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Quantifying the nitrogen benefits of cool season pulse crops to an Alberta prairie cropping system

by

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To those who taught me to love all little green things that grow.

Abstract

Diverse crop rotations are an important part of sustainable agricultural systems. More information is needed in Alberta on the effects of adding pulse crops to current rotations. This experiment investigated the effects of 'Snowbird' tannin-free faba bean (*Vicia faba* L.), 'Arabella' narrow-leafed lupin (*Lupinus angustifolius* L.), and 'Canstar' field pea (*Pisum sativum* L.) on subsequent barley (*Hordeum vulgare L.),* canola (*Brassica napus* L.) and wheat (*Triticum aestivum* L.) crops in rotation at two sites in central Alberta (Barrhead and St. Albert). In YR1 of rotation faba bean had the highest potential for N fixation followed by pea and lupin and N returned to the soil in above ground crop residues was similar across pulse species. In YR2 of rotation faba bean and pea stubble was able to maintain the yield and quality of subsequent barley, canola and wheat crops. Pulse crops can improve the sustainability of the Alberta cropping system.

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Table of Contents

List of Tables

Chapter 1

Chapter 2

Chapter 3

List of Figures

Chapter 2

Chapter 3

List of Abbreviations

BN	barley +N treatment
BO	barley no N treatment
C	carbon
cm	centimetre
CN	canola +N treatment
CO	canola no N treatment
^{o}C	degrees Celsius
df	degrees of freedom
Fb	faba bean treatment
g	gram
ha	hectare
HI	harvest index
K	potassium
kg	kilogram
L	litre
Lu	lupin treatment
m	meter
mg	milligram
Mg	megagram
ml	millilitre
mm	millimetre
Mt	megatonne
N	nitrogen
Ndfa	nitrogen derived from the atmosphere
NHI	nitrogen harvest index
P	phosphorus
Pe	pea treatment
S	sulphur
spp	species
t	tonnes
TSW	thousand seed weight
YR1	year 1 of rotation
YR2	year 2 of rotation
%	percent

Chapter 1: Literature Review

Over the past 50 years agriculture has increased production through the addition of large quantities of nitrogen fertilizer. In the more recent past the environmental and economic costs of nitrogen fertilizer have become a more apparent issue and focus has shifted to investigate options for creating a more sustainable agricultural system. The production of legume crops, with their ability to fix atmospheric nitrogen, has been used throughout the world to improve sustainability. The addition of legume crops to rotations has many benefits but also creates unique challenges for producers.

Crop Rotation

Crop rotation in Alberta is currently dominated by the production of 4 crops; wheat, barley, canola and tame hay (Table 1-1). These four crops occupy 90.8% of the seeded acres in Alberta while dry peas are grown on a mere 3.3% of the seeded land. This creates a production situation which requires heavy use of inputs such as nitrogen (N) fertilizers, herbicides and pesticides to maintain optimal yields (Miller and Holmes 2005). Extensive research has investigated the effects of crop rotation on agricultural systems. Results demonstrate that monocropping reduces crop yield and quality while increasing disease and weed problems (Stevenson and van Kessel 1996b, Miller and Holmes 2005). Even with the knowledge of these negative impacts of reduced crop rotation much of the developed world continues to practice limited crop rotation. Canadian producers have specialized in production of specific high value and high yielding crops to increase profitability. Economic pressure on agricultural systems has resulted in limited crop diversity which may reduce overall productivity (Johnston et al. 2005).

Implementing a diverse crop rotation can have long term effects on the yield and quality of crops in a cropping system. Subsequent crops in rotation are affected by the previous crop. Cereals grown after peas generally have higher yields and protein content than when grown after another cereal (Wright 1990a, b, Jensen 1996b, Strydhorst et al. 2008). Strydhorst et al. (2008) reported that different pulses – peas, faba beans and lupins, had varying effects on subsequent wheat crops. Wheat yield and protein content was higher when grown on pea or faba bean stubble than on lupin. In contrast, Armstrong et al. (1997) reported that wheat grown in Australia had higher dry matter yields and N yields following lupins than peas, or barley. Other crop responses include a yield reduction when crops are grown on their own stubble accompanied by increased disease, or reduced flax yields when sown on canola stubble (Johnston et al. 2005). These subsequent crops responses are due to changes in soil nitrogen content (Strydhorst et al. 2008, Stevenson and van Kessel 1996b, Walley et al. 2007), soil microbial activity (Gan et al. 2003), mycorrhizal populations (Johnston et al. 2005), soil water availability (Gan et al. 2003), and disease cycles (Johnston et al. 2005) influenced by the previous crop.

Understanding these crop interaction effects and modifying management practices accordingly is essential to maximizing the productivity of an agricultural system. Diversifying the limited crop rotation practiced in Alberta would have long term effects on sustainability. Pulses are good candidate crops for production in Alberta (Strydhorst 2008). Adaption to the regional climatic conditions in Alberta is a concern with the addition of new crops to this cropping system. Thomson et al. (1997) noted that peas, faba beans, and lupins were among the earliest pulses to flower and set pods which indicates that production in the short Alberta growing season should be possible. Addition of pulse crops to the Alberta system would add diversity to the crop rotation and provide additional nitrogen and non-nitrogen pulse benefits.

Crop Rotation as a Sustainable Agriculture Practice

Crop rotation is an ancient principle that diminished with the introduction of chemical fertilizers, pesticides and mechanization of agriculture (Bullock 1992, Liebman and Dyck 1993). Crop rotation can play an important role in development of more sustainable agricultural systems. It is currently becoming a more valued and practiced principle due to changes in our understanding of the effects of agriculture on the environment and a desire for sustainability.

Diversifying crop rotations has many benefits. Inclusion of legume crops has been noted to improve available soil N (Miller et al. 2002b, Miller et al. 2003). Inclusion of a forage or hay crop increases organic matter (Bullock 1992). Soil organic matter can improve nutrient availability, improve water infiltration and retention, increase soil aeration, improve soil bulk density, aggregate formation and stabilization, and minimize soil erosion (Bullock 1992). Short rotations, tillage and production of low biomass crops can reduce soil organic matter (Bullock 1992). When crops are grown in a diverse rotation there is a yield benefit that generally cannot be obtained with the addition of chemical fertilizers, pesticides and other inputs (Liebman and Dyck 1993, Bullock 1992).

Crops differ in their effect on soil microbes. Production of host crops can increase microbe populations while non-host crops limit microbial growth. Beneficial and harmful microbes are affected by the crop in rotation. This can be a rotational benefit for the control of soil borne diseases (Bullock 1992). Generally, microbial activity is higher in diverse crop rotations than in monocropping situations and this can increase the amount of decomposition and mineralization occurring in the soil (Bullock 1992, Lupwayi et al. 2004a).

Crop rotation is a powerful tool for the control of some pests (Bullock 1992). Similar to the effect on soil microbes, when host crops are produced pest levels can increase but production of non-host crops can reduce pest survival (Liebman and Dyck 1993). Pests that are most responsive to crop rotation have limited mobility, require a host organism and are very selective about the host they choose (Bullock 1992). Insect and disease damage can be significantly reduced with a diverse crop rotation (Evans et al. 2003, Bullock 1992, Stevenson and van Kessel 1996a).

For effective weed control, crop rotation can be included in combination with herbicides and tillage (Blackshaw 1994, Blackshaw et al. 2005). Crop rotation can facilitate a change in herbicide use which helps to prevent the development of herbicide resistant weeds or infestations of non target noxious weeds (Liebman and Dyck 1993, Beckie et al. 2006, Beckie 2006). With the current production of herbicide tolerant crops, rotation between crop type and herbicide system will help to prevent the growth of herbicide resistant volunteer crops (Beckie et al. 2006). Optimal plant density, rate of canopy closure, competitive ability, production of allelopathic chemicals, growth pattern and cultural management practices differ between crops and can all affect weed emergence, growth and reproduction (Bullock 1992, Liebman and Dyck 1993). Effective weed control is important to maintain crop yield and quality.

Preceding crops can have a continuing effect on subsequent crops in a rotation, so crop sequences should be designed to provide optimal benefit to subsequent crops in rotation. Compounds released from plant residues can stimulate or limit the growth of subsequent crops. Legume residues have been reported as releasing a growth promoting substance (Stevenson and van Kessel 1996b). Some studies on canola suggest that it may limit growth in some other crops, but results are inconclusive (Miller et al. 2002b). Monocropping maize results in reduced maize yields and studies indicate that chemicals leached from maize residues can inhibit growth of subsequent maize plants (Bullock 1992). Allelopathy is a common mechanism that helps plants persist in highly competitive environments. It is generally not seen as a positive trait in production agriculture but could be a benefit for weed control (Liebman and Dyck 1993).

Crop sequencing also affects mycorrhizae persistence and growth in the soil (Hamel and Strullu 2006). Growth of mycorrhizal host crops or weeds will increase mycorrhizal populations while non-host crops or weeds can depress mycorrhizal populations and diversity in the soil (Douds et al.1997). Mycorrhizae fungi aid some crops in the acquisition of nutrients but crop reliance on mycorrhizae associations varies. Flax is highly dependent on mycorrhizae whereas canola is a non-mycorrhizal crop that has no root association with the fungi (Johnston et al. 2005, Lafond et al. 2006).

Modifying management practices to include a well designed rotation that accounts for tillage requirements, herbicide usage, and subsequent crop effects, will increase profitability and sustainability in the agricultural system. Benefits of rotations have been recognized for several centuries, as has the benefit of including legumes. In the highly mechanized agricultural system of western Canada it is necessary to increase our understanding of rotational benefits and quantify the impact of including pulse crops.

Pulse Crops

Pulse crops are grown in many areas of the world to improve agricultural productivity and sustainability. Pulses are defined as the edible seed of annual legumes and are recognized as an important source of protein (Park et al. 1999). Pulse crops have been reported to provide many benefits to human health, as well as agricultural production and environmental sustainability (Park et al. 1999). The world produces 58 – 64 Mt of pulses on 69 – 74 million ha per year including field pea, dry bean, chickpea, lentil, faba bean, dry bean, cowpea, lupin, pigeon pea, and vetches (FAOSTAT 2011). Legumes have an advantage over many crop species because of their symbiotic relationship with *Rhizobium* bacteria which allows them to fix atmospheric nitrogen. This reduces their dependence on nitrogen fertilizer which reduces some of the negative economic and environmental impacts of agriculture production.

There are many notable benefits to producing pulses in rotation. In the year that the pulse is produced N fixation generally supplies enough N for pulse growth when inoculants are applied and soil N is low (Clayton et al. 2004a, Walley et al. 2007). Previous studies have indicated that N fixation can be reduced when crops are not inoculated with the appropriate *Rhizobium* species; due to non-effective nodulation or a reduction in the number of nodules (Clayton et al. 2004a). Inherent levels of N in the soil or the addition of N fertilizer can also reduce N fixation of a pulse crop (Clayton et al. 2004a, Peoples et al. 2001, Armstrong et al. 1999). N fixation by a pulse crop reduces the use of soil mineral N to fill the N requirement for growth, often termed N sparing (Jensen 1994). N sparing, rhizodeposition (Sawatsky and Soper 1991, Jensen 1996a), and high N content of pulse residues (Jensen 1996a, b, Stevenson and van Kessel 1996b) contribute to the pulse crop's influence on the N supplying power of the soil to subsequent crops (Walley et al. 2007).

The N dynamics of pulse production have variable effects on total net N in the system. Some studies report a positive net N balance (Maidl et al. 1996, Soon and Arshad 2004a) while others indicate a negative N balance (Jensen 1994, Unkovich et al. 1995, Soon and Arshad 2004a). Pulse seed is high in protein; this results in a large amount of N being removed with harvested seed (Jensen 1994, Carranca et al. 1999, Beck et al. 1991). N removal in the seed can exceed the amount of N fixed by the plant (Jensen 1994, 1996a, b). N benefits of pulses to subsequent crop growth are generally accepted but, due to challenges in measuring those benefits and the interactions of environmental effects, studies have not agreed on the magnitude of that benefit. In some environments nitrate leaching has been considered a concern with the production of legume crops due to their influence on increasing soil N (Campbell et al. 1991, 2006).

The shallow root systems of peas and faba beans result in less water and nutrients being removed from deeper soil levels (Gan et al. 2009, Siddique et al. 2001, Jensen et al. 2010). Gan et al. (2009) reported that chickpea, field pea, lentil and flax had much shallower roots (little beyond 60cm) than canola, mustard and wheat (roots present at 80 – 100cm). Shallow rooting may leave more nutrients and water in the soil for subsequent crops but also makes pulses more susceptible to low moisture conditions (Jensen et al. 2010). Water stress has been demonstrated to reduce both yield and N fixation in pulse crops (Kurdali et al. 2002, French and Turner 1991, Thomson et al. 1997, Abd-Alla and Abdel Wahab 1995). Key adaptations such as drought escape through early flowering and pod set occur in peas, faba beans and lupins as mechanisms to deal with water stress (Thomson et al. 1997, French and Buirchell 2005, Siddique et al. 2001). Higher water use efficiency in pea has been demonstrated to increase its production in comparison to chickpea or lentil (Gan et al. 2009). Reduced water use by pulse crops allows cropping intensity to be increased through the reduction or elimination of fallow years (Cutforth et al. 2007). The improvement of soil structure by legumes is often noted as one of the non-N benefits (Stevenson and van Kessel 1996b). Atwell (1988) described radial swelling of roots in lupins in response to compacted soils as one example of this benefit.

Pulse crops are sensitive to seeding date; late or delayed seeding can reduce seed yields (Payne et al. 2004, Schulz et al. 1999). One benefit of diversifying a crop rotation with pulses is that the pulse can be seeded earlier than some other crops due to inherent large seed size (Jensen et al. 2010). Slow early growth of pulses however, often limits their ability to compete with weeds (Kettel et al. 2003, Soon et al. 2004). Competition with weeds reduces grain yields and N fixation levels (Strydhorst et al. 2008). Timely applications of herbicides and other cultural practices such as increasing plant density can help to control weeds and minimizes their effects on pulse growth.

