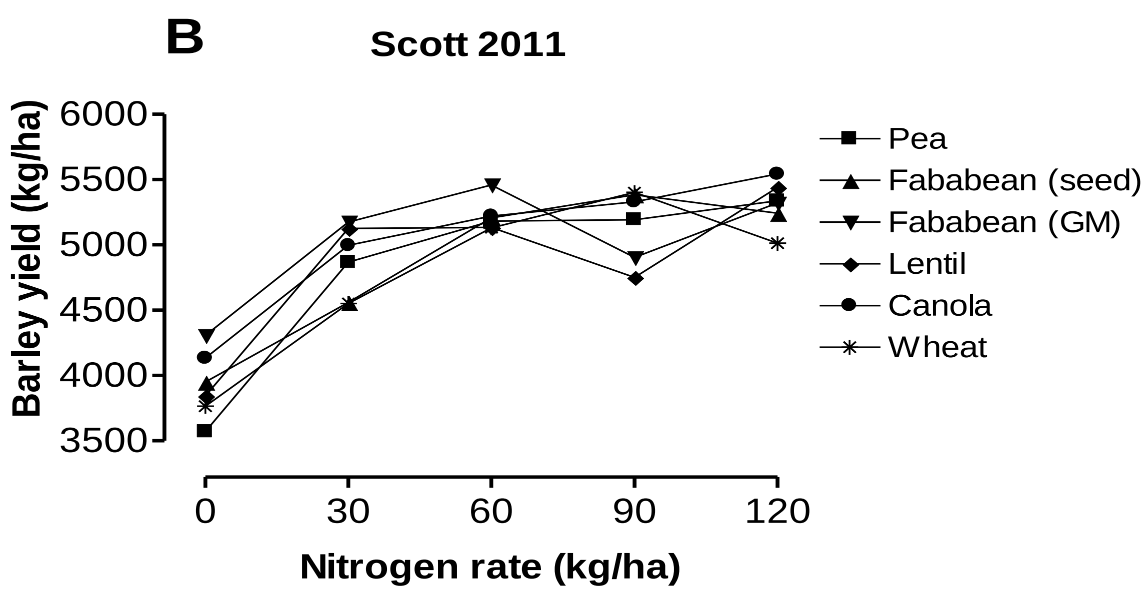


Fig. 4. Canola (2010, 2012) and barley (2011) yield at Scott as affected by nitrogen rate and various crop residues established in 2009. See Tables 1 and 2 for statistical analyses.

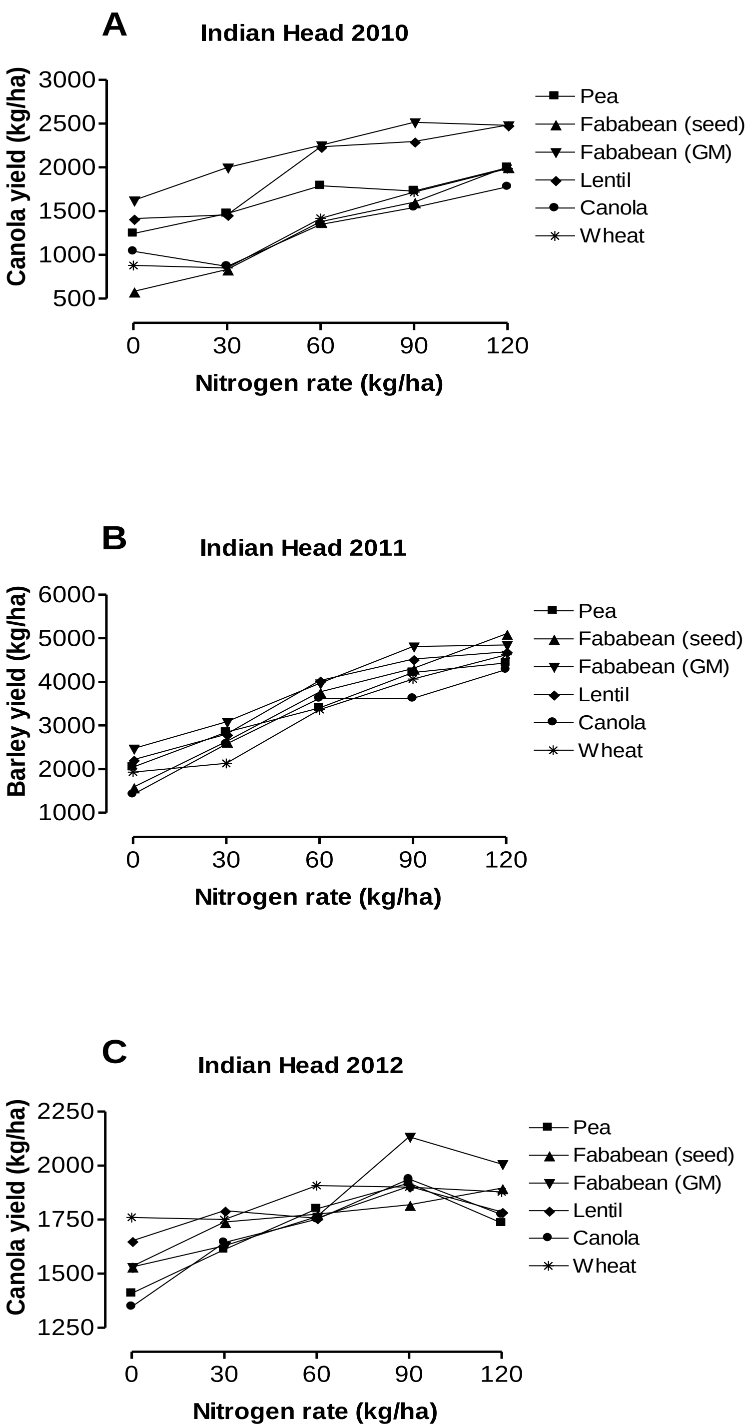


Fig. 5. Canola (2010, 2012) and barley (2011) yield at Indian Head as affected by nitrogen rate and various crop residues established in 2009. See Tables 1 and 2 for statistical analyses.