As with many crops, environmental conditions have a considerable effect on the growth and quality of a pulse crop (Wang and Daun 2004), which in turn affects the pulse benefit to the cropping system. Pulses are sensitive to soil pH. Faba bean and pea prefer a neutral to alkaline soil while lupins prefer acidic soils (Thomson et al. 1997, Tang and Thomson 1996, Tang and Robinson 1995, French and Buirchell 2005, Jensen et al. 2010). High temperatures during flowering have been reported to be detrimental to yields causing flower and pod abortion (Kettel et al. 2003, Thomson et al. 1997). Finding a pulse well adapted to regional conditions is important for maximizing the benefit to the cropping system (Przednowek et al. 2004). While it is generally accepted that pulses are a benefit to rotations, the magnitude of these benefits may vary between pulses, and effects may persist through multiple years of rotation. Economic issues such as crop price and the development of market access affect the use of pulses in rotation despite their agronomic benefit (Miller et al. 2002a, Johnston et al. 2005). The adjustment of equipment and cultural production practices also influence adoption of changes to crop rotations (Miller et al. 2002a).

Peas

Peas (*Pisum sativum* L.) are grown on 6 – 6.6 million ha worldwide and produce 9.3 – 11.7 Mt of seed per year (FAOSTAT 2011). Field pea is one of the most commonly grown pulse crops in Alberta. In 2009, 323,700 ha of peas were seeded in Alberta accounting for 3.3% of the total seeded area in the province (Table 1-1) (Su 2010). Peas are produced for livestock or human consumption and are marketed in a variety of forms including: whole, split, flour, protein concentrate, pea sprouts, or silage (Park et al. 1999). The high protein content of peas makes them a desired ingredient to improve the nutritional value of food or feed. Crude protein content has been recorded to range between 202 and 268 mg g^{-1} (Miller et al. 2006, Wang and Daun 2004). Environmental conditions and genotype affect the protein content of the crop (Wang and Daun 2004).

High protein in pulse seed is made possible by their ability to fix N from the atmosphere. Peas have been recorded to fix between 18 and 246 kg N ha^{-1} with %Ndfa (nitrogen derived from the atmosphere) ranging from 12 to 92% (Table 1-2). N fixation can be optimized under conditions of low soil N and adequate moisture when crops are inoculated with appropriate *Rhizobium* bacteria (Clayton et al. 2004b, Hill and McGregor 2002, Peoples et al. 2001). N fixation is seen as one of the major benefits of producing a pea crop but the N balance of these rotations has given both positive and negative results (Unkovich et al. 1995, Soon and Arshad 2004b, Maidl et al. 1996, Beck et al. 1991, Armstrong et al. 1994, Hauggaard-Nielson et al. 2009). Although research is not completely conclusive on the N benefit from pea crops it is generally accepted that there is some N benefit from their production. The N content of pea tissue ranges from 28 to 145 kg N ha^{-1} for seed (Stevenson and van Kessel 1996b, Soon and Arshad 2004a, Maidl et al. 1996, Beck et al. 1991, Armstrong et al. 1994, Miller et al. 2006, Unkovich et al. 1995) and 7 to 55 kg N ha^{-1} for straw (Soon and Arshad 2004a, b, Carranca et al. 1999, Beck et al. 1991). Generally pea residues (straw and pods) that are returned to the soil for decomposition have a higher N content and lower C:N ratio than cereal residues (Stevenson and van Kessel 1996b, Maidl et al. 1996). This enhances decomposition, resulting in more N being made available for uptake by subsequent crops (Soon and Arshad 2004b, Stevenson and van Kessel 1996b). Peas have been reported as being a water efficient crop. The shallow root system (Siddique et al. 2001) and lower water use (Miller et al. 2002b, Miller and Holmes 2005) of a pea crop results in more water being left in the soil for subsequent crops (Miller et al. 2006). The benefits of nitrogen and soil moisture accompanied by the rotational benefits of diversifying a cropping system indicate that the addition of peas to a cropping system could improve profitability and sustainability of the system.

Peas are grown in many areas of Alberta because they can adapt to varied growing conditions. Although they are adapted to a wide range of environmental conditions, optimal yields are achieved when peas are produced on a neutral to alkaline soil with adequate moisture and mild temperatures (optimal 23^{o}C days and 10^{o}C nights) (Thomson et al. 1997, Park et al. 1999). Soil pH affects nodulation, dry matter accumulation and yield of peas (Tang and Thomson 1996, Park et al. 1999, French 2002). Tang and Thomson (1996) reported that peas where generally sensitive to low pH (<6). This is consistent with other studies but the pH range has been reported as low as 5.5 (French 2002, Park et al. 1999). Studies have indicated that peas respond positively to soil liming when produced on more acidic soils (Sparrow et al. 1995, French 2002) Flower blasting and pod abortion are caused by high temperatures and/or moisture limiting conditions during the onset of flowering, and results in reduced yields (Park et al. 1999). Due to this temperature sensitivity peas are often seeded early so that flowering occurs before the possible onset of late summer heat and drought (Park et al. 1999, Siddique et al. 2001). Frost tolerance also makes early seeding possible (Park et al. 1999). Moisture stress can reduce nodulation and decrease dry matter accumulation, often reducing seed yield (Hill and McGregor 2002, Clayton et al. 2004b).

In Alberta the most common diseases in pea include: fusarium root rot (*Fusarium solani*), fusarium wilt (*Fusarium oxysporum*), pythium root rot (*Pythium irregulare, Pythium ultimum*), rhizoctonia root rot (*Rhizoctonia solani*), mycosphaerella blight (*Mycosphaerella pinodes*), ascochyta blight (*Ascochyta pisi*), sclerotinia rot (*Sclerotinia sclerotiorum*), powdery mildew (*Blumeria pisi*), downy mildew (*Peronospora viciae*), bacterial blight (*Pseudomonas syringae*), pink seed (*Erwinia rhapontici*), aphanoyces root rot (*Aphonomyces euticheS*), thielaviopsis root rot/black root (*Thielaviopsis basicola*), septoria blotch (*Septoria pisi*), grey mold (*Botrytis cinerea*), anthracnose (*Colletotrichum pisi*), alternaria blight (*Alternaria alternate*), cladosporium blight (*Cladosporium pisicolum*), black leaf (*Fusicladium pisicola*), brown spot (*Pseudomonas syringae*), pea seed-borne mosaic virus, pea enation mosaic virus, bean (pea) leaf roll virus, pea streak virus, red clover mosaic virus (causes pea stunt) (Park et al. 1999). Development of these diseases is dependent on environmental conditions but management practices such as diverse crop rotations, use of pathogen-free seed, and application of seed and foliar fungicides can reduce their occurrence and severity (Park et al. 1999). Crop production can be limited by environmental conditions but breeding efforts have focused on developing more adapted genotypes where yield is optimized under limiting conditions.

Faba bean

Faba bean (*Vicia faba* L.) is a less common crop in world and Alberta production systems. In global production, 3.9 – 4.5 Mt of faba bean seed is harvested from 2.4 – 2.7 million ha (FAOSTAT 2011). In 2009, 2,226 ha of faba beans were seeded in Alberta; compared to the 323,748 ha of peas (Alberta Agriculture and Rural Development 2010). Faba bean crops are grown for both human and animal consumption. In developing countries they are one of the pulse crops used as a main protein source in human diets (Duc 1997). For animal feed they are a protein supplement that can be fed to poultry, swine, dairy and beef cattle, calves and sheep (Park et al. 1999). Previously the presence of tannins reduced use of faba beans because of their anti-nutritional effects (Duc 1997). With the development of tannin free varieties the protein benefits of faba beans may be utilized more in feed supplements (Simpson 1983). Increased knowledge of production practices, access to processing, and development of markets for faba bean may increase their use in Alberta to diversify crop rotations, improve soil N dynamics and increase sustainability of the agricultural system.

Faba bean production is optimized under cool moist conditions (Park et al. 1999). Jensen et al. (2010) reported optimal temperatures ranged from 18 to 27^{o}C; other studies report that flowering is sensitive to high temperatures (Park et al. 1999, Evans and Slinkard 1975, Siddique et al. 2001). Moisture stress can be a limiting factor to both dry matter accumulation and N fixation (Kurdali et al. 2002). To avoid unfavourable temperature and moisture conditions faba bean crops can be seeded early, as seedlings are frost tolerant (Park et al. 1999, Jensen et al. 2010). Early seeding provides a longer growing season for the faba bean to develop and results in earlier flowering and pod set (Thomson et al. 1997, Siddique et al. 2001, Jensen et al. 2010). Seedlings are slow to emerge (2 weeks), making faba bean a poor weed competitor (Evans and Slinkard 1975, Strydhorst et al. 2008, Park et al. 1999). Effective weed control is necessary for optimal production (Strydhorst et al. 2008) and there are currently a limited number of herbicides registered for use on faba beans in Alberta (Alberta Agriculture and Rural Development 2011a).

Diseases reported in faba beans in Alberta include: ascochyta blight (*Ascochyta fabae*), chocolate spot (*Botrytis fabae*, *Botrytis cinerea*), powdery mildew (*Microsphaera penicillata*), root rot and seedling blight (*Rhizoctonia solani*, *Fusarium* spp.), rust (*Uromyces viciae-fabae*), sclerotinia stem rot (*Sclerotinia sclerotiorum*), bean yellow mosaic (bean yellow mosaic virus), and aster yellows (aster yellows mycoplasma-like organism) (Park et al. 1999). Currently there is only one registered pesticide in Alberta to aid producers in control of these diseases (Alberta Agriculture and Rural Development, 2011b) but diversifying crop rotations and sowing pathogen free seed can reduce disease occurrence (Park et al. 1999).

Soil pH also has an effect on the growth and N fixation of faba beans. Studies indicate that faba bean crops perform best on neutral to alkaline soils with shoot and root growth, nodulation, and N fixation reduced at pH <6 (Tang and Thomson 1996, Park et al. 1999). Faba beans have a high potential for nitrogen fixation and have been recorded to fix between 2 and 350 kg N ha^{-1} in a growing season (Table 1-3). Their %Ndfa ranges from 4 – 96%, suggesting that if grown in favourable conditions they can fix most of their own nitrogen (Table 1-3). N fixation can be suppressed by high soil N, poor nodulation success, limited moisture conditions, and pH stress (Peoples et al. 2001, Kurdali et al. 2002, Park et al. 1999, Carranca et al. 1999). Generally studies indicate that production of faba beans results in a positive N balance with N being added to the agricultural system (Walley et al. 2007, Beck et al. 1991). Maidl et al. (1996) reported that faba bean added more N to the agricultural system than did peas and less N was leached from the soil under a faba bean crop. An N benefit transferring to the yield and quality of subsequent crops has been reported by Wright (1990a, b) but a difference between faba bean and pea stubble was not detected.

Faba bean seed has high protein content, ranging from 270 to 340 mg g^{-1} (Duc 1997). High levels of N fixation provide adequate N for seed fill to maintain seed protein levels. Similar to pea, faba bean has a relatively shallow root system and extracts less water from below 0.8 m than an oat crop (Jensen et al. 2010). The shallow root system leaves more water in the soil profile for subsequent crops but makes the faba bean crop more susceptible to drought stress (Jensen et al. 2010).

Lupin

Narrow-leafed lupin (*Lupinus angustifolius* L.) is a new crop to Alberta and has been recently investigated as another potential pulse crop in rotation. It is a minor crop in world production where it is grown on 0.7 to 1.2 million ha and produces 0.8 – 1.6 Mt of seed (FAOSTAT 2011). New varieties from German breeding lines have been introduced for Canadian production as Australian varieties are not adapted for this environment (Strydhorst 2008). Lupin has become the dominate pulse crop in Western Australia due to its unique adaptation to acidic soils (French 2002). Optimal soil pH for lupin ranges from 5.0 to 6.8 (Strydhorst 2008). Studies report that root and shoot growth, nodulation, N fixation and yield are reduced when lupin is produced on more alkaline soils (Tang and Thomson 1996, French 2002, Tang and Robson 1995, French and Buirchell 2005). Alkaline soils may decrease nodulation success in lupins by restricting root growth and reducing the establishment and persistence of *Bradyrhizobium* in the soil (Tang and Robson 1995). Lupin is well adapted to areas of acidic soils but pea or faba bean crops will perform better on neutral to alkaline soils (French 2002, Thomson et al. 1997). There are acidic soils throughout Alberta which occur more frequently in the central and peace regions on 11 – 31% of the cultivated land (Alberta Agriculture, Food and Rural Development 2002). Choosing a pulse crop that is well adapted to local soil and climatic conditions is essential to optimizing the benefits of including these crops in rotation (Tang and Thomson 1996). Studies indicate that lupins are more responsive to soil properties than peas (French 2002). Saline, sodic or water retentive soils can reduce lupin yields (French 2002, Tang and Thomson 1996).

Moisture limiting conditions are another factor that affects the yield of a lupin crop. Lupins are very sensitive to moisture limiting conditions as water deficits result in a reduction of photosynthesis (Palta et al. 2007). With adequate moisture conditions leaves track the sun to increase interception of solar radiation but with the development of moisture stress leaflets roll and wilt, reducing solar interception (French and Buirchell 2005). Lupins' primary mechanism to deal with moisture limiting conditions is drought escape; they complete their life cycle before the onset of terminal drought (French and Buirchell 2005, Palta et al. 2007). When compared with other erect legume species, water use efficiency of lupin was lower than faba bean (Siddique et al. 2001). Characterised by a deep tap root (Russell and Fillery 1996) lupins are able to access deeper soil water and nutrients (Kettel et al. 2003) and have equal water uptake to wheat (French and Buirchell 2005).

Similar to pea and faba bean, lupin is sensitive to temperature; maximum temperature ranges from 15 to 25^{o}C (Park et al. 1999). Flower abortion, reduced pod set and retention are a result of high temperatures during flowering and pod fill (Park et al. 1999, Kettel et al. 2003). Since lupins are still mainly an experimental crop in Alberta, common diseases have not yet been identified nor have pesticides been developed. In Australia common diseases include: pleiochaeta root rot (*Pleiochaeta setosa*), rhizoctonia bare patch (*Rhizoctonia solani*), rhizocotonia root and hypocotyl rot (*Rhizoctonia solani*), sclerotinia collar rot (*Sclerotinia minor*), charcoal rot (*Macrophomina phaseolina*), brown leaf spot (*Pleiochaeta setosa*), phomopsis stem blight (*Phomopsis leptostromiformis*), sclerotinia stem rot (*Sclerotinia sclerotiorum*), cucumber mosaic and bean yellow mosaic virus (Kettel et al. 2003). Disease control includes a variety of practices including proper crop rotation, fungicide treatments, sowing resistant varieties, and planting early (Kettel et al. 2003). Early seeding provides many advantages to the lupin crop; reduction in disease development and earlier flowering allowing for more time for maturity before terminal drought (Kettel et al. 2003). Lupins are tolerant to some freezing temperatures (Kettel et al. 2003). Weed control is important in a lupin crop as it is a poor weed competitor (Strydhorst et al. 2008).

One of the major advantages of producing a lupin crop in comparison to a non legume crop is its ability to fix N from the atmosphere. Research from Australia indicates the variability of N fixation by lupin crops; N fixation ranges from 26 to 283 kg N ha^{-1} with %Ndfa ranging from 42 to 99% (Table 1-4). One recent study of lupins in Alberta reported N fixation of 46 to 173 kg N ha^{-1} with %Ndfa averaging 43% (Strydhorst et al. 2008). N yield of lupin seed has been recorded to range from 63 to 193 kg N ha^{-1} (Anderson et al. 1998, Herridge and Doyle 1988, Armstrong et al. 1997, Ayaz et al. 2004), straw 17 to 207 kg N ha^{-1} (Herridge and Doyle 1988, Ayaz et al. 2004) and root 22 to 41 kg N ha^{-1} (Anderson et al. 1998). Russell and Fillery (1996) reported a higher estimate of below ground N (91 kg N ha^{-1}), and that C:N ratios of below ground biomass were lower than that of above ground biomass, which would enhance decomposition and N cycling. N returned to the system through decomposition of straw and roots provides an N benefit to subsequent crops. Studies reporting the N balance of lupins (-3 to +129 kg N ha^{-1}) suggest that lupins can add a significant amount of N to an agricultural system under good growing conditions (Unkovich et al. 1995, Armstrong et al. 1997). N fixation is important to provide adequate N to the plant to produce a high protein seed. The crude protein of lupin seed ranges from 272 to 372 mg g^{-1} (Park et al. 1999, Fraser et al. 2005). The value of lupin seed comes as a result its high protein content. Seed can be used as a protein supplement in human and animal diets. Lupin is commonly fed to poultry or livestock as whole, cracked or ground seed and research is investigating the use of lupin flour to improve the nutritional value of many food products (Kettel et al. 2003).

Nitrogen Fixation

N fixation does come at a cost to the plant. The symbiotic relationship formed between the plant roots and *Rhizobium* bacteria requires the plant to provide carbohydrates for the bacteria while the bacteria fixes N from the atmosphere. Pulse crops have reduced N fixation if N is available in the soil (Clayton et al. 2004a, Hardarson and Atkins 2003), indicating that the plant may reduce the amount of carbohydrate provided to the bacteria when fixed N is not required for growth. Reduced rates of growth and competitiveness of N fixing crops may partially be because of the additional resource sink that the nodules create. For adequate nodulation to occur, inoculation of soil with *Rhizobium* bacteria is often required. There are many inoculant formulations, including granular, peat, and liquid forms (Clayton et al. 2004a). For production of pulse crops on soils that have not previously grown pulse crops, or have had many years between pulse crops, inoculation is suggested to improve nodulation. This helps to stabilize yields and increase profitability of the crop (Clayton et al. 2004a). Inoculation of peas increased seed protein content and harvest index (Clayton et al. 2004a). Nodulation is also affected by environmental conditions; moisture stress can reduce the development of effective nodules (Abd-Alla and Abdel Wahab 1995, Clayton et al. 2004b, Hill and McGregor 2002).

Quantification of the nitrogen benefit of pulses is a major research area. The need for accurate quantification of nitrogen fixation by pulse crops has lead researchers to investigate many different methods of quantification. No method has been developed that is a perfect assessment of nitrogen fixation so a variety of methods are still commonly used. These include: N balance, N difference, ^{15}N natural abundance, ^{15}N isotopic methods and the ureide method (Unkovich et al. 2008). Studies comparing N fixation estimates from two or more of these methods have had variable success in correlating results between methods (Herridge et al. 1990, Rennie 1984). There are advantages and disadvantages to each method for estimating N fixation.

The N balance method calculates the amount of N leaving the system, subtracts all the N inputs into the system and the balance is attributed to N fixation (Eq. 1).

Eq. 1. N fixed = Outputs - Inputs

The simplest form occurs in experiments where crops are grown on N-free media so the only N inputs are N in the seed, inoculum and from N fixation, and output is the N yield of the crop (Eq. 2).

Eq. 2. N fixed = N yield $_{\text{total plant}}$ – N $_{\text{seed+inoculum}}$ (Unkovich et al. 2008)

Under field conditions this calculation is much more complicated. N input needs to include: sources of organic N (manure, organic matter), fertilizer N, N in water source, wet deposition, dry deposition, run-on, N from lateral subsoil flow, seed N and N in inoculum (Unkovich et al. 2008). Outputs include N yield of crop, NH_3 volatilisation, gaseous losses through denitrification, soil erosion, run-off, and leaching. Some losses are difficult to measure including: NH_3 volatilisation, denitrification, leaching, run-off and erosion (Unkovich et al. 2008). This method is best used in greenhouse experiments where inputs and outputs can be controlled (Unkovich et al. 2008). In some cases it can be used for measuring N fixation in agroforesty or pasture systems in longer term studies but its use for measuring pulse fixation is limited (Unkovich et al. 2008).

The N difference method is commonly used in field experiments because it is a simple low cost method only requiring measurements of dry matter and N concentration of plant material (Unkovich et al. 2008). For this method the total N in a fixing crop is compared to the total N in a non-fixing reference crop (Eq. 3). The difference in total N is attributed to N fixation by the fixing crop.

$$\text{Eq. 3. N Fixed} = \text{Total N Yield}_{\text{Fixing Plant}} - \text{Total N Yield}_{\text{Non-Fixing Reference Plant}}$$

(Rennie 1984)

The total N in the reference crop is used as an estimate of the soil N taken up by the N fixing crop. A major limitation of this method is determining a good reference crop that reflects the actual soil N uptake of the N fixing crop. The N assimilation by different crops is affected by their ability to access soil N due to differences in root morphology, and rate of shoot and root growth (Herridge et al. 2008). Some studies have reported different N fixation estimates based on the different reference crop used (Rennie 1984, Pate et al. 1994). Non-nodulating isolines are available for some legume species (peanut, pigeon pea, chickpea, soybean, common bean, faba bean, cowpea, alfalfa, and crimson and subterraneaum clover) but have been only used in a limited number of studies and may still not have the same N uptake pattern as the nodulating species (Unkovich et al. 2008). The N difference method has been most successful when used under low soil N conditions when there are large differences in total N between the N fixing crop and the reference crop (Unkovich et al. 2008).

The uriede method can only be used on ureide exporting legume crops (ie. soybean) which limits its use for many crop species (Unkovich et al. 2008). A measurement of the relative composition of N solutes (ureides, amino compounds and nitrate) in plant tissue or xylem sap is taken and the plants reliance on N_2 fixation is determined (Unkovich et al. 2008, Herridge et al. 1990). Ureides are mainly synthesised in the nodules and are used by these plants to transport fixed N throughout the plant (Unkovich et al. 2008). Through calibration experiments the relationship between ureide concentration and %Ndfa can be determined (Unkovich et al. 2008). Once calibrated the uriede method is a simple procedure of harvesting plant tissues or xylem sap and measuring N solutes with colorimetric assays (Unkovich et al. 2008).

There are three main techniques that involve the use of ^{15}N isotopes. They are used to varying degrees because of the cost of materials and equipment, as well as the expertise in mass spectrometry that is required (Unkovich et al 2008). The first is $^{15}N_2$ feeding. Exposing plants to $^{15}N_2$ gas and measuring the amount of ^{15}N in the plant gives a direct measure of fixation. This method can only be used in small scale laboratory experiments where a closed gas chamber can be created. It is limited to short time frames but is very useful for measuring N translocation or N fixation by free living organisms (Unkovich et al. 2008).

The second is ^{15}N isotope dilution method. Crops are grown with ^{15}N fertilizers and the difference in ^{15}N concentration between fixing crops and the reference crop give a measure of the amount of N fixed (Eq. 4).

$$\text{Eq. 4. } \%Ndfa = \left(1- \frac{\text{atom}\%^{15}\text{N excess N fixing plant}}{\text{atom}\%^{15}\text{N excess reference plant}}\right) \times 100$$

(Unkovich et al. 2008)

This technique can be used in field experiments but with advances in mass spectrometry the third method has become more popular for field and large scale experiments (Unkovich et al. 2008).

The ^{15}N natural abundance method does not require the addition of any ^{15}N labelled inputs. This method involves measuring the subtle differences in the ratio of ^{14}N and ^{15}N in the soil profile compared to the atmosphere (Eq. 5) (Unkovich et al. 1994, 2008).

$$\text{Eq. 5. } \%Ndfa = \frac{^{15}\text{N of soil N} - {}^{15}\text{N of N fixing plant}}{^{15}\text{N of soil N} - {}^{15}\text{N of atmosphere N}_2} \times 100$$

(Unkovich et al. 2008)

A non-fixing reference crop is used to determine the ^{15}N signature of the soil (Unkovich et al. 2008). Generally ^{15}N concentration in the atmosphere is slightly lower than that in the soil therefore an N fixing plant will have a lower ^{15}N composition than a non fixing plant. This method cannot be used on all soils as some have inherent low ^{15}N and others are too variable (Unkovich et al. 2008).

Acetylene reduction and hydrogen evolution are both methods that are largely used in laboratory experiments that measure the conversion of gasses by the roots (Herridge et al. 2008). Nitrogenase is active in nodules converting atmospheric N_2 into NH_3 (Eq. 6) but when exposed to acetylene it converts it into ethylene (Eq. 7).

Eq. 6. $N{\equiv}N + 8H^+ + 8e^- \rightarrow 2NH_3 + H_2$ (Unkovich et al. 2008)

Eq. 7. $\underset{\text{(acetylene)}}{HC{\equiv}CH} + 2H^+ + 2e^- \rightarrow \underset{\text{(ethylene)}}{H_2C{=}CH_2}$ (Unkovich et al. 2008)

For acetylene reduction the amount of ethylene produced is measured after exposure to acetylene, which can be used as a measure of nitrogenase activity.

Hydrogen evolution involves measuring the H_2 produced in N fixation (Eq. 6) to measure nitrogenase activity (Unkovich et al. 2008). Both are inexpensive and sensitive but require extensive work with the roots which is challenging (Unkovich et al. 2008).

Often studies have only included above ground biomass in N fixation calculations because of the difficulty of retrieving belowground biomass. This results in an underestimation of N fixation as studies that have investigated below ground biomass report that 22 to 68% of total plant N is located below ground (McNeill and Fillery 2008, Herridge et al. 2008). Recent research in Alberta reported nitrogen accumulation in the roots of barley (37 kg N ha^{-1}), faba bean (36 kg N ha^{-1}), lupin (65 kg N ha^{-1}) and pea (24 kg N ha^{-1}) while N accumulated in the above ground biomass was 190 kg N ha^{-1} for barley, 403 kg N ha^{-1} for faba bean, 417 kg N ha^{-1} for lupin and 280 kg N ha^{-1} for pea (Strydhorst et al. 2008).

Nodulation assessments at late vegetative stages can provide additional information to help determine the effectiveness of nitrogen fixation. For nodulation assessments plant growth and nodule colour, number and position are evaluated; high scores indicate potential for good fixation as plants are healthy and well nodulated (Zaychuk 2006). The limitation of nodulation assessments is that an actual amount of N is not measured but data collected from these assessments can support that of actual N fixation measurements.

Residue Breakdown and N Return

The impact of returned residues to soil organic matter and the quantity of nutrients available to subsequent crops is dependent on the amount of the residues returned, the residue nutrient composition and the rate of decomposition. Crop breeding has focused on increasing harvest index which means shifting the ratio of biomass and seed toward a greater portion of seed. This increases the profitability of the crop by providing more seed yield but reduces the amount of biomass that is returned to the system for decomposition. A reduction in residue return can impact nutrient availability and the amount of soil organic matter in the soil. The importance and value of returning crop residues to the soil is reflected in improvements to soil structure due to increases in soil organic matter and the effect that residues have on the nutritional status of the soil (Curtin et al. 2008, Lupwayi et al. 2004b).

Crops differ in their residue composition. Generally pulse and canola crop residues have higher N concentrations than do cereal residues (Soon and Arshad 2002). Soon and Arshad (2002) reported that 31 – 41 kg ha^{-1} of N was returned to the soil in pea straw residues, 17 – 24 kg N ha^{-1} in wheat straw residues and 16 – 20 kg N ha^{-1} in canola straw residues. Nitrogen returned in root residues was also measured: 2 – 3 kg N ha^{-1} for peas and 2 – 6 kg N ha^{-1} for wheat and canola. Over the 10 – 11 months of the study that decomposition was measured, only 7 kg ha^{-1} of N was mineralized from the pea residue and 1.6 kg ha^{-1} of N from the wheat and canola residue (Soon and Arshad 2002). Lupwayi et al. (2006) reported mineralization values of 46 – 69 kg N ha^{-1} for green manure residues, 4 – 18 kg N ha^{-1} for pea residues, 10 – 25 kg N ha^{-1} for canola residues and 2 kg N ha^{-1} for wheat residues over 12 months of study. In north-central Alberta, barley residues released 74 – 80 kg N ha^{-1}, faba bean 62 – 76 kg N ha^{-1}, lupin 118 – 134 kg N ha^{-1}, and pea 54 – 57 kg N ha^{-1} over 12 months (Strydhorst 2008). Nitrogen release is affected by N yield and environmental conditions.