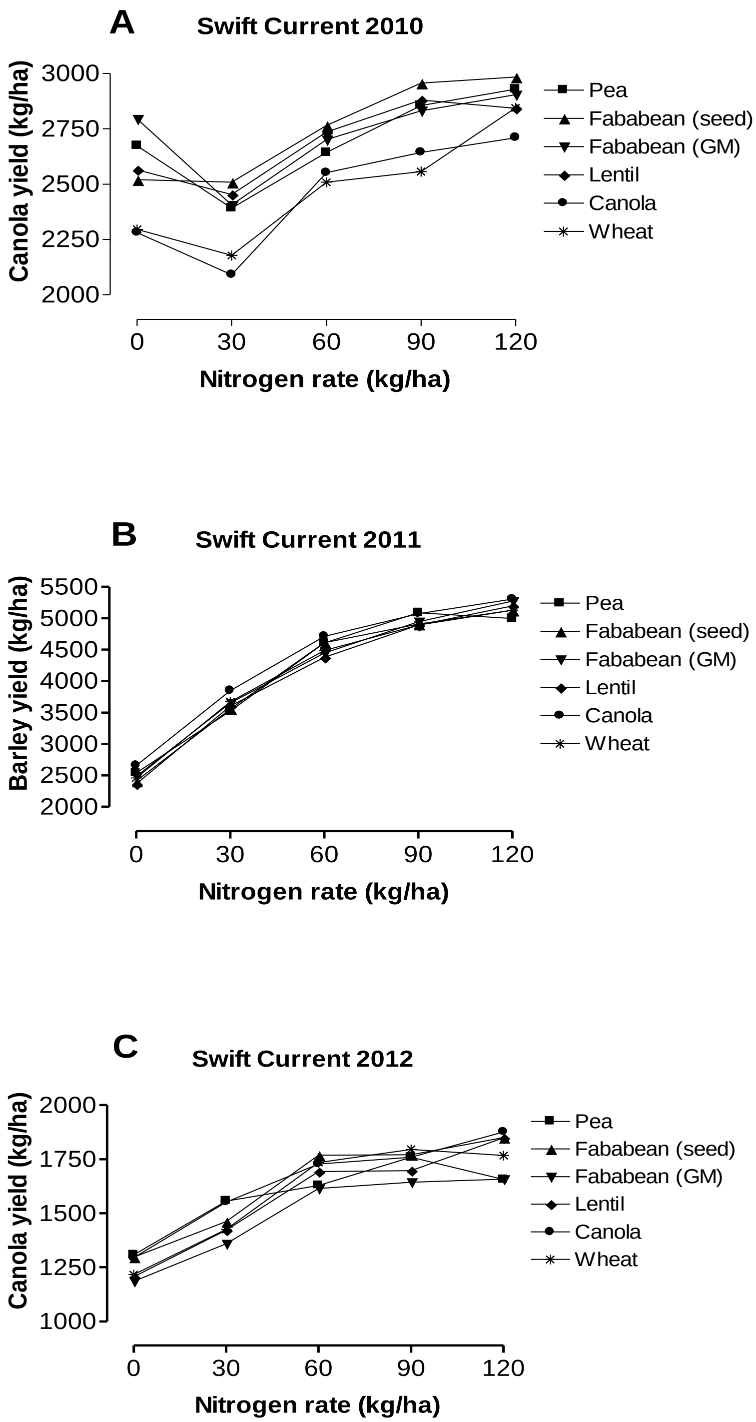


Fig. 6. Canola (2010, 2012) and barley (2011) yield at Swift Current as affected by nitrogen rate and various crop residues established in 2009. See Tables 1 and 2 for statistical analyses.

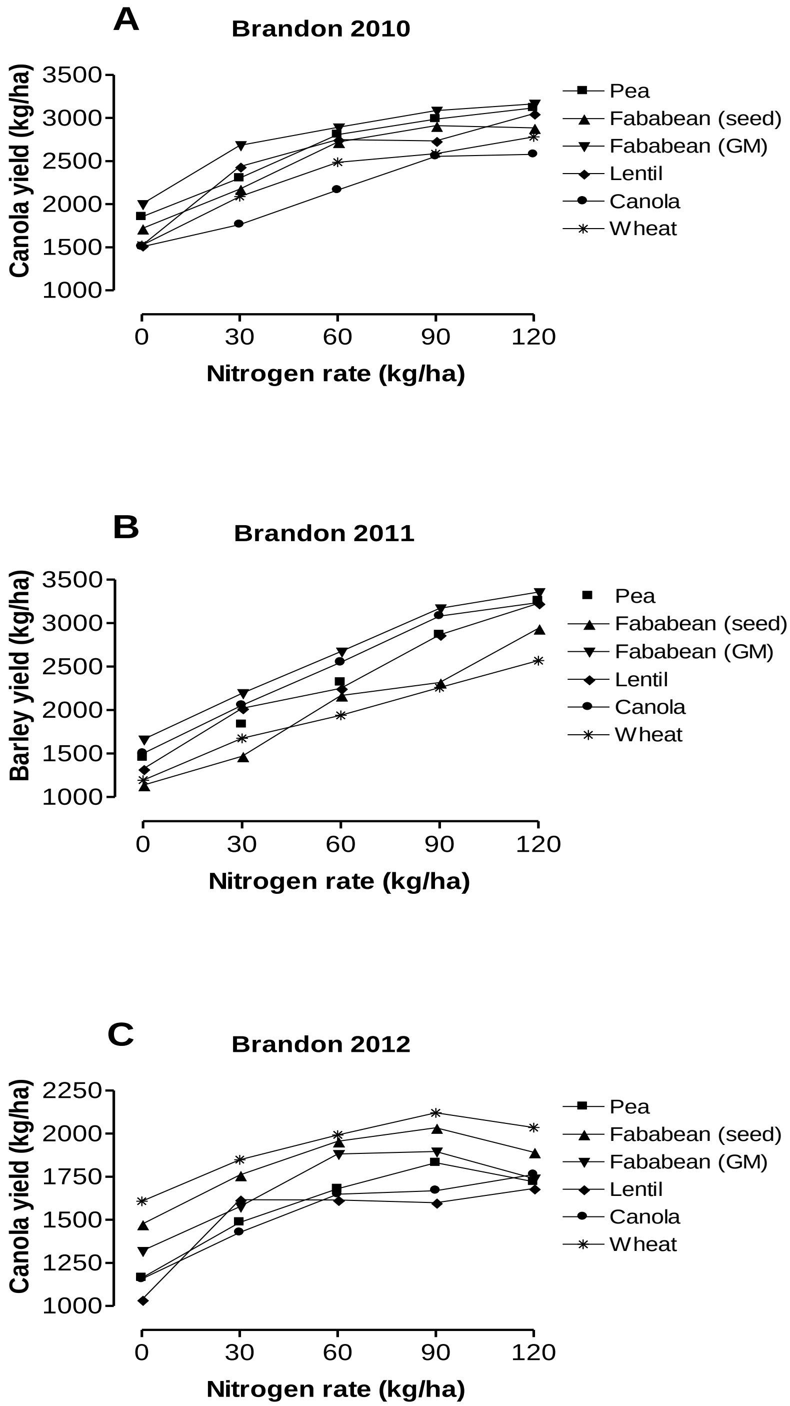


Fig. 7. Canola (2010, 2012) and barley (2011) yield at Brandon as affected by nitrogen rate and various crop residues established in 2009. See Tables 1 and 2 for statistical analyses.