Decomposition rates are affected by residue composition and generally residues with low lignin content, low C:N ratio and higher total N will decompose more quickly (Stubbs et al. 2009, Lupwayi et al. 2006). Canola straw has a higher lignin concentration than does pea or wheat straw yet wheat has a higher C:N ratio that either pea or canola (Lupwayi et al. 2004b). For the decomposition of high C:N residues, soil microbes have to access N from an alternative source; the microbes take up soil N (immobilization) reducing the amount of N available for plant uptake (Curtin et al. 2008). Residue composition is affected by the growing environment; climatic conditions (precipitation and temperature), production location (soil properties) and crop management practices (crop rotations, tillage, fertilization) (Stubbs et al. 2009).

Decomposition rates and mineralization of N are affected by the growing environment (Lupwayi et al. 2006). The growing environment determines the populations of soil microbes which are active in decomposing crop residues (Curtin et al. 2008). N release from pea residue is reduced under moisture limiting conditions (Lupwayi and Soon 2009). Crop management practices will also affect decomposition of residues. Strydhorst (2008) reported that decomposition of surface placed residues was slower than the decomposition of residues incorporated in the soil in central Alberta. The release of N from the crop residues through mineralization is important for the growth of subsequent crops.

Influence of Crop Rotation on Barley, Canola and Wheat Production

The benefits of growing a pulse crop are often seen in subsequent years of crop production. Barley, canola and wheat are the main crops produced in Alberta and it is important to understand their response to a preceding pulse. Differences in response may indicate that certain rotational sequences should be followed to optimize the benefit received from the pulse.

Barley

Barley (*Hordeum vulgare* L.) follows wheat, maize, rice and soybeans in importance on a world scale of production (FAOSTAT 2011). It is also one of the main crops grown in Alberta and is seeded on 16.2% of the total seeded land (1,602,500 ha) (Su, 2010). Barley is well adapted to a broad range of environmental conditions though seems to prefer a cool moderately dry climate (Poehlman 1985). Drought escape is its main adaption allowing it to be grown in relatively dry conditions (Poehlman 1985). Diseases that affect barley include: black point (*Alternaria* spp., *Cochliobolus sativus*, *Fusarium* spp.), browning root rot (*Pythium* spp.), common root rot (*Cochliobolus sativus*, *Fusarium* spp.), covered smut (*Ustilago hordei*), fusarium head blight (*Fusarium graminearum*), leaf stripe (*Pyrenophora graminea*), loose smut (*Ustilago nuda*), net blotch (*Pyrenophora teres*), powdery mildew (*Erysiphe graminis*), scald (*Rhynchosporium secalis*), false loose smut (*Ustilago nigra*), speckled leaf blotch (*Septoria passerinii*), spot blotch (*Cochliobolus sativus*), stem rust (*Puccinia graminis*), barley stripe mosaic virus and barley yellow dwarf virus (Kiesling 1985, Alberta Agriculture and Rural Development 2003a,b). Control of these fungal and viral diseases involves the utilization of proper management practices such as planting pathogen free seed, proper rotation, using resistant cultivars, and applying seed and foliar fungicide treatments (Kiesling 1985).

Barley crops are produced for use as animal feed, malt and human food. The different uses have different sets of optimal characteristics and require different processing for end use. As animal feed, high protein content is desirable as barley provides both protein and carbohydrate to the animal ration (Poehlman 1985). Barley grain is generally processed (cracked, ground or rolled) and mixed with other grains and forages to make a balanced animal ration (Poehlman 1985, Newman and McGuire 1985). Barley grain is fed to swine, poultry, cattle (beef and dairy), and sheep (Newman and McGuire 1985). Malt quality barley must meet a different set of quality characteristics including, among others, kernel plumpness and protein level (between the range of 105 and 130 mg g^{-1}) (McLelland et al. 2009). Processing barley for human consumption involves dehulling, and grinding into flour or pearling (Poehlman 1985).

The quality characteristics of a barley crop are dependent on the management and growing environment. Due to the variety of uses for barley grain, knowledge of how it responds to growing conditions is important to meet the quality characteristics that optimize the value of the crop produced. Crop sequencing has an effect on yield and quality of a barley crop. Barley yields are generally increased when grown on pulse stubble in comparison with cereal stubble. Wright (1990b) reported barley yields of 2.8 Mg ha^{-1} on barley stubble, 3.3 Mg ha^{-1} on lentil stubble, 3.4 Mg ha^{-1} on pea stubble and 3.4 Mg ha^{-1} on faba bean stubble. This indicates that the response of barley to pulse stubble may differ in magnitude depending on the type of proceeding pulse crop. Decreased barley yields when preceding crop was a cereal could be in part due to increases in diseases (Jensen 1996b). Soon et al. (2004) reported that barley yields following canola where similar to those following barley and numerically less than those following peas. Pulses can provide a superior rotational benefit to subsequent crops because of the N benefits that come with N fixation.

Nitrogen uptake by a subsequent barley crop is also increased when produced on pulse stubble. In Australia, N uptake by barley was 82 kg N ha^{-1} when grown on lupin stubble, 63 kg N ha^{-1} on canola stubble, 64 kg N ha^{-1} on ryegrass stubble, and 48 kg ha^{-1} on wheat stubble (Chalk et al. 1993). Increases in barley N uptake following peas have been partially attributed to an increase in available soil N due to the lower C:N ratio of pea residues which have higher N mineralization and lower N immobilization than barley residues (Jensen 1996b). Larger amounts of residue derived N are in the subsequent crop following pea (11.3%) in comparison to barley (8.3%) (Jensen 1996b). Wright (1990b) calculated nitrogen fertilizer equivalence for faba bean (120 kg N ha^{-1}), pea (100 kg N ha^{-1}), and lentil (80 kg N ha^{-1}). Barley is known to respond to nitrogen fertilizer with increased yields and seed protein content. It responds similarly to the N provide by the preceding pulse crop. Protein content of barley seed grown in Saskatchewan on pulse stubble averaged 124 mg g^{-1} while barley seed grown on barley stubble averaged 118 mg g^{-1} (Wright 1990a). For malt quality barley protein content needs to fall within the range of 105 and 130 mg g^{-1} (McLelland et al. 2009). In production of malting barley increases in protein content are a concern due to malting quality requirements (McKenzie et al. 2005). This may be one limitation of growing a malt barley crop after a pulse crop. Conversely, the increase in protein may be seen as an advantage if the end use of the barley crop is for feed. In western Canada approximately 20% of total barley produced is used for malting and the remaining 80% is used as animal feed (McKenzie 2008). Barley protein content increases in drought conditions, with the addition of N fertilizer, and sometimes when seeding is delayed; but decreases with higher seeding rates (McKenzie et al. 2005). In contrast to the disadvantage preceding pulses are to protein content of malt barley they have also been reported to increase kernel plumpness (Wright 1990a) which is another requirement of malt quality (McLelland et al. 2009). Increases in protein content and kernel plumpness improve the quality of feed barley which dominates the production area in Western Canada. Pulse crops can provide a benefit to subsequent barley crops that can be optimized based on end use of the barley crop.

Canola

Canola (*Brassica napus* L.) is a less common world crop than wheat, maize, rice and barley (FAOSTAT 2011). In Canada canola has gained popularity because of its profitability compared to a cereal based system. Canola production in Alberta in 2009 occupied 20.4% of the seeded land (2,023,400 ha) (Table 1-1) (Su 2010). Canola has proven to be well adapted to a wide range of environmental conditions. It can tolerate soil pH ranging from 5.5 to 8.3 but on more acidic soils canola does respond positively to liming (Thomas 1984). Relatively cool temperatures (12^{o}C to 30^{o}C) will result in optimal growth (Thomas 1984). Hail and frost damage can reduce yields and quality of canola. Adequate moisture is necessary to achieve good yields. Water use is maximized at flowering and plants have demonstrated drought sensitivity during germination and establishment (Thomas 1984, Booth and Gunstone 2004). Canola is a more drought sensitive crop than wheat (Miller et al. 2003).

Root mass of canola and wheat are very similar at maturity (Gan et al. 2009). Root biomass increases in moisture limiting conditions and there is a significant portion of roots at a depth of 80-100 cm (Gan et al. 2009). The deep tap root allows plants to access moisture and nutrients from lower soil profiles (Booth and Gunstone 2004). Canola is a very plastic plant and can adjust plant structure and many yield parameters to different environmental conditions (Booth and Gunstone 2004, Karamzadeh et al. 2010). For example, changes in seeding rate affect branching and height (Booth and Gunstone 2004), the addition of fertilizer can increase plant height, number of pods, and seed weight, and increases in nitrogen availability increase grain fill period and delay maturity (Karamzadeh et al. 2010). Expression of plasticity in canola is dependent on the availability of soil nutrients, water and sunlight (Karamzadeh et al. 2010).

Nitrogen addition is often required for optimal canola growth. According to Evans et al. (2006) canola may not be as efficient at acquiring soil N as wheat. This may be a result of canola being a non-mycorrhizal crop and therefore having reduced access to soil nutrients. The application of N fertilizer increased dry matter, seed yields, and seed protein content, but high rates of N fertilizer can decrease oil content (Thomas 1984). A similar trend occurred with the production of canola on legume crop stubble; seed yield and N concentrations were higher in comparison to canola produced on unfertilized wheat stubble, but oil concentration was lower (Evans et al. 2006).

Common diseases of canola in Alberta include: alternaria black spot (*Alternaria brassicae*), blackleg (*Leptosphaeria maculans*), foot and root rot (*Fusarium* spp., *Rhizoctonia solani*), sclerotinia stem rot (*Sclerotinia sclerotiorum*), seedling blight (*Rhizoctonia solani*), white leaf spot/gray stem (*Pseudocercosporella capsellae*), white rust/staghead (*Albugo candida*), aster yellows (*Phytoplasma*), and bacterial pod spot (*Pseudomonas syrigae*) (Alberta Agriculture and Rural Development 2003c). These diseases can be controlled through the production of resistant cultivars, application of fungicides, and proper crop rotation. More recently clubroot (*Plasmodiophora brassicae*) has become a major concern in Alberta. Clubroot is a soil born disease that causes galls to form on the roots which restricts moisture and nutrient uptake causing the plant to wilt, yellow and prematurely ripen (Hartman 2011). The reduction in yield and quality of canola when infected with clubroot has severe economic consequences for the producer. Clubroot can spread between fields in the soil left on machinery and can persist in the soil for many years. Currently researchers are investigating resistant varieties of canola but proper crop rotation and good sanitization of equipment can help to control this disease (Hartman 2011).

Canola was developed through the breeding of rapeseed for low levels of erucic acid and glucosinolates (Ratnayake and Daun 2004). Both of these characteristics were anti-nutritional and reduced the use and production of rapeseed. Currently, varieties of rapeseed low in both erucic acid and glucosinolates are called canola. Due to the unique composition of canola oil, it has been marketed as a healthy alternative to many other vegetable oils. It is notably low in saturated fatty acids but has a high amount of monounsaturated fatty acids (oleic acid) and polyunsaturated fatty acids (α-linolenic and linoleic acid) (McDonald 2004). Some research indicates that the fatty acid composition of canola oil can have a positive impact on the reduction of cardiovascular disease (McDonald 2004).

Canola oil is a common ingredient in salad dressings and food formations and is used in a variety of cooking methods (McDonald 2004). Non-food uses of canola oil are also wide-reaching, including biodiesel, lubricants (hydraulic fluids, greases, mould release agents, motor and gear oils, metal working fluids and chainsaw oil), surfactants, paints, inks, and polymers (Walker 2004). Canola meal is also a valuable bi-product that can be used as a protein supplement for livestock production.

The effects of preceding crops in rotation on canola growth and the effect of canola on subsequent crops are important to investigate. Canola has a variety of responses to preceding crops that are often confounded by environmental conditions. Generally, canola growth on legume stubble is greater than canola growth on canola or wheat stubble (Miller et al. 2003). Yields in North Dakota of canola grown on canola (1.1 – 1.4 Mg ha^{-1}), pea (1.5 Mg ha^{-1}), wheat (1.3 – 1.5 Mg ha^{-1}), and barley (1.4 – 1.6 Mg ha^{-1}) stubble demonstrate a numeric advantage of pea stubble over canola stubble, but no advantage of pea stubble over cereal stubble (Krupinsky et al. 2006). N fertilizer was applied to all crops in this study which may have reduced the N fixation benefit that a pea crop would have provided to the rotation. Canola yields are generally greater when grown on crop stubbles other than canola or closely related oilseed crops. The reduction in disease and weed pressure may provide that yield advantage. Johnston et al. (2005) reported lowest canola yields and highest blackleg incidence when canola was repeatedly grown on canola stubble, with the exception of lower canola yields on pea and flax stubble under severe drought. Early competition from volunteer oilseed crops can reduce establishment of seedlings and access to early nutrients, which reduces final yields (Miller et al. 2003). Most canola varieties produced in Canada are herbicide tolerant which simplifies in-crop weed control but presents a challenge in controlling volunteer canola in subsequent crop production (Booth and Gunstone 2004).