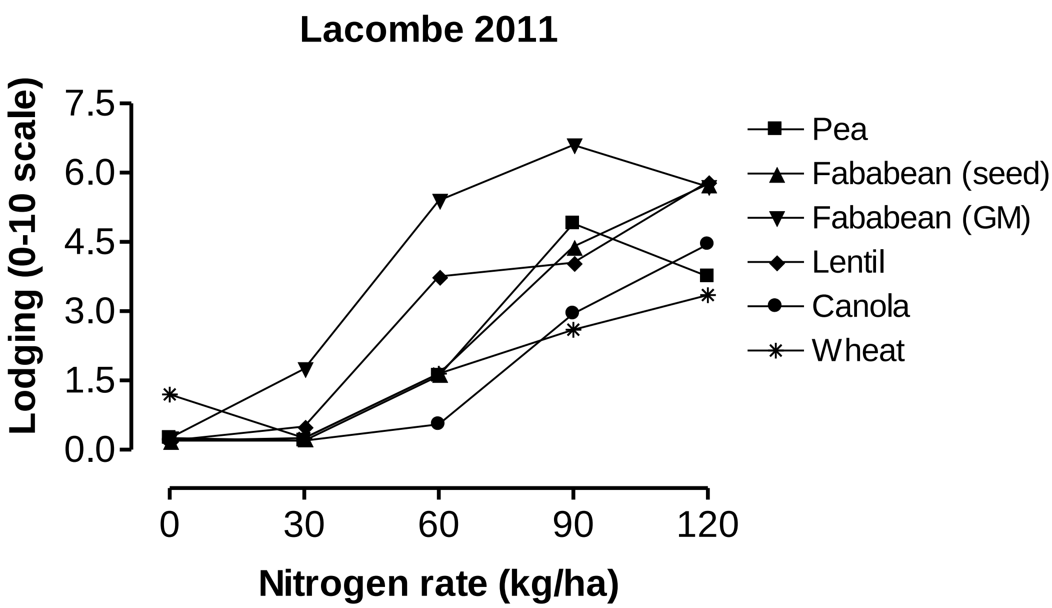


Fig. 8. Effect of crop residues and nitrogen rate on barley lodging at Lacombe in 2011.

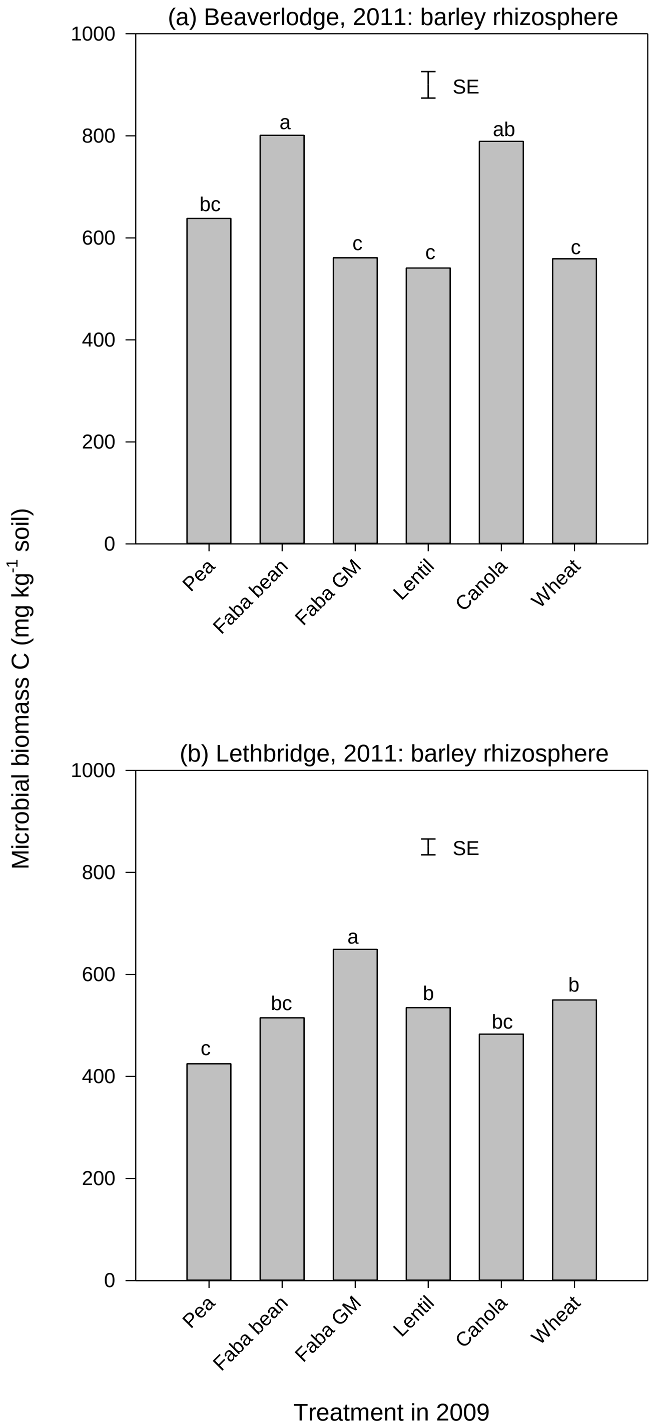


Fig. 9. Soil microbial biomass in the rhizosphere of barley, the second crop grown after 2009 treatments, at Beaverlodge (a) and Lethbridge (b).

Table 1. P values from the ANOVA for the effects of crop residue, nitrogen rate and their interaction on canola yield and barley yield. Crop residues were established in 2009. Bolded values indicate significance at p < 0.10

Year - Crop	Location	Crop residue	Nitrogen rate	Crop residue x nitrogen rate
2010 - Canola	Beaverlodge	**<0.001**	**<0.001**	0.406
	Lacombe	**<0.001**	0.113	0.971
	Lethbridge	**<0.001**	**<0.001**	0.999
	Indian Head	**<0.001**	**<0.001**	0.811
	Scott	**<0.001**	**<0.001**	0.872
	Swift Current	**<0.001**	**<0.001**	0.931
	Brandon	**<0.001**	**<0.001**	0.931
2011 - Barley	Beaverlodge	**<0.001**	**<0.001**	**0.010**
	Lacombe	**<0.001**	**<0.001**	**0.003**
	Lethbridge	**<0.001**	**<0.001**	0.662
	Indian Head	**<0.001**	**<0.001**	0.219
	Scott	0.381	**<0.001**	0.685
	Swift Current	**0.007**	**<0.001**	0.814
	Brandon	**<0.001**	**<0.001**	0.999
2012 - Canola	Beaverlodge	**0.030**	**<0.001**	0.957
	Lacombe	**<0.001**	**<0.001**	0.154
	Lethbridge	**<0.001**	**<0.001**	0.999
	Indian Head	0.112	**<0.001**	0.622
	Scott	-	**-**	-
	Swift Current	**0.017**	**<0.001**	0.883
	Brandon	**<0.001**	**<0.001**	0.988