Some concern has been raised about the effects of a canola crop on subsequent crops. Some studies report reduced yields in subsequent crops (Grant et al. 2009, Beckie and Brandt 1997, Soon and Arshad 2004a); other studies indicate that the canola crop has no effect (Roberson et al. 2009) or even increased subsequent crop yield (Soon and Clayton 2002). Flax seems to be one of the most responsive crops following canola in rotation. Lower yields and phosphorus accumulation have been reported in flax when following canola in comparison to wheat (Grant et al. 2009, Beckie and Brandt 1997). Reasons for this negative reaction to canola residues could include allelopathy of canola residues, weed completion from volunteer canola, and reduced mycorrhizal colonization (Grant et al. 2009, Soon and Arshad 2004a). Since flax is a poor weed competitor and known to be reliant on mycorrhizae fungi associations for nutrient uptake, reduced growth and yield following canola is understandable. Other crops may not be as responsive to preceding canola crops based on their ability to access soil nutrients without mycorrhizal associations, and the climatic conditions of the study (soil nutrient levels, moisture conditions etc).

Wheat

Wheat (*Triticum aestivum* L.) is a main cereal crop in world production. More production area is used to grow wheat than any of the other main cereal crops, including maize, rice and barley (FAOSAT 2011). In Alberta wheat is seeded on 2,859,000 ha and occupies 28.9% of the total seeded area in the province (Su, 2010). Wheat is adapted to a very broad range of environmental conditions, allowing it to be produced worldwide. Drought resistance allows it to be produced in many moisture limiting environments (Lamb 1967). Temperature can affect growth and quality of wheat. Wheat can tolerate moderately high temperatures (Lamb 1967). Frost in the spring or fall can reduce value of the crop due to shrivelled kernels, low seed weights, reduced yields, and lower germination (Lamb 1967).

There are many diseases that affect wheat production. Viral diseases in Alberta include barley yellow dwarf, wheat streak mosaic and spot mosaic virus (Alberta Agriculture and Rural Development 2003e). Many more fungal diseases exist and infect crops to varying degrees based on seasonal conditions. Fungal diseases included: black point/kernel smudge (*Alternaria alternata*, *Cochliobolus sativus*), common bunt (*Tilletia caries*, *Tilletia foetida*), common root rot (*Cochliobolus sativus*, *Fusarium* spp.), ergot (*Claviceps purpurea*), fusarium head blight/scab (*Fusarium graminearum*, *Fusarium* spp.), leaf rust (*Puccinia recondita*, *Puccinia triticina*), loose smut (*Ustilago tritici*), powdery mildew (*Erysiphe graminis*), speckled leaf blotch (*Septoria avenae*, *Septoria nodorum*), glume blotch (*Septoria nodorum*, *Stagonospora nodurum*), spot blotch (*Cochliobolus sativus*), stem rust (*Puccinia graminis*), stripe rust (*Puccinia striiformis*), take-all (*Gaeumannomyces graminis*), tan spot (*Pyrenophora tritici-repentis*), and red smudge (*Pyrenophora tritici-repentis*) (Alberta Agriculture and Rural Development 2003d). For control of these diseases methods range from planting resistant cultivars to managing diverse crop rotations to application of seed and foliar fungicides (Alberta Agriculture and Rural Development 2003d).

Wheat is commonly used in a large number of food, feed and industrial products. For human consumption wheat is a main ingredient in baked goods (bread, rolls, cookies, doughnuts, etc), crackers, pasta, breakfast cereal, soups, sauces, candies, and beverages (Reitz 1967). The different quality characteristics of the many classes of wheat make each class ideal for a different use. Durum wheat is used to make pasta whereas soft wheat is more suited to cake and cookie production and hard wheat is used to make bread (Finney and Yamazaki 1967). Wheat is also fed to livestock (cattle, sheep, and pigs) and poultry. Feed can include whole or processed grain, wheat by-products from milling or green forage (Reitz 1967). Wheat straw is used as livestock bedding but can also be added to ruminant rations for roughage. The starch in wheat can be used in pastes, alcohol, oil and gluten (Reitz 1967).

Wheat response to preceding crops has been investigated in many studies globally. Generally wheat has higher yields, N uptake and protein content when it is grown on pulse stubble in comparison to wheat stubble (Gan et al. 2003, Maidl et al. 1996, Stevenson and van Kessel 1996b, Miller et al. 2002b, Doyle et al. 1988, Evans et al. 2003). Miller et al. (2002b) reported higher wheat yield, protein content and N uptake when grown on pea stubble (2.6 Mg ha^{-1}, 162 mg g^{-1}, 67 kg ha^{-1}) than on wheat stubble (2.0 Mg ha^{-1}, 150 mg g^{-1}, 47 kg ha^{-1}) in Saskatchewan. Recent research in Alberta compared the different effects of faba bean, lupin and pea stubble on wheat yields (4.5, 4.1, and 4.6 Mg ha^{-1}) generally reporting lower wheat yields on lupin stubble (Strydhorst et al. 2008). The effect of pulse crops on wheat can last multiple years (Gan et al. 2003). Preceding oilseed crops have had different effects on wheat depending on environmental conditions. Gan et al. (2003) reported increased wheat yields when grown on canola stubble and Miller et al. (2006) reported that mustard stubble decreased wheat yield.

Wheat responds to increases in N in the soil. The addition of N to the soil by pulse crops from N fixation may be one of the contributing factors to improved wheat yield and increases in protein and N content (Evans et al. 2003). Since grain protein is one determinant of quality for wheat, the effect of previous crops can have an economic impact. Protein content is affected by both moisture and soil fertility (Doyle et al. 1988). The effect of environmental conditions on protein content is some times greater than soil N (Soon and Arshad 2004a). Studies that report a protein response in wheat indicate that the increase in soil N from mineralization of pulse residues or the addition of N fertilizer raise wheat protein levels (Evans et al. 2003, Gan et al. 2003, Miller et al. 2002b, Beckie et al. 1997).

Wheat is also responsive to rotational benefits or non-N benefits that come with the production of pulses. Stevenson and van Kessel (1996b) reported that wheat following pea or wheat, only recovered 8% of the ^{15}N present in the residue of the preceding crop. The benefit seen in wheat yield and quality was greater than was attributable to pulse provided N. The interactions of preceding crop on soil water, disease prevalence, availability of other nutrients, and effects on soil structure can all contribute to the improved growth of the subsequent wheat crop (Strydhorst et al. 2008, Doyle et al. 1988).

Sustainable Crop Production

With the green revolution and the introduction of synthetic N fertilizers, crop production has increased in the developed world, providing a better and more reliable source of food and feed. The increased size and scale of agriculture has impacted the natural environment in many areas of the world. There has also been a recent push to reduce N fertilizer use due to rising fertilizer and energy prices. Researchers are investigating alternative N sources to decrease the environmental and economic impact while maintaining both crop yields and quality. Pulse crops are an alternative source for N due to their ability to fix N from the atmosphere. The effect of different pulses in rotation is important to understand to design optimal cropping systems. The response of different subsequent crops also impacts the benefit that is gained from including a pulse in rotation. There have been a limited number of studies comparing multiple pulse crops and the response of multiple subsequent crops. These interactions are essential to understand to improve the sustainability of the cropping systems in Alberta.

This study addresses some of the knowledge gaps of the effects of pulse crops on rotations in Alberta. It investigates the effects of faba bean, lupin and pea on multiple subsequent crops (barley, canola and wheat) in rotation by quantifying the N contribution by the pulses and measuring the response in yield and quality of the subsequent crop. The objective is to increase our knowledge of pulses in rotation and provide producers with information on crop sequencing and the use of pulse crops to improve the sustainability of the agricultural system. The null hypothesis for this study is; faba bean, lupin and pea all grow and fix nitrogen similarly in central Alberta and will all have a similar impact on the growth of subsequent barley, canola and wheat crops.

Table 1-1: Total seeded area and % seeded area of crops in Alberta, Canada in 2009.

Crop	% of Total Seeded Area	Seeded Area (‘000 ha)
Wheat	28.9	2859.0
Tame Hay	25.3	2508.9
Canola	20.4	2023.4
Barley	16.2	1602.5
Other Grains	4.5	445.1
Peas	3.3	323.7
Total	98.6	9762.6

Data from Su, 2010.

Table 1-2: Summary of N fixation (%Ndfa, and kg N ha^{-1}) by field pea measured by a variety of methods from research worldwide.

%Ndfa	N Fixed (kg N ha^{-1})	Method	Reference Species	Location and Conditions	Reference
53-67	104-163	^{15}N natural abundance	Barley and Capeweed	Australia, no N fertilizer, above ground biomass	Armstrong et al. 1997
60-91	n/a	^{15}N natural abundance	Wild Radish (*Raphanus raphanistrum*)	Australia, no N fertilizer, above ground biomass	Armstrong et al. 1994
63-74	33-126	A-value and ^{15}N dilution	Barley and Non-nodulating chickpea	Syria and France, 20-100 kg N ha-1 of N fertilizer added, above ground biomass	Beck et al. 1991
n/a	0-180	N difference	Canola (*Brassica rapa*)	Alberta, different inoculants and 0-80 kg N ha^{-1} of N fertilizer added, above ground biomass	Clayton et al. 2004b
44-92	35-183	^{15}N natural abundance	In crop weeds and/or non legume crops	Australia, no N fertilizer, above ground biomass	Peoples et al. 2001
12-68	18-73	^{15}N isotopic dilution	Barley	Alberta, N fertilizer added (0.7g N m^{-2}), above ground biomass	Soon and Arshad 2004b
43-78	62-108	^{15}N isotopic dilution	Barley and Canola	Alberta, N fertilizer added (16.8 g m^{-2} of 4-17-35-11), above ground biomass	Soon et al. 2004
75-81	36-120	^{15}N isotopic dilution	Wheat	Saskatchewan, different N fertilizer rates added, above ground biomass	Stevenson and van Kessel 1996b
49	78-147	N difference	Barley	Alberta, no N fertilizer, above ground biomass	Strydhorst et al. 2008
60-91	54-165	^{15}N natural abundance	Wild Radish (*Raphanus raphanistrum*)	Australia, no N fertilizer, above ground biomass	Unkovich et al. 1995
55	n/a	Various	Various	Northern Great Plains of Canada and the United States, review of 79 studies	Walley et al. 2007
35-90	42-144	^{15}N isotope dilution and N difference	Barley, alfalfa, Kale	Alaska, N fertilizer added (20 kg N ha^{-1}), above ground biomass	Sparrow et al. 1995
n/a	215-246	Extended difference	Oats	Germany, no N fertilizer, above ground biomass	Maidl et al. 1996
n/a	127 -153	N difference	Wheat	Nepal, no N fertilizer, above ground biomass	Schulz et al. 1999
57-62	81-97	^{15}N isotope dilution	Barley	Saskatchewan, N fertilizer added (5 kg ha^{-1} of 34-0-0), above ground biomass	Beckie et al. 1997

n/a: data not available

Table 1-3: Summary of N Fixation (%Ndfa, and kg N ha^{-1}) by faba bean reported by worldwide research.

%Ndfa	N Fixed (kg N ha^{-1})	Method	Reference Species	Location and Conditions	Reference
63-92	78-181	A-value and ^{15}N dilution	Barley	Syria and France, 20-100 kg N ha^{-1} of N fertilizer added, above ground biomass	Beck et al. 1991
4-96	2-174	^{15}N natural abundance	In crop weeds and/or non legume crops	Australia, no N fertilizer, above ground biomass	Peoples et al. 2001
54	70-223	N difference	Barley	Alberta, no N fertilizer, above ground biomass	Strydhorst et al. 2008
88	n/a	Various	Various	Northern Great Plains of Canada and the United States, review of 10 studies	Walley et al. 2007
60-94	82-249	^{15}N isotope dilution and N difference	Barley, alfalfa, Kale	Alaska, N fertilizer added (20 kg N ha^{-1}), above ground biomass	Sparrow et al. 1995
13-96	10-350	^{15}N natural abundance	Weeds	Australia, ^{15}N Urea added mid flowering, above and below ground biomass	Rochester et al. 1998
n/a	165-240	Extended difference	Oats	Germany, no N fertilizer, above ground biomass	Maidl et al. 1996
n/a	189-213	N difference	Wheat	Nepal, no N fertilizer, above ground biomass	Schulz et al 1999

Table 1-4: Summary of N fixation by narrow-leafed lupin in Australia and Canada.

%Ndfa	N Fixed (kg N ha^{-1})	Method	Reference Species	Location and Conditions	Reference
77-87	247-253	^{15}N Natural Abundance	Barley and Capeweed	Australia, no N fertilizer, above ground biomass	Armstrong et al. 1997
72-88	n/a	^{15}N Natural Abundance	Wild Radish (*Raphanus raphanistrum*)	Australia, no N fertilizer, above ground biomass	McNeill and Fillery 2008
42-90	26-244	^{15}N Natural Abundance	In crop weeds and/or non legume crops	Australia, no N fertilizer, above ground biomass	Peoples et al. 2001
43	46-173	N difference method	Barley	Alberta, no N fertilizer, above ground biomass	Strydhorst et al. 2008
74-93	95-283	^{15}N Natural Abundance	*Bromus diandrus* Roth., Barley and *Arctotheca calendula*	Australia, no N fertilizer, above ground biomass	Unkovich et al. 1995
74-77	217-242	Isotope dilution	Canola, ryegrass, wheat	Australia, N fertilizer at 2.5 g N m^{-2} , above ground biomass	Smith et al. 1992
63-84	90-151	^{15}N natural abundance	Capeweed and/or radish	Australia, no N fertilizer, above ground biomass	Anderson et al. 1998
50-99	72-223	N difference	Wheat	Australia, no N fertilizer, above and below ground biomass	Herridge and Doyle 1988

Literature Cited

Abd-Alla, M.H. and Abdel Wahab, A.M. 1995. Response of nitrogen fixation, nodule activities, and growth to potassium supply in water-stressed broad bean. Journal of Plant Nutrition. 18: 1391-1402.

Alberta Agriculture and Rural Development. 2003a. Diseases of barley – fungal. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/prm7770 [8 June 2011].

Alberta Agriculture and Rural Development. 2003b. Diseases of barley – viral. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/prm7771 [8 June 2011].

Alberta Agriculture and Rural Development. 2003c. Diseases of oilseed crops – Canola. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/prm7710 [13 June 2011].

Alberta Agriculture and Rural Development. 2003d. Diseases of wheat – Fungal. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/prm7802 [15 June 2011].