Table 2. Effect of different crop residues on canola and barley seed yield (kg/ha) gain or loss compared to wheat residue. Crop residues were established in 2009. P values are in parentheses. Bolded values indicate significance at p < 0.10

		Crop residue				
Year - Crop	**Location**	**Pea**	**Lentil**	**Fababean (seed)**	**Fababean (GM)**	**Canola**
2010 - Canola	Beaverlodge	158 (**0.061**)	173 (**0.041**)	31 (0.714)	597 (**<0.001**)	-171 (**0.043**)
	Lacombe	-	-	447 (**0.079**)	1028 (**<0.001**)	-292 (0.247)
	Lethbridge	149 (0.226)	43 (0.723)	-217 (**0.081**)	562 (**<0.001**)	-567 (**<0.001**)
	Indian Head	276 (**0.017**)	606 **(<0.001**)	-90 (0.439)	802 (**<001**)	-54 (0.633)
	Scott	77 (0.605)	-15 (0.919)	-140 (0.347)	618 **(<0.001**)	-59 (0.689)
	Swift Current	222 (**0.002**)	219 (**0.002**)	270 **(<0.001**)	251 (**<0.001**)	-21 (0.755)
	Brandon	320 (**0.003**)	205 (**0.051**)	189 (**0.071**)	472 (**<0.001**)	-181 (**0.085**)
2011 - Barley	Beaverlodge	381 (**0.006**)	463 (**<0.001**)	330 (**0.016**)	972 (**<0.001**)	176 (0.192)
	Lacombe	-1 (0.997)	654 (**<0.001**)	471 (**0.006**)	756 (**<0.001**)	208 (0.214)
	Lethbridge	474 (**0.005**)	136 (0.404)	19 (0.905)	861 (**<0.001**)	-190 (0.246)
	Indian Head	166 (0.219)	427 (**0.002**)	255 (**0.053**)	612 (**<0.001**)	-118 (0.373)
	Scott	58 (0.707)	86 (0.573)	156 (0.310)	263 (**0.090**)	273 (**0.083**)
	Swift Current	22 (0.724)	-41 (0.508)	-6 (0.920)	32 (0.614)	192 (**0.003**)
	Brandon	418 (**0.013**)	410 (**0.015**)	79 (0.632)	684 (**<0.001**)	557 (**<0.001**)
2012 - Canola	Beaverlodge	-92 (**0.063**)	-21 (0.673)	-45 (0.355)	8 (0.869)	-134 (**0.007**)
	Lacombe	-301 (**0.043**)	145 (0.297)	65 (0.638)	442 (**0.002**)	-125 (0.374)
	Lethbridge	341 (**<0.001**)	171 (**0.048**)	68 (0.428)	376 (**<0.001**)	-65 (0.448)
	Indian Head	-144 (**0.024**)	-61 (0.332)	-87 (0.171)	-26 (0.679)	-148 (**0.021**)
	Scott	-	-	-	-	-
	Swift Current	-5 (0.900)	-14 (0.751)	42 (0.339)	-96 (**0.031**)	54 (0.220)
	Brandon	-344 (**<0.001**)	-411 (**<0.001**)	-97 (0.164)	-238 (**<0.001**)	-388 (**<0.001**)

Table 3. P values from the ANOVA for the effects of crop residue, nitrogen rate and their interaction on % canola oil in 2010 and 2012 and % barley protein in 2011. Crop residues were established in 2009. Bolded values indicate significance at p < 0.10

Year - Crop	Location	Crop residue	Nitrogen rate	Crop residue x nitrogen rate
2010 - Canola	Beaverlodge	**<0.001**	**<0.001**	0.417
	Lacombe	**<0.001**	**0.002**	0.989
	Lethbridge	**0.002**	0.704	0.999
	Indian Head	**<0.001**	**<0.001**	0.574
	Scott	0.859	**0.010**	0.668
	Swift Current	**0.043**	**<0.001**	0.841
	Brandon	**0.008**	**<0.001**	0.984
2011 - Barley	Beaverlodge	**<0.001**	**<0.001**	0.730
	Lacombe	**<0.001**	**<0.001**	0.848
	Lethbridge	**<0.001**	**<0.001**	0.980
	Indian Head	**<0.001**	**<0.001**	0.244
	Scott	0.568	**<0.001**	**0.060**
	Swift Current	0.161	**<0.001**	0.628
	Brandon	**0.034**	**<0.001**	0.807
2012 - Canola	Beaverlodge	**0.056**	**<0.001**	0.941
	Lacombe	**0.003**	**<0.001**	0.703
	Lethbridge	0.561	**<0.001**	0.916
	Indian Head	**<0.001**	**<0.001**	0.526
	Scott	-	**-**	-
	Swift Current	0.598	**<0.001**	0.998
	Brandon	**<0.001**	**<0.001**	0.309

Table 4. Effect of crop residues established in 2009 (averaged over nitrogen rates) on % canola oil in 2010 and 2012 and % barley protein in 2011.

		Crop residue						
Year - Crop	**Location**	**Pea**	**Lentil**	**Fababean (seed)**	**Fababean (GM)**	**Canola**	**Wheat**	**SE**
2101 - Canola	Beaverlodge	46.3	46.1	46.7	45.4	46.4	46.6	0.373
	Lacombe	-	-	45.8	44.8	46.6	46.7	0.253
	Lethbridge	48.4	48.5	49.4	47.6	49.4	48.4	0.357
	Indian Head	47.4	47.3	48.8	46.6	47.7	47.8	0.196
	Scott	46.1	45.6	45.6	46.0	45.7	46.6	0.719
	Swift Current	46.1	46.0	46.5	46.4	46.4	46.1	0.233
	Brandon	47.4	47.5	47.8	47.5	47.5	46.8	0.266
2011 - Barley	Beaverlodge	10.5	11.1	10.4	11.0	10.6	10.5	0.119
	Lacombe	11.8	12.6	12.0	12.8	11.7	11.8	0.149
	Lethbridge	11.1	11.2	10.4	11.5	10.4	10.9	0.205
	Indian Head	11.2	10.4	10.4	10.9	11.0	10.7	0.118
	Scott	12.5	11.7	12.3	12.3	12.6	12.2	0.485
	Swift Current	10.6	10.8	10.6	10.6	10.6	10.6	0.095
	Brandon	12.2	12.6	12.3	12.6	12.4	12.6	0.248
2012 - Canola	Beaverlodge	47.7	46.9	47.6	47.4	47.5	47.5	0.224
	Lacombe	44.1	44.0	44.8	44.0	44.8	44.2	0.269
	Lethbridge	46.4	46.5	46.9	46.5	46.8	46.4	0.263
	Indian Head	46.1	46.9	46.7	46.2	46.0	46.5	0.209
	Scott	-	-	-	-	-	-	-
	Swift Current	46.1	45.8	46.0	46.0	45.9	46.0	0.222
	Brandon	44.4	44.7	44.8	45.1	44.7	43.7	0.278