Alberta Agriculture and Rural Development. 2003e. Diseases of Wheat – Viral. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/prm7803 [15 June 2011].

Alberta Agriculture and Rural Development 2010. Alberta 2010 specialty crop report. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd13340/$file/specialty_crop_report_2010.pdf?OpenElement [8 July 2011].

Alberta Agriculture and Rural Development. 2011a. Herbicide selector. [Online] Available: http://www.agric.gov.ab.ca/app23/processquery?function=products [1 June 2011].

Alberta Agriculture and Rural Development. 2011b. Pesticide selector. [Online] Available: http://www.agric.gov.ab.ca/app100/loadMain [1 June 2011].

Alberta Agriculture, Food and Rural Development. 2002. Liming Acid Soils. AGDEX 534-1. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex3684/$file/534-1.pdf?OpenElement [16 June 2011].

Anderson, G.C., Fillery, I.R.P., Dolling, P.J. and Asseng, S. 1998. Nitrogen and water flows under pasture-wheat and lupin-wheat rotations in deep sands in Western Australia 1. Nitrogen fixation in legumes, net N mineralization, and utilization of soil-derived nitrogen. Aust. J. Agric. Res. 49: 329-343.

Armstrong, E.L., Heenan, D.P., Pate, J.S. and Unkovich, M.J. 1997. Nitrogen benefits of lupins, field pea, and chickpea to wheat production of south-eastern Australia. Aust. J. Agric. Res. 48: 39-47.

Armstrong, E.L., Pate, J.S. and Unkovich, M.J. 1994. Nitrogen balance of field pea crops in south Western Australia, studied using the ^{15}N natural abundance technique. Aust. J. Plant Physiol. 21: 533-549.

Armstrong, R. D., McCosker, K., Johnson, S. B., Walsh, K. B., Millar, G., Kuskopf, B., Standley, J. and Probert, M. E. 1999. Legume and opportunity cropping systems in central Queensland. 1. Legume growth, nitrogen fixation, and water use. Aust. J. Agric. Res. 50: 909-924.

Atwell, B.J. 1988. Physiological responses of lupin roots to soil compaction. Plant and Soil. 111: 277-281.

Ayaz, S., McKenzie, B.A., Hill, G.D. and McNeil, D.L. 2004. Nitrogen distribution in four grain legumes. Journal of Agricultural Science. 142: 309-317.

Beck, D. P., Wery, J., Saxena, M. C. and Ayadi, A. 1991. Dinitrogen fixation and nitrogen balance in cool-season food legumes. Agron. J. 83: 334-341.

Beckie, H.J. 2006. Herbicide-resistant weeds: Management tactics and practices. Weed Technology. 20: 793-814.

Beckie, H.J. and Brandt, S.A. 1997. Nitrogen contribution of field pea in annual cropping systems. 1. Nitrogen residual effect. Can. J. Plant Sci. 77: 311-322.

Beckie, H.J., Brandt, S.A., Schoenau, J.J., Campbell, C.A., Henry, J.L. and Janzen, H.H. 1997. Nitrogen contribution of field pea in annual cropping systems. 2. Total nitrogen benefit. Can. J. Plant Sci. 77: 323-331.

Beckie, H.J., Harker, K.N., Hall, L.M., Warwick, S.I., Légère, A., Sikkema, P.H., Clayton, G.W., Thomas, A.G., Leeson, J.Y., Séguin-Swartz, G. and Simard, M.-J. 2006. A decade of herbicide-resistant crops in Canada. Can. J. Plant Sci. 86: 1234-1264.

Blackshaw, R.E. 1994. Rotation affects downy brome (*Bromus tectorum*) in winter wheat (*Triticum aestivum*). Weed Technology. 8: 728-732.

Blackshaw, R.E., Moyer, J.R., Harker, N. and Clayton, G.W. 2005. Integration of agronomic practices and herbicides for sustainable weed management in a zero-till barley field pea rotation. Weed Technology. 19: 190-196.

Booth, E.J. and Gunstone, F.D. 2004. Rapeseed and rapeseed oil: Agronomy, production and trade. Pages 1-16. *in* F.D. Gunstone, ed. Rapeseed and canola oil: Production, processing, properties and uses. Blackwell Publishing Ltd., Oxford, UK.

Bullock, D.G. 1992. Crop rotation. Critical Reviews in Plant Science. 11: 309-326.

Campbell, C.A., LaFond, G.P., Leyshon, A.J., Zentner, R.P. and Janzen, H.H. 1991. Effect of cropping practices in the initial potential rate of N mineralization in a thin black chernozem. Can. J. Soil. Sci. 71: 43-53.

Campbell, C.A., Selles, F., Zentner, R.P., De Jong, R., Lemke, R. and Hamel, C. 2006. Nitrate leaching in the semiarid prairie: Effect of cropping frequency, crop type, and fertilizer after 37 years. Can. J. Soil Sci. 86: 701-710.

Carranca, C., de Varennes, A. and Rolston, D. 1999. Biological nitrogen fixation by fababean, pea and chickpea, under field conditions, estimated by the ^{15}N isotope dilution technique. European Journal of Agronomy. 10: 49-56.

Chalk, P.M., Smith, C.J., Hamilton, S.D. and Hopmans, P. 1993. Characterization of the N benefit of a grain legume (*Lupinus angustifolius* L.) to a cereal (*Hordeum vulgare* L.) by an in situ ^{15}N isotope dilution technique. Biol. Fertil. Soils. 15: 39-44.

Clayton, G.W., Rice, W.A., Lupwayi, N.Z., Johnston, A.M., Lafond, G.P., Grant, C.A. and Walley, F. 2004a. Inoculant formulation and fertilizer nitrogen effects on field pea: Crop yield and seed quality. Can. J. Plant Sci. 84: 89-96.

Clayton, G.W., Rice, W.A., Lupwayi, N.Z., Johnston, A.M, Lafond, G.P., Grant, C.A. and Walley, F. 2004b. Inoculant formulation and fertilizer nitrogen effects on field pea: Nodulation, N_2 fixation and nitrogen partitioning. Can. J. Plant Sci. 84: 79-88.

Curtin, D., Francis, G.S. and McCallum, F.M. 2008. Decomposition rate of cereal straw as affected by soil placement. Australian Journal of Soil Research. 46: 152-160.

Cutforth, H.W., McGinn, S.M., McPhee, K.E. and Miller, P.R. 2007. Adaptation of pulse crops to the changing climate of the northern Great Plains. Agron. J. 99: 1684-1699.

Douds, D.D., Galvez, L., Franke-Snyder, M., Reider, C. and Drinkwater, L.E. 1997. Effect of compost addition and crop rotation point upon VAM fungi. Agriculture, Ecosystems and Environment. 65: 257-266.

Doyle, A.D., Moore, K.J. and Herridge, D.F. 1988. The narrow-leafed lupin (*Lupinus angustifolius* L.) as a nitrogen-fixing rotation crop for cereal production. III. Residual effects of lupins on subsequent cereal crops. Aust. J. Agric. Res. 39: 1029-1037.

Duc, G. 1997. Faba bean (*Vicia faba* L.). Field Crops Research. 53: 99-109.

Evans, J., Murray, G.M., Scott, G., Orchard, B., Brennan, J., Lemerle, D., Kaiser, A. and Armstrong, E.L. 2006. Impact of annual legume 'break' crops on the yield and quality of canola in comparison with the impact on yield of wheat. Australian Journal of Experimental Agriculture. 46: 1489-1497.

Evans, J., Scott, G., Lemerle, D., Kaiser, A., Orchard, B., Murray, G.M. and Armstrong, E.L. 2003. Impact of legume 'break' crops on the yield and grain quality of wheat and relationship with soil mineral N and crop N content. Australian Journal of Agricultural Research. 54: 777-788.

Evans, L.E. and Slinkard, A.E. 1975. Production of pulse crops in Canada. Pages 287-324. *in* J.T. Harapiak, ed. Oilseed and Pulse Crops in Western Canada – A Symposium. Western Co-operative Fertilizers Limited, Calgary, Alberta.

FAOSTAT. 2011. Food and Agriculture Organization of the United Nations. [Online] Available: http://faostat.fao.org/site/567/default.aspx#ancor [13 June 2011].

Finney, K.F. and Yamazaki, W.T. 1967. Quality of hard, soft and durum wheats. Pages 471-503. *in* K.S. Quisenberry and L.P. Reitz, eds. Wheat and wheat improvement. Agronomy Series Number 13, American Society of Agronomy, Wisconsin, USA

Fraser, M.D., Fychan, R. and Jones, R. 2005. Comparative yield and chemical composition of two varieties of narrow-leafed lupin (*Lupinus angustifolius*) when harvested as whole-crop, moist grain and dry grain. Animal Feed Science and Technology. 120: 43-50.

French, R.J. 2002. Soil factors influencing growth and yield of narrow-leafed lupin and field pea in Western Australia. Aust. J. Agric. Res. 53: 217-225.

French, R. J. and Buirchell, B.J. 2005. Lupin: the largest grain legume crop in Western Australia, its adaptation and improvement through plant breeding. Australian Journal of Agricultural Research. 56: 1169-1180.

French, R.J. and Turner, N.C. 1991. Water deficits change dry matter partitioning and seed yield in narrow-leafed lupins (*Lupinus angustifolius* L.). Aust. J. Agric. Res. 42: 471-484.

Gan, Y.T., Campbell, C.A., Janzen, H.H., Lemke, R., Liu, L.P., Basnyat, P. and McDonald, C.L. 2009. Root mass for oilseed and pulse crops: Growth and distribution in the soil profile. Can. J. Plant Sci. 89: 883-893.

Gan, Y.T., Miller, P.R., McConkey, B.G., Zentner, R.P., Stevenson, F.C. and McDonald, C.L. 2003. Influence of diverse cropping sequences on durum wheat yield and protein in the semiarid northern great plains. Agron. J. 95: 245-252.

Grant, C.A., Monreal, M.A., Irvine, R.B., Mohr, R.M., McLaren, D.L. and Khakbazan, M. 2009. Crop response to current and previous season applications of phosphorus as affected by crop sequence and tillage. Can. J. Plant Sci. 89: 49-66.

Hamel, C. and Strullu, D-G. 2006. Arbuscular mycorrhizal fungi in field crop production: Potential and new direction. Can. J. Plant Sci. 86: 941-950.

Hauggaard-Nielson, H., Mundus, S. and Jensen, E.S. 2009. Nitrogen dynamics following grain legumes and subsequent catch crops and the effects on succeeding cereal crops. Nutr Cycl Agroecosyst. 84: 281-291.

Hardarson, G. and Atkins, C. 2003. Optimising biological N_2 fixation by legumes in farming systems. Plant and Soil. 252: 41-54.

Hartman, M. 2011. Clubroot disease of canola and mustard. Alberta Agriculture and Rural Development. Agdex 140/ 638-1. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex8593/$file/140_638-1.pdf?OpenElement [13 June 2011].

Herridge, D.F., Bergersen, F.J. and Peoples, M.B. 1990. Measurement of nitrogen fixation by soybean in the field using the ureide and natural ^{15}N abundance methods. Plant Physiol. 93: 0708-0716.

Herridge, D.F. and Doyle, A.D. 1988. The narrow-leafed lupin (*Lupinus angustifolius* L.) as a nitrogen-fixing rotation crop for cereal production. II Estimates of fixation by field-grown crops. Aust. J. Agric. Res. 39: 1017-1028.

Herridge, D.F., Peoples, M.B. and Boddey, R.M. 2008. Global inputs of biological nitrogen fixation in agricultural systems. Plant Soil. 311: 1-18.

Hill, G.D. and McGregor, R. 2002. The effect of water stress and nitrogen on the nodulation and dry matter partitioning of *Lupinus angustifolius* compared to *Pisum sativum*. Pages 129-131. *in* E. van Santen and G.D. Hill, eds. Wild and Cultivated Lupins from the tropics to the poles. Proceedings of the 10^{th} International Lupin Conference, Laugarvatn, Iceland, 19-24 June 2002. International Lupin Association, Canterbury, New Zealand.

Jensen, E. S. 1994. Availability of nitrogen in ^{15}N-labelled mature pea residues to subsequent crops in the field. Soil Biol. Biochem. 26: 465-472.

Jensen, E. S. 1996a. Rhizodeposition of N by pea and barley and its effect on soil N dynamics. Soil Biol. Biochem. 28: 65-71.

Jensen, E. S. 1996b. Nitrogen acquisition by pea and barley and the effect of their crop residues on available nitrogen for subsequent crops. Biol. Fertil. Soils. 23: 459-464.

Jensen, E.S., Peoples, M.B. and Hauggaard-Nielsen, H. 2010. Faba bean in cropping systems. Field Crops Research. 115: 203-216.

Johnston, A.M., Kutcher, H.R., and Bailey, K.L. 2005. Impact of crop sequence decisions in the Saskatchewan parkland. Can. J. Plant Sci. 85: 95-102.

Karamzadeh, A., Mobasser, H.R., Ramee, V. and Ghanbari-Malidarreh, A. 2010. Effects of nitrogen and seed rate on yield and oil content of canola (*Brassica napus* L.). American-Eurasian J. Agric. & Environ. Sci. 8: 715-721.

Kettel, K., Tuck, B., Payne, W.A., Chen, C., Machado, S. and Karow, R. 2003. Narrow-leaf lupin. Dryland Cropping System, June 2003. Oregon State University Extension Service. EM 8842-E

Krupinsky, J.M., Tanaka, D.L., Merrill, S.D., Liebig, M.A. and Hanson, J.D. 2006. Crop sequence effects of 10 crops in the northern Great Plains. Agricultural Systems. 88: 227-254.

Kiesling, R.L. 1985. The diseases of barley. Pages 269-312. *in* D.C. Rasmusson, ed. Barley. Agronomy Series Number 26, American Society of Agronomy, Madison, Wisconsin.