Table 5. Effect of different crop residues on % canola oil and % barley protein gain or loss compared to wheat residue. Crop residues were established in 2009. P values are in parentheses. Bolded values indicate significance at p < 0.10

		Crop residue				
Year - Crop	**Location**	**Pea**	**Lentil**	**Fababean (seed)**	**Fababean (GM)**	**Canola**
2010 - Canola	Beaverlodge	-0.280 (0.168)	-0.465 (**0.023**)	0.120 (0.553)	-1.12 (**<0.001**)	-0.125 (0.537)
	Lacombe	-	-	-0.975 (**<0.001**)	-1.97 (**<0.001**)	-.170 (0.502)
	Lethbridge	0.040 (0.930)	0.160 (0.726)	1.02 (**0.028**)	-0.803 (0.109)	1.03 (**0.027**)
	Indian Head	-0.442 (0.114)	-0.512 (**0.068**)	0.998 (**<0.001**)	-1.19 (**<0.001**)	-0.112 (0.687)
	Scott	-0.509 (0.583)	-1.06 (0.255)	-1.05 (0.259)	-0.673 (0.469)	-0.897 (0.335)
	Swift Current	0.064 (0.714)	-0.090 (0.606)	0.374 (**0.033**)	0.292 (**0.096**)	0.300 (**0.089**)
	Brandon	0.635 (**0.015**)	0.725 (**0.006**)	0.986 (**<0.001**)	0.697 (**0.008**)	0.713 (**0.006**)
2011 - Barley	Beaverlodge	-0.007 (0.961)	0.642 **(<0.001**)	-0.100 (0.475)	0.543 (**<0.001**)	0.074 (0.580)
	Lacombe	0.001 (0.997)	0.818 (**<0.001**)	0.204 (0.167)	0.989 (**<0.001**)	-0.064 (0.664)
	Lethbridge	0.223 (0.445)	0.348 (0.233)	-0.521 (**0.076**)	0.635 (**0.046**)	-0.505 (**0.085**)
	Indian Head	0.460 (**0.007**)	-0.279 (**0.099**)	-0.312 (**0.066**)	0.183 (0.278)	0.351 (**0.039**)
	Scott	0.261 (0.615)	-0.539 (0.300)	0.117 (0.822)	0.125 (0.810)	0.346 (0.512)
	Swift Current	0.043 (0.603)	0.201 (**0.017**)	0.029 (0.726)	0.015 (0.856)	0.024 (0.771)
	Brandon	-0.395 (**0.009**)	-0.027 (0.855)	-0.303 (**0.044**)	-0.029) (0.847)	-0.214 (0.151)
2012 - Canola	Beaverlodge	0.220 (0.416)	-0.580 (**0.034**)	0.150 (0.579)	-0.020 (0.941)	0.085 (0.753)
	Lacombe	-0.135 (0.606)	-0.155 (0.554)	0.595 (**0.025**)	-0.170 (0.517)	0.570 (**0.032**)
	Lethbridge	-0.008 (0.982)	0.093 (0.781)	0.468 (0.162)	0.132 (0.693)	0.417 (0.212)
	Indian Head	0.448 (**0.055**)	0.372 (0.109)	0.121 (0.601)	0.353 (0.128)	0.578 (**0.013**)
	Scott	-	-	-	-	-
	Swift Current	0.119 (0.487)	-0.186 (0.279)	-0.060 (0.728)	0.008 (0.963)	-0.093 (0.587)
	Brandon	0.705 (**0.011**)	0.992 **(<0.001**)	1.12 (**<0.001**)	1.36 (**<0.001**)	0.946 (**<0.001**)

Table 6. Effect of nitrogen rates (averaged over crop residues) on % canola oil in 2010 and 2012 and % barley protein in 2011.

		Nitrogen rate (kg/ha)					
Year - Crop	**Location**	**0**	**30**	**60**	**90**	**120**	**SE**
2101 - Canola	Beaverlodge	47.3	47.0	46.2	45.5	45.2	0.368
	Lacombe	46.6	46.3	45.9	45.6	45.5	0.268
	Lethbridge	48.8	48.7	48.8	48.5	48.3	0.339
	Indian Head	47.6	48.2	47.8	47.8	46.8	0.179
	Scott	46.9	47.1	45.9	45.5	44.3	0.667
	Swift Current	46.9	45.8	46.0	46.3	46.2	0.227
	Brandon	48.4	48.2	47.3	46.7	46.3	0.255
2011 - Barley	Beaverlodge	9.6	9.8	10.5	11.3	12.2	0.112
	Lacombe	10.9	11.3	12.0	12.7	13.5	0.143
	Lethbridge	9.8	10.3	10.7	11.6	12.2	0.192
	Indian Head	11.0	10.4	10.2	10.7	11.7	0.108
	Scott	10.7	11.1	12.4	12.5	14.5	0.463
	Swift Current	9.9	9.8	10.4	11.1	12.0	0.092
	Brandon	12.2	12.1	12.4	12.7	13.0	0.243
2012 - Canola	Beaverlodge	48.0	48.4	47.9	46.8	46.1	0.210
	Lacombe	44.6	45.1	44.6	44.0	43.2	0.258
	Lethbridge	47.9	47.3	46.8	45.8	45.2	0.245
	Indian Head	47.6	47.6	46.3	45.8	44.6	0.199
	Scott	-	-	-	-	-	-
	Swift Current	47.4	46.9	46.1	45.0	44.5	0.216
	Brandon	44.4	44.9	45.1	44.7	44.7	0.278

Table 7. Effect of crop residue on barley quality

Location	Stubble	Plump (%)	Kernel Weight(g)	Barley Protein(%)	Germination 4mL(%)	Germination Index
Brandon	Canola	69.2	33.6	12.5	99	9.2
Brandon	FBGM	65.9	33.1	12.5	99	9.3
Brandon	Faba Beans	62.2	32.6	12.3	99	8.9
Brandon	Field Pea	64.5	32.8	12.3	99	8.9
Brandon	Lentils	65.3	33.0	12.6	100	9.1
Brandon	Wheat	68.2	33.5	12.5	99	9.3
Lacombe	Canola	89.3	41.0	11.5	98	6.8
Lacombe	FBGM	84.2	38.2	**12.3***	98	6.6
Lacombe	Faba Beans	88.2	40.9	11.7	99	7.0
Lacombe	Field Pea	82.4	38.5	11.7	97	7.0
Lacombe	Lentils	**81.4***	38.8	**12.6***	98	6.6
Lacombe	Wheat	85.9	39.7	11.7	99	6.9
Swift Current	Canola	89.3	39.3	10.5	100	7.9
Swift Current	FBGM	**88.5***	**38.6***	10.4	100	8.2
Swift Current	Faba Beans	90.0	39.5	10.4	100	7.9
Swift Current	Field Pea	89.7	40.2	10.4	100	7.5
Swift Current	Lentils	90.1	39.5	10.3	99	7.9
Swift Current	Wheat	89.2	39.3	10.4	100	8.2

* indicates significantly different from Wheat (p<0.05) using Dunnett's test

Table 8. Effect of nitrogen on barley quality

Location	Nitrogen Rate	Plump (%)	Kernel Weight(g)	Barley Protein(%)	Germination 4mL(%)	Germination Index
Brandon11	0	59.4	30.8	12.1	99.2	9.3
Brandon11	30	62.1	32.1	12.1	99.1	9.4
Brandon11	60	63.6	32.6	12.3	99.4	9.1
Brandon11	90	70.0	34.4	12.7	99.2	9.0
Brandon11	120	74.3	35.7	13.1	99.6	8.9
Lacombe11	0	89.1	41.4	11.0	98.1	7.2
Lacombe11	30	89.3	41.4	11.1	98.6	7.1
Lacombe11	60	86.4	39.8	11.9	98.4	6.8
Lacombe11	90	82.7	38.1	12.6	98.8	6.7
Lacombe11	120	78.7	36.9	13.1	96.9	6.4
Swift Current11	0	91.0	38.7	9.5	99.6	8.0
Swift Current11	30	90.8	39.3	9.4	99.6	7.9
Swift Current11	60	89.4	39.4	10.2	99.7	7.9
Swift Current11	90	88.7	39.7	11.0	99.7	8.0
Swift Current11	120	87.4	39.8	12.0	99.9	7.9

Table 9. Effect of nitrogen on malt quality

Location	Nitrogen Rate	Extract %	Soluble Protein(%)	Kolbach %	β-glucan mg/L	FAN mg/L	DP °L	alpha amylase	Friability %
Brandon11	0	80.6	5.4	43.7	119.1	225.0	171.7	82.3	71.0
Brandon11	30	80.8	5.6	45.4	106.9	233.4	164.7	82.7	70.7
Brandon11	60	80.8	5.5	43.9	120.7	227.8	170.3	83.0	69.0
Brandon11	90	80.7	5.4	41.6	137.9	223.5	177.4	83.2	64.9
Brandon11	120	80.6	5.3	39.8	169.3	216.5	174.5	82.9	60.8
Lacombe11	0	81.3	4.6	42.7	128.5	203.1	171.3	73.7	73.8
Lacombe11	30	81.2	4.6	42.5	158.6	203.7	173.9	73.0	70.0
Lacombe11	60	80.5	4.8	40.8	209.3	207.7	179.1	74.7	62.9
Lacombe11	90	80.0	4.9	39.7	211.8	210.4	189.7	76.0	59.1
Lacombe11	120	79.4	5.0	38.8	186.1	210.8	195.2	74.7	55.8
Swift Current11	0	82.0	4.6	48.6	57.2	195.7	154.3	77.1	94.8
Swift Current11	30	81.8	4.6	48.0	66.8	192.6	148.4	76.5	93.9
Swift Current11	60	81.3	4.7	46.4	87.6	193.8	152.9	77.4	89.1
Swift Current11	90	81.0	4.8	44.3	122.0	195.3	163.9	79.4	81.5
Swift Current11	120	80.1	4.8	40.7	142.3	194.4	168.4	79.7	72.9

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Table 10. effect of crop residue on malt quality

Location	Stubble	Extract %	Soluble Protein(%)	Kolbach %	β-glucan mg/L	FAN mg/L	DP °L	alpha amylase	Friability %
Brandon	Canola	80.6	5.31	42.1	148	225	172	85.3	66.2
Brandon	FBGM	80.7	5.46	42.7	117	220	175	82.1	67.5
Brandon	Faba Beans	80.7	5.60	44.7	119	236	166	80.8	68.4
Brandon	Field Pea	80.8	5.43	43.0	131	224	171	81.6	67.4
Brandon	Lentils	80.6	5.33	41.5	126	217	170	83.3	67.0
Brandon	Wheat	80.8	5.52	43.3	145	229	177	84.0	67.0
Lacombe	Canola	80.7	4.64	40.9	152	205	176	74.1	67.4
Lacombe	FBGM	80.4	4.87	40.1	204	209	**186***	75.9	61.7
Lacombe	Faba Beans	80.8	4.76	40.9	191	204	183	74.8	64.5
Lacombe	Field Pea	80.2	4.95	43.2	134	212	**187***	71.1	69.6
Lacombe	Lentils	80.2	4.79	**38.9***	**232***	206	185	75.4	**57.5***
Lacombe	Wheat	80.6	4.74	41.5	160	207	175	75.1	65.1
Swift Current	Canola	81.2	4.66	44.9	96	194	160	78.4	85.8
Swift Current	FBGM	81.3	**4.76***	46.0	93	196	156	79.1	86.4
Swift Current	Faba Beans	81.3	**4.74***	46.1	99	193	156	77.0	86.5
Swift Current	Field Pea	81.1	4.70	45.2	98	192	153	77.2	85.6
Swift Current	Lentils	81.3	**4.75***	46.7	91	198	163	79.5	86.5
Swift Current	Wheat	81.3	4.61	44.6	94	194	157	76.9	87.8

***** indicates significantly different from Wheat ($p<0.05$) using Dunnett's test

Table 11. P values from the ANOVA for the effects of crop residue on % soil moisture in the fall of 2009. Crop residues were established in spring 2009. Bolded values indicate significance at p < 0.10

	Soil depth (cm)				
Location	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**
Beaverlodge	0.827	0.498	0.564	**0.022**	-
Lacombe	0.660	0.134	0.824	0.927	0.927
Scott	0.829	**0.030**	0.684	0.182	-
Swift Current	0.164	0.569	0.191	0.141	**0.019**
Brandon	0.781	0.717	0.295	0.595	-