Kurdali, F., Al-Ain, F. and Al-Shamma, M. 2002. Nodulation, dry matter production, and N_2 fixation by fababean and chickpea as affected by soil moisture and potassium fertilizer. Journal of Plant Nutrition. 25: 355-368.

Lafond, G.P., May, W.E., Stevenson, F.C. and Derksen, D.A. 2006. Effects of tillage systems and rotations on crop production for a thin black chernozem in the Canadian prairies. Soil & Tillage Research. 89: 232-245.

Lamb, C.A. 1967. Physiology. Pages 181-223. *in* K.S. Quisenberry and L.P. Reitz, eds. Wheat and wheat improvement. Agronomy Series Number 13, American Society of Agronomy, Wisconson, USA.

Liebman, M. and Dyck, E. 1993. Crop rotation and intercropping strategies for weed management. Ecological Applications. 3: 92-122.

Lupwayi, N.Z., Clayton, G.W., Hanson, K.G., Rice, W.A. and Biederbeck, V.O. 2004a. Populations and functional diversity of bacteria associated with barley, wheat and canola roots. Can. J. Soil Sci. 84: 245-254.

Lupwayi, N.Z., Clayton, G.W., O'Donovan, J.T., Harker, K.N., Turkington, T.K. and Rice, W.A. 2004b. Decomposition of crop residues under conventional and zero tillage. Can. J. Soil Sci. 84: 403-410.

Lupwayi, N.Z., Clayton, G.W., O'Donovan, J.T., Harker, K.N., Turkington, T.K. and Soon, Y.K. 2006. Nitrogen release during decomposition of crop residues under conventional and zero tillage. Can. J. Soil Sci. 86: 11-19.

Lupwayi, N.Z. and Soon, Y.K. 2009. Nitrogen release from field pea residues and soil inorganic N in a pea-wheat rotation in northwestern Canada. Can. J. Plant Sci. 89: 239-246.

Maidl, F.X., Haunz, F.X., Panse, A. and Fischbeck, G. 1996. Transfer of grain legume nitrogen within a crop rotation containing winter wheat and winter barley. J. Agronomy & Crop Science. 176: 47-57.

McDonald, B.E. 2004. Food uses and nutritional properties. Pages 131-153. *in* F.D. Gunstone, ed. Rapeseed and canola oil: Production, processing, properties and uses. Blackwell Publishing Ltd., Oxford, UK.

McKenzie, R.H. 2008. Agronomic and fertilizer management of barley in Alberta. Government of Alberta. AGDEX 114/540-2. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex12433/$file/114_540-2.pdf?OpenElement [20 September 2011].

McKenzie, R.H., Middleton, A.B. and Bremer, E. 2005. Fertilization, seeding date, and seeding rate for malting barley yield and quality in southern Alberta. Can. J. Plant Sci. 85: 603-614.

McLelland, M., Panchuk, K., Green, B., Campbell, D., Harvey, B., Rossnagel, B., Foster, J. and Kendall, N. 2009. Malting Barley. Government of Alberta. AGDEX 114/20-2. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex98 [29 March 2011].

McNeill, A.M., and Fillery, I.R.P. 2008. Field measurement of lupin belowground nitrogen accumulation and recovery in the subsequent cereal-soil system in a semi-arid Mediterranean-type climate. Plant Soil. 302: 297-316.

Miller, P.R., Engel, R.E. and Holmes, J.A. 2006. Cropping sequence effect of pea and pea management on spring wheat in the northern great plains. Agron. J. 98: 1610-1619.

Miller, P.R., Gan, Y., McConkey, B.G. and McDonald, C.L. 2003. Pulse crops for the northern Great Plains: II. Cropping sequence effects on cereal, oilseed, and pulse crops. Agron. J. 95: 980-986.

Miller, P.R. and Holmes, J.A. 2005. Cropping sequence effects of four broadleaf crops on four cereal crops in the northern Great Plains. Agron. J. 97: 189-200.

Miller, P.R., McConkey, B.G., Clayton, G.W., Brandt, S.A., Staricka, J.A., Johnston, A.M., Lafond, G.P., Schatz, B.G., Baltensperger, D.D. and Neill, K.E. 2002a. Pulse crop adaptation in the northern Great Plains. Agron. J. 94: 261-272.

Miller, P.R., Waddington, J., McDonald, C.L. and Derksen, D.A. 2002b. Cropping sequence affects wheat productivity on the semiarid northern Great Plains. Can. J. Plant Sci. 82: 307-318.

Newman, C.W. and McGuire, C.F. 1985. Nutritional quality of barley. Pages 403-456. *in* D.C. Rasmusson, ed. Barley. Agronomy Series Number 26, American Society of Agronomy, Madison, Wisconsin.

Palta, J.A., Turner, N.C., French, R.J. and Buirchell, B.J. 2007. Physiological responses of lupin genotypes to terminal drought in a Mediterranean-type environment. Annals of Applied Biology. 150: 269-279.

Park, B., Lopetinsky, K., Bjorklund, R., Buss, T., Eppich, S., Laflamme, P., Miller, N., Olson, M. and Piquette, K. 1999. Pulse crops in Alberta. B. Park and K. Lopetinsky, eds. Alberta Agriculture and Rural Development, Edmonton, Alberta. AGDEX 142/20-1

Pate, J. S., Unkovich, M. J., Armstrong, E. L. and Sanford, P. 1994. Selection of reference plants for ^{15}N natural abundance assessment of N_2 fixation by crop and pasture legumes in south-west Australia. Aust. J. Agric. Res. 45: 133-147.

Payne, W.A., Chen, C. and Ball, D.A. 2004. Agronomic potential of narrow-leafed and white lupins in the inland pacific northwest. Agronomy Journal. 96: 1501-1508.

Peoples, M.B., Bowman, A.M., Gault, R.R., Herridge, D.F., McCallum, M.H., McCormick, K.M., Norton, R.M., Rochester, I.J., Scammell, G.J. and Schwenke, G.D. 2001. Factors regulating the contribution of fixed nitrogen by pasture legumes to different farming systems in eastern Australia. Plant and Soil. 228: 29-41.

Poehlman, J.M. 1985. Adaption and distribution. Pages 1-17. *in* D.C. Rasmusson, ed. Barley. Agronomy Series Number 26, American Society of Agronomy, Madison, Wisconsin.

Przednowek, D.W.A., Entz, M.H., Irvine, B., Flaten, D.N. and Thiessen Martens, J.R. 2004. Rotational yield and apparent N benefits of grain legumes in southern Manitoba. Can. J. Plant Sci. 84: 1093-1096.

Ratnayake, W.M.N. and Daun, J.K. 2004. Chemical composition of canola and rapeseed oils. Pages 37-78. *in* F.D. Gunstone, ed. Rapeseed and canola oil: Production, processing, properties and uses. Blackwell Publishing Ltd., Oxford, UK.

Reitz, L.P. 1967. World distribution and importance of wheat. Pages 1-18. *in* K.S. Quisenberry and L.P. Reitz, eds. Wheat and wheat improvement. Agronomy Series Number 13, American Society of Agronomy, Wisconson, USA

Rennie, R.J. 1984. Comparison of N balance and ^{15}N isotope dilution to quantify N_2 fixation in field-grown legumes. Agronomy Journal. 76: 785-790.

Robertson, M.J., Holland, J.F. and Bambach, R. 2009. Canola residues do not reduce establishment, growth, and yield of following summer crops. Crop & Pasture Science. 60: 640-645.

Rochester, I.J., Peoples, M.B., Constable, G.A. and Gault, R.R. 1998. Faba beans and other legumes add nitrogen to irrigated cotton cropping systems. Australian Journal of Experimental Agriculture. 38: 253-260.

Russell, C. A. and Fillery, I. R. P. 1996. Estimates of lupin below-ground biomass nitrogen, dry matter, and nitrogen turnover to wheat. Aust. J. Agric. Res. 47: 1047-1059.

Sawatsky, N. and Soper, R. J. 1991. A quantitative measurement of the nitrogen loss from the root system of field peas (*Pisum avense* L.) grown in the soil. Soil Biol. Biochem. 23: 255-259.

Schulz, S., Keatinge, J.D.H. and Wells, G.J. 1999. Productivity and residual effects of legumes in rice-based cropping systems in a warm-temperate environment I. Legume biomass production and N fixation. Field Crops Research. 61: 23-35.

Siddique, K.H.M., Regan, K.L., Tennant, D. and Thomson, B.D. 2001. Water use and water use efficiency of cool season grain legumes in low rainfall Mediterranean-type environments. European Journal of Agronomy. 15: 267-280.

Simpson, A.D.F. 1983. Utilization of *Vicia faba* L. Pages 535-552. *in* P.D. Hebblethwaite, ed. The faba bean (*Vicia faba* L.): A basis for improvement. Butterworths, London.

Soon, Y.K. and Arshad, M.A. 2002. Comparison of the decomposition and N and P mineralization of canola, pea and wheat residues. Biol. Fertil. Soils. 36: 10-17.

Soon, Y.K. and Arshad, M.A. 2004a. Contribution of di-nitrogen fixation by pea to the productivity and N budget of a wheat based cropping system. 142: 629-637.

Soon, Y. K. and Arshad M. A. 2004b. Tillage, crop residue, and crop sequence effects on nitrogen availability in a legume-based cropping system. Can. J. Soil Sci. 84: 421-430.

Soon, Y.K. and Clayton, G.W. 2002. Eight years of crop rotation and tillage effects on crop production and N fertilizer use. Can. J. Soil Sci. 82: 165-172.

Soon, Y.K., Harker, K.N. and Clayton, G.W. 2004. Plant competition effects on the nitrogen economy of field pea and the subsequent crop. Soil Sci. Soc. Am. J. 68: 552-557.

Sparrow, S.D., Cochran, V.L. and Sparrow, E.B. 1995. Dinitrogen fixation by seven legume crops in Alaska. Agronomy Journal. 87: 34-41.

Stevenson, F.C. and van Kessel, C. 1996a. A landscape-scale assessment of the nitrogen and non-nitrogen benefits of pea in a crop rotation. Soil Sci. Soc. Am. J. 60: 1797-1805.

Stevenson, F.C. and van Kessel, C. 1996b. The nitrogen and non-nitrogen rotational benefits of pea to succeeding crops. Can. J. Plant Sci. 76: 735-735.

Strydhorst, S.M. 2008. Faba bean and Lupin: New grain legume crops. University of Alberta, Edmonton PhD thesis.

Strydhorst, S.M., King, J.R., Lopetinsky, K.J. and Harker, K.N. 2008. Weed interference, pulse species, and plant density effects on rotational benefits. Weed Science. 56: 249-258

Stubbs, T.L., Kennedy, A.C., Reisenauer, P.E. and Burns, J.W. 2009. Chemical composition of residue from cereal crops and cultivars in dryland ecosystems. Agronomy Journal. 101: 538-545.

Su, C. 2010. Alberta 2009 crop year in review. Alberta Agriculture and Rural Development, Economics and Competitiveness Division, Statistics and Data Development Branch, Government of Alberta, Edmonton, Alberta.[Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd13100 [8 February 2011].

Tang, C. and Robson, A.D. 1995. Nodulation failure is important in the poor growth of two lupin species on an alkaline soil. Australian Journal of Experimental Agriculture. 35: 87-91.

Tang, C. and Thomson, B.D. 1996. Effects of solution pH and bicarbonate on the growth and nodulation of a range of grain legume species. Plant and Soil. 186: 321-330.

Thomas, P. 1984. Canola growers manual. Canola Council of Canada, Saskatoon, Saskatchewan.

Thomson, B.D., Siddique, K.H.M., Barr, M.D. and Wilson, J.M. 1997. Grain legume species in low rainfall Mediterranean-type environments I. Phenology and seed yield. Field Crop Research. 54: 173-187.

Unkovich, M.J., Herridge, D., Peoples, M., Cadisch, G., Boddey, B., Giller, K., Alves, B. and Chalk, P. 2008. Measuring plant-associated nitrogen fixation in agricultural systems. ACIAR, Canberra, Australia. Monograph No. 136.

Unkovich, M.J., Pate, J.S., Armstrong, E.L. and Sanford, P. 1995. Nitrogen economy of annual crop and pasture legumes in southwest Australia. Soil Biol. Biochem. 27: 585-588.

Walker, K. 2004. Non-food uses. Pages 154-185. *in* F.D. Gunstone, ed. Rapeseed and canola oil: Production, processing, properties and uses. Blackwell Publishing Ltd., Oxford, UK.

Walley, F.L., Clayton, G.W., Miller, P.R., Carr, P.M. and Lafond, G.P. 2007. Nitrogen economy of pulse crop production in the northern Great Plains. Agron. J. 99:1710-1718.

Wang, N. and Daun, J.K. 2004. Effect of variety and crude protein content on nutrients and certain antinutrients in field peas (*Pisum sativum*). Journal of the Science of Food and Agriculture. 84: 1021-1029.

Wright, A.T. 1990a. Quality effects of pulses on subsequent cereal crops in the northern prairies. Can. J. Plant Sci. 70: 1013-1021.

Wright, A.T. 1990b. Yield effect of pulses on subsequent cereal crops in the northern prairies. Can. J. Plant Sci. 70: 1023-1032.

Zaychuk, K. 2006. Nodulation and nitrogen fixation field guide for the assessment of pulse crops. [Online] Available: http://pulse.ab.ca/LinkClick.aspx?fileticket=L2ECTm3zf14=&tabid=125 [March 30 2011].

Chapter 2: Yield and nitrogen dynamics of cool season pulse crops in north central Alberta

Null Hypotheses

Faba bean, lupin and pea will not have significantly different amounts of N fixation when grown in north central Alberta.

Barley (with and without N fertilizer), canola (with and without N fertilizer), faba bean, lupin and pea will not remove significantly different amounts of N from the agricultural system in harvested seed.

The seven crop treatments (barley +N, barley no N, canola +N, canola no N, faba bean, lupin and pea) will not return significantly different amounts of N to the soil with the return of above ground residues to the soil surface.