Table 12: Total nitrate-N (kg/ha to 60 cm) as affected by preceding crops at seven locations across western Canada (2009)

	Beaverlodge	Brandon	Indian Head	Lacombe	Lethbridge	Scott	Swift Current	Mean
Canola	19.0	54.8	10.4	24.5	14.5	23.0	38.3	33.5
Fababean (GM)	45.3	73.4	27.8	55.3	13.5	75.8	57.4	55.8
Fababean (seed)	16.9	63.9	8.3	31.9	10.6	26.0	49.3	36.3
Field peas	20.6	65.4	27.2	40.1	15.4	26.4	59.3	39.8
Lentils	16.5	73.7	26.9	34.8	9.6	21.2	58.5	35.7
Wheat	24.9	72.8	14.2	23.0	55.2	27.5	46.8	31.6
SE	3.17	8.60	2.25	3.08	3.66	13.8	8.23	
ANOVA		P>F						
Crop	<0.0001	0.0060	0.0001	<0.0001	<0.0001	0.0470	0.0386	
Nrate	ns	ns	ns	ns	ns	ns	ns	
N rate*Crop	ns	ns	ns	ns	ns	ns	ns	

1. Severe disease destroyed the wheat crop leading to high N carryover after wheat at the Lethbridge site.
2. Since differential N rates were not applied in 2009 there was no effect of N rate at any site.

Table 13: Total nitrate-N (kg/ha to 60 cm) as affected by preceding crops at seven locations across western Canada (2010).

	Beaverlodge	Brandon	Indian Head	Lacombe	Lethbridge	Scott	Swift Current	Mean
Canola	31.8	27.0	16.0	29.2	19.3	45.8	12.4	25.9
Faba Grn M	45.0	33.5	21.9	51.4	26.3	60.9	10.4	35.6
Fababeans	22.9	27.1	11.8	33.1	19.6	48.8	10.1	24.8
Field Pea	25.3	28.7	19.4	41.0	25.1	42.1	11.1	27.5
Lentil	53.6	31.4	16.2	32.9	23.9	47.8	14.1	31.4
Wheat	18.9	25.9	14.1	32.7	25.3	39.5	10.4	23.8
SE	4.2	3.54	1.76	8.8	2.34	7.94	2.1	3.51
ANOVA	P>F							
Crop	<0.0001	0.009	0.0003	<0.0001	<0.0001	ns	0.0038	
Nrate	<0.0001	<0.0001	0.0271	<0.0001	0.0003	0.0143	0.0333	
N rate*Crop	ns	ns	0.0654	ns	ns	ns	ns	

Table 14: Total nitrate-N (kg/ha to 60 cm) as affected by preceding crops at seven locations across western Canada (2011).

	Beaverlodge	Brandon	Indian Head	Lacombe	Lethbridge	Scott	Swift Current	Mean
Canola	7.2	45.2	16.5	27.8	22.4	27.2	5.1	21.6
Faba Grn M	9.3	53.8	22.6	29.3	23.1	45.5	5.1	26.9
Fababeans	7.1	45.5	12.1	28.9	23.6	26.9	5.2	21.3
Field Pea	7.4	47.3	19.8	33.1	23.3	23.9	4.9	22.8
Lentil	13.1	51.6	16.6	34.8	19.0	23.9	5.3	23.5
Wheat	7.1	51.6	14.5	28.8	18.5	22.0	4.9	21.0
SE	0.93	4.29	1.8	2.36	3.93	7.89	5.12	3.76
ANOVA	P>F							
Crop	<0.0001	ns	0.0002	ns	ns	ns	ns	
Nrate	<0.0001	<0.0001	0.0257	0.0016	0.0966	0.002	0.0419	
N rate*Crop	<0.0001	ns	0.0659	ns	ns	ns	ns	

Table 15: Total nitrate-N (kg/ha to 60 cm) as affected by N application at seven locations across western Canada (2010).

N Rate	Beaverlodge	Brandon	Indian Head	Lacombe	Lethbridge	Scott	Swift Current	Mean
0	20.3	25.0	14.3	34.2	19.6	39.3	9.8	23.2
30	24.5	26.1	15.3	32.4	21.8	39.4	10.9	24.3
60	24.8	26.6	15.2	33.7	22.9	41.2	11.3	25.1
90	42.0	31.0	17.7	36.6	24.4	47.2	11.9	30.1
120	52.9	36.3	20.3	46.9	27.0	69.2	13.1	38.0
SE	4.2	3.47	1.64	2.54	2.31	7.29	2.08	3.36
ANOVA	P>F							
Crop	<0.0001	0.009	0.0003	<0.0001	<0.0001	ns	0.0038	
Nrate	<0.0001	<0.0001	0.0271	<0.0001	0.0003	0.0143	0.0333	
N rate*Crop	ns	ns	0.0654	ns	ns	ns	ns	

Table 16: Total nitrate-N (kg/ha to 60 cm) as affected by N application at seven locations across western Canada (2011)
.

N Rate	Beaverlodge	Brandon	Indian Head	Lacombe	Lethbridge	Scott	Swift Current	Mean
0	6.9	36.6	14.7	25.1	21.8	18.3	6.0	18.5
30	6.1	46.0	15.7	27.7	18.5	18.4	5.1	19.7
60	6.7	43.5	15.6	31.2	16.0	20.3	4.6	19.7
90	8.1	52.2	18.2	31.0	28.0	30.7	4.4	24.7
120	14.8	67.4	20.8	37.3	24.0	53.3	5.2	31.8
SE	0.92	4.02	1.68	2.16	3.64	7.25	0.37	2.86
ANOVA	P>F							
Crop	<0.0001	ns	0.0002	ns	ns	ns	ns	
Nrate	<0.0001	<0.0001	0.0257	0.0016	0.0966	0.002	0.0419	
N rate*Crop	<0.0001	ns	0.0659	ns	ns	ns	ns	

NEXT STEPS

A Canola Cluster proposal has been submitted to continue this experiment for an additional two years mainly to look at the effects of the treatments on soil nitrate levels and mineralization. Dr. Cindy Grant will be PI for this final phase.

An economic analysis is being conducted by Dr. Elwin Smith and is anticipated to be completed in the next 6 months.

A scientific paper will be prepared and submitted in the next 6 months. It is anticipated that at least four scientific papers will result from the study.

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B (I). Funded Collaborators (Co-PI, AAFC, other federal scientists) • Include the name of scientist / organization.
Cynthia Grant, AAFC, Brandon, MB (Co-PI) Robert Blackshaw, AAFC, Lethbridge, AB (CO-PI) Neil Harker, AAFC, Lacombe, AB Kelly Turkington, AAFC, Lacombe, AB Eric Johnson, AAFC, Scott, SK Guy Lafond, AAFC, Indian Head, SK William May, AAFC, Indian Head, SK Michael Edney, Canadian Grains Commission, Winnipeg, MB Yantai Gan, AAFC, Swift Current, SK Elwin Smith, AAFC, Lethbridge, AB

B (II). Acknowledgement of non-funded collaborators (who provide support, e.g. access to other laboratory or other facilities and equipment input / advice / guidance / assistance, etc). • For research supported by targeted funding programs (e.g. DIAP, Clusters, etc.) please list any collaborators who are receiving Contribution Vote 10 funds (e.g., university and industry collaborators). In addition, please list separately the participants who support your project but are not receiving any funding through the program. • Include name of scientist / organization.
Anne Kirk, Western Applied Research Corporation (WARC), Scott, SK Patricia Juskiw, Alberta Agriculture & Rural Development, Lacombe, AB

C. Variance Report (if applicable, describe how the work differs from the proposed research) • Include changes to objectives and project work plan / budget, changes to the team, other constraints.
As expected, inclement weather and other factors sometimes disrupted field trials and compromised the results. Problems included flooding and cutworm damage to canola grown on pea and lentil residue plots

at Lacombe in 2010, an outbreak of stripe rust on wheat residue plots at Lethbridge in 2009 which may have resulted in higher than expected soil residual nitrogen levels in 2010, and wind damage and loss of canola swaths at Scott in 2012.

On the positive side, extra research related to the effects of the treatments on soil nitrates and mineralization (than was outlined in the original cluster proposal) was conducted by Cindy Grant and her collaborators with funding from an AAFC A-Base project.

D. Impact Assessment (if applicable, describe how the variance factors above will impact project continuation)

- Include changes to the objectives, changes to the project work plan / budget, changes to performance (i.e. meeting targets).

While unfortunate, these climatic events had little impact on the overall results and conclusions since experiments were conducted at seven locations over the 4-year course of the study.

The additional soil research has greatly embellished the value of this project to the canola industry.

E. Achievements (include only those related to this project)

- Include innovations, publications / conferences, technology transfer, capacity building, success stories, media, recognition and other outputs.

John O'Donovan delivered Invited presentations on growing legumes before canola at ACPC regional meetings, Camrose, Lacombe and St. Paul, November, 23, 24 and 25, 2010, respectively.

John O'Donovan participated in a Canola Science Summit, Saskatoon, SK (March 11, 2010) and presented an outline of first year results on growing canola after legume crops.

"Canola needs help", Western Producer, July 15, 2010. Based on press Interview with John O'Donovan on the results of this project.

John O'Donovan was interviewed on the project for the Alberta Canola Producers Commission (ACPC) "Growing with Canola" radio program. The interview was broadcast on 27 radio stations in Alberta on March 8, 2011. The interview can be accessed on the ACPC website (http://canola.ab.ca/growing_with_canola_listen_online.aspx).

Blackshaw, R. E. 2011. Potential for canola after pulse crops. Proc. Agronomy Update Conference, Lethbridge, AB. Available at http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/crop13462. Based on a presentation by Bob Blackshaw on the project.

O'Donovan, J. T., R.E. Blackshaw, C. A. Grant, K. N. Harker, G. P. Lafond, E. N. Johnson, Y. Gan, W. May, T. K. Turkington, and N. Z. Lupwayi. 2011. Legume Crops to Improve Soil Fertility for Enhanced Canola Production. Abstract. Proc. Am. Soc. of Agron., San Antonio TX, Oct. 16-19, 2011. http://a-c-s.confex.com/crops/2011am/webprogram/Paper65038.html

John O'Donovan participated in the Lacombe annual field day and presented information on research studies related to growing legume crops in rotation with canola and on the effects of the legumes on a subsequent malting barley crop, July 28, 2011.

John O'Donovan interviewed by Jay Whetter of the Canola Council of Canada for a sustainable Canola article for Canola Digest: Article "Not your everyday agronomy issues" March, 2011 edition.

John O'Donovan interviewed by Caitlin Reasoner for the radio program Call of the Land. The interview entitled "Growing legume crops before canola" was aired on August 3, 2011.

John O'Donovan interviewed by Donna Fleury (August 24), Top Crop Manager, on project related to growing legumes before canola. Article entitled "Canola thrives on pulse stubble" published in December, 2011 edition of Top Crop Manager, pgs. 12-14.

John O'Donovan interviewed by Jay Whetter of the Canola Council of Canada for a sustainable Canola article for Canola Digest: Article "Continuous canola yields less, but why?" December, 2011 edition.

John O'Donovan participated in a Canola Science Summit, Winnipeg, MB (April 13, 2011) and presented a talk entitled "Legume crops to improve soil fertility for enhanced canola production". The project is funded under a Growing Forward Canola Cluster.

John O'Donovan participated in the Lacombe annual field day and presented information on research studies related to growing legume crops in rotation with canola and on the effects of the legumes on a subsequent malting barley crop, July 28, 2011.

Invited presentation to students and staff entitled "The role of agronomic research in relation to meeting agricultural and cropping systems challenges". Included results of this project. Department of Agriculture, Food and Nutritional Science, University of Alberta, March 13, 2012 and March 14 2013.

Invited to speak to a Japanese delegation and members of the Canola Council of Canada on canola-related research at Beaverlodge Research Farm, July 2012.

Harker, K. N. 2012. Canola after pulse crops (Oral presentation). Proc. Agonomy Update 2012. January 17-18, Red Deer, AB. p. 9.

Beaudoin, N., J. Sansoulet, E. Pattey, C. Grant, R. Blackshaw, N. Harker, E. Johnson, J. O'Donovan, S. Gervois, 2012. Adaptation de STICS à la culture de canola au Canada à partir du module colza en vue de simuler les émissions de N2O par ModuloSTICS. IXe Séminaire du modèle de culture STICS, Sainte-Montaine, France, 16-19 Octobre 2012.

F. Lessons learned (self-evaluation of project)

This rotational experiment has been one of the more exciting projects that I have been involved in, and provided the opportunity to develop a collaborative team involving scientists from numerous plant science disciplines. It also deviated from the more traditional commodity based funding models, obtaining support from canola and barley commodity groups, and from AAFC A-Base funds. The information generated will be of interest to three commodity groups, canola, barley and pulses. The study again confirmed the fact that multiple locations are important when conducting studies of this nature since information was lost at some locations due to adverse biotic and abiotic factors. This was again an important lesson learned.

PI Name	Date	Signature
John O'Donovan	25-04-2013	John O'Donovan

Note: After completion and signature, this report must be provided to the appropriate Science Director for assessment. A PDF copy of this report will be sent to Science Operations by the Science Director's office along with the project assessment.