Introduction

Crop rotation is an important component of sustainable agricultural systems and further diversification can have a positive impact on the environmental and economic aspects of current crop production practices. In many areas of the world, very limited crop rotations have been practiced since the green revolution. The Alberta cropping system is dominated by the production of four crops – tame hay, wheat, barley and canola (Su 2010). Although much research effort has gone into the development of well adapted varieties, with disease resistance and high yields, researchers and producers are questioning the sustainability of such a limited cropping system. Integrating new crops into a cropping system calls for an investigation into the crop's properties and their effect on subsequent crops.

Pulse crops are known for their benefit to human health, agriculture production and environmental sustainability (Park et al. 1999). Through the symbiotic relationship pulse crops have with *Rhizobium* bacteria, allowing them to fix atmospheric nitrogen (N), there are many benefits from including pulse crops in rotations. Nitrogen and non-nitrogen benefits of pulse crops include; improved soil structure and organic matter content, increased nutrient availability (P, K, S, and N), reduced root and shoot diseases, improved yields of subsequent crops, reduced N fertilizer additions to current and subsequent crops, and reduced weed populations (Stevenson and van Kessel 1996, Strydhorst et al. 2008). The possibility of reducing dependence on chemical fertilizers and pesticides has far reaching economic and environmental impacts.

Strydhorst (2008) identified faba bean (*Vicia faba* L.), lupin (*Lupinus angustifolius* L.) and pea (*Pisum sativum* L.) as candidate pulse crops to add to the north-central Alberta cropping system. All of these pulse crops would be produced for animal or human consumption. Each has varying properties in terms of preferred growing environment, nitrogen fixation capability, yield potential, and nitrogen cycling.

Faba bean is best adapted for cooler, moist environments with neutral soils (pH > 6.0) (Park et al. 1999). Under optimal conditions faba bean can fix a large amount of N in a growing season. Nitrogen fixation has been recorded to range from 2 to 350 kg N ha^{-1}, with %Ndfa (nitrogen derived from the atmosphere) ranging from 4 – 96% (Beck et al. 1991, Peoples et al. 2001, Strydhorst et al. 2008, Walley et al. 2007, Sparrow et al. 1995, Rochester et al. 1998, Maidl et al. 1996, Schulz et al. 1999).

Narrow-leafed lupin is an economically important crop in Australia because it provides an N benefit to deficient soils and performs better when grown on acidic soils (French 2002, French and Buirchell 2005, Park et al. 1999). Some studies have indicated that lupins are very sensitive to soil pH and performance is reduced with soil pH equal to or above 6.0 (French 2002, Tang and Thomson 1996). Previous studies report N fixation to range from 26 to 283 kg N ha^{-1} with %Ndfa ranging from 42 to 93% (Armstrong et al. 1997, McNeill and Fillery 2008, Peoples et al. 2001, Strydhorst et al. 2008, Unkovich et al. 1995, Smith et al. 1992). Lupin is a potential cool season pulse for production in Alberta but some agronomic and economic issues have limited its adoption (Park et al. 1999).

Pea is the most common pulse grown in Alberta (Su 2010). It requires timely moisture during vegetative growth and flowering, well drained neutral to alkaline soils and moderate temperatures, especially during flowering, to maximize yields (Thomson et al. 1997, Park et al. 1999). Peas also have a wide range of recorded values for N fixation (18 – 246 kg N ha^{-1}) and %Ndfa (12 – 92%) (Armstrong et al. 1997, Armstrong et al. 1994, Beck et al. 1991, Clayton et al. 2004, Peoples et al. 2001, Soon and Arshad 2004, Soon et al. 2004, Stevenson and van Kessel 1996, Strydhorst et al. 2008, Unkovich et al. 1995, Walley et al. 2007, Sparrow et al. 1995, Maidl et al. 1996, Schulz et al. 1999).

The unique characteristics of each pulse crop indicate that they could respond differently within a cropping system and possibly impact subsequent crops differentially.

Research has been conducted globally investigating pulse crop growth and its effects in a cropping system but there is a need for this information in Alberta, specific to local environmental and economic conditions.

This study is part of a 3 year rotational study investigating pulse crop growth (year 1 of rotation, YR1) and the effects of pulse stubble on subsequent crops (year 2 of rotation, YR2). Quantification of N fixation, N return, and N removal of YR1 crops, barley, canola, faba bean, lupin and pea, will provide a comparison of N cycling by non-legume and legume crops. Evaluation of seed quality characteristics (thousand seed weight and protein content) and the N distribution in above ground biomass will increase our understanding of yield parameters that can affect the value of current and subsequent crops. This provides producers with information about the production of pulse crops in comparison with other commonly grown crops in the area and quantifies the differences between the crops. By identifying and understanding these differences, optimal crop sequencing and management decisions can be made. The objective of this experiment was to quantify N fixation, N return and N removal by faba bean, lupin and pea crops grown in north central Alberta and to compare the N dynamics of the pulse crops to non-legume species (barley and canola). Above ground biomass yield and quality were determined for each species to compare N contribution and dynamics within the rotational system.

Materials and Methods

Experiment Location, Design and Management

This study was conducted at two locations in north-central Alberta – Barrhead and St. Albert (Figure 2-1). The site at Barrhead has an orthic humic gleysol soil (Browser et al. 1962) with a pH of 4.8 – 5.6 and organic matter content of 2.7% (0 – 15cm depth) (Figure 2-1, Table 2-1). The St. Albert site has a Malmo eluviated black chenozemic soil (Strydhorst 2008) with a pH of 7.1 – 7.8 and an organic matter content of 11.6% (0 – 15 cm depth) (Figure 2-1, Table 2-1). As part of a three year rotational study, rotations were initiated in the summers of 2008 and 2009. Crops produced in the first year (YR1) of rotation became the treatments applied to subsequent crops (YR2). All crops were produced in a randomized complete block design (Figure 2-2) with four blocks. The seven YR1 treatments were (Table 2-2): 'Metcalf' barley (*Hordeum vulgare* L.) with and without N fertilizer, '71-45 RR' canola (*Brassica napus* L.) with and without N fertilizer, 'Snowbird' tannin-free faba bean (*Vicia faba* L.), 'Arabella' narrow-leafed lupin (*Lupinus angustifolius* L.), and 'Canstar' field pea (*Pisum sativum* L.). Plots were 6.1 m by 3.1 m with 2.1 m alleys between all plots (Figure 2-3). The four blocks were separated with 12.2 m alleys. All alleys were seeded to barley which was mowed throughout the growing season.

All plots received P, K, and S fertilizer as recommended by soil tests (Table 2-1, Appendix A). Nitrogen fertilizer was only added to two treatments: barley +N and canola +N. Fertilizer was applied prior to seeding with a pre-seeding pass over the plots with a hoe-drill seeder.

All YR1 crops were seeded into barley stubble with a 3.05 m wide John Deer hoe drill (9450 John Deer Hoe Drill, Deere & Company, Moline, IL) with 17.5 cm row spacing at recommended seeding rates and depths (Table 2-3). In 2008, YR1 crops were seeded on May 10 at Barrhead (with a canola re-seed on June 2 due to poor emergence), and on May 7 at St. Albert. In 2009, YR1 crops were seeded on May 7 at Barrhead and May 8 at St. Albert. Each pulse crop was inoculated with the appropriate type of *Rhizobium* bacteria (Granular Soil Implant+ from EMD Crop Bioscience) at a rate of 6.7 kg ha^{-1} (Table 2-3).

Emergence counts were completed when crop rows were visible; the number of plants in 2 rows x 1 m was counted at one representative location in each plot (Figure 2-3). Weeds were also assessed early in the growing season. Weeds at St. Albert included wild oat (*Avena fatua*), volunteer barley (*Hordeum vulgare*), volunteer canola (*Brassica napus*), wild buckwheat (*Polygonum convolvulus*), lamb's quarter (*Chenopodium album*), hemp-nettle (*Galeopsis tetrahit*), sow thistle (*Sonchus asper*), dandelion (*Taraxacum officinale*), and stinkweed (*Thlaspi arvense*). At Barrhead, weeds included volunteer canola, dandelion, stinkweed, chickweed (*Stellaria media*), and Canada thistle (*Cirsium arvense*). Herbicides were applied according to recommended rates at appropriate crop stages (Tables 2-4 & 2-5). Hand weeding occurred throughout the growing season to control subsequent flushes of weeds.

Crop growth was monitored throughout the growing season and pest problems were addressed as needed. Insecticide (Decis) was applied on June 17, 2009 for cutworms and thrips at St. Albert (Table 2-5). Grasshopper bait was applied to the alleyways at Barrhead in 2009 to prevent crop damage (Table 2-5). No insecticides were applied in 2008. As part of the mid-season observations, pulse roots were examined at mid-flowering and scored for nodulation success according to Zaychuk (2006). Three nodulated plants were scored from each of the faba bean, lupin and pea plots in each of the four blocks at Barrhead and St. Albert. Plants were taken from one corner of the plot for evaluation (Figure 2-3).

Subsamples (2 rows x 1m) of above ground biomass were collected from each plot just prior to desiccation (Figure 2-3). Crops were desiccated at physiological maturity – pulse crops and canola with Reglone, and barley with Roundup Transorb HC (Table 2-5). Following dry down (1–2 weeks with Reglone and 2–3 weeks with Roundup Transorb HC), combine seed samples were taken from the center of the plot (Figure 2-3), using a Wintersteiger plot combine (Elite Wintersteiger Plot Combine, Ried, Austria). The remainder of the plot was then harvested and the straw was returned to the respective plot, spread evenly and chopped. All crops were harvested in August and September (Table 2-6).

Sample Analysis

Subsamples of above ground biomass were separated into plant components. Pulse crops were divided into straw, pod, and seed. Canola was divided into straw/pod and seed components and barley was divided into straw, chaff and seed. Samples were dried at 40^{o}C to a constant weight. Some separations occurred before drying. Pulses had pods removed and barley had heads removed, with threshing occurring after plants were dry. Each of the component samples was ground using a Wiley mill (to 1mm) with the exception of canola seed which underwent a solvent oil extraction. Canola seed was mixed with 20 mL of n-pentane and ground for approximately one minute using a Polytron homogenizer (Model PT1035, Brinkmann Instruments, Rexdale, ON, Canada). The ground canola-pentane mixture was filtered through #1 Whatman filter paper and the canola meal was collected and dried over night at room temperature. All ground samples were analyzed for N content using a Leco N analyzer (LECO CN-2000, LECO Corporation, St. Joseph, MI).

Calculations

Total N yield for each YR1 treatment was calculated using %N obtained from the Leco N analysis and the yield of each plant component in the subsamples. For barley, canola and pulse treatments the following formulas were used:

Barley N Yield = $(\%N_{(seed)} \times Yield_{(seed)}) + (\%N_{(chaff)} \times Yield_{(chaff)}) + (\%N_{(straw)} \times Yield_{(straw)})$

Canola N Yield = $(\%N_{(seed)} \times Yield_{(seed)}) + (\%N_{(straw + pods)} \times Yield_{(straw + pods)})$

Pulse N Yield == $(\%N_{(seed)} \times Yield_{(seed)}) + (\%N_{(pod)} \times Yield_{(pod)}) + (\%N_{(straw)} \times Yield_{(straw)})$

Nitrogen fixation was calculated for each of the three pulses using the N difference method with barley as the reference species according to the following formula:

N_2 fixed (kg N ha^{-1}) = N Yield $_{(N2\text{-}Fixing\ Plant)}$ – N Yield $_{(Reference\ Plant)}$ (Rennie 1984)

%Ndfa was estimated with barley no N as the reference species based on the following formula:

$$\%Ndfa = (N\ Yield_{(N2\ Fixing\ Plant)} - N\ Yield_{(Reference\ Species)}) / N\ Yield_{(N2\ Fixing\ Plant)} \times 100$$

(Rennie 1984)

The ^{15}N natural abundance method for estimating N fixation was attempted in this study but due to low inherent levels of ^{15}N in the soil at the Barrhead site, the data was unusable and the N difference method was used to estimate N fixation. Strydhorst (2008) reported a similar problem with using the ^{15}N natural abundance method at the same site.

Statistical Analysis

Data was analyzed using SAS 9.2 (SAS Institute 2008). Each data set was tested for normality using PROC UNIVARIATE (SAS Institute 2008). Most data sets had normally distributed data and no transformations were used.

Sites were analyzed separately because of the environmental differences between Barrhead and St. Albert. Barrhead received less moisture and had a lower soil pH, these environmental conditions altered treatment response therefore sites where best analyzed separately. An ANOVA analysis was performed using PROC MIXED (Littell et al. 2006) with treatment as a fixed effect and year, block and their interactions as random effects. A set of orthogonal contrasts was used to make specific comparisons between treatments. Significance was determined at $p \leq 0.05$ with the exception of data comparing among the 3 pulse treatments, where $p \leq 0.1$ was considered significant due to the small sample size (Steel et al. 1997).

Results and Discussion

Climatic Conditions

This study was conducted under below average moisture conditions at all site-years and slightly above average temperatures at three of four site-years (Figure 2-1). In

2008, both sites received only 64% of normal moisture with close to normal average temperatures. In 2009, the growing season precipitation levels at Barrhead were only 48% of normal and at St. Albert 56% of normal, but average temperatures were close to normal.

Nodulation

Nodulation scoring at flowering is one qualitative measure of the N fixing capability and success of a pulse crop. Nodulation of pulse crop roots was assessed at Barrhead on July 15, 2008 and July 27, 2009 and at St. Albert on July 16, 2008 and July 28, 2009. Nodulation success varied between plants within a species. Nodulation can be reduced by environmental stress such as low moisture conditions or unfavourable soil pH. Plants with no nodulation on the roots were observed at both sites, and this was most common in lupin plots (personal observation). Faba bean plants were assigned the highest nodulation scores, 10.8 at Barrhead and 12.0 at St. Albert (Table 2-7). Lupin had a higher nodulation score at Barrhead (7.6) than St. Albert (6.7) whereas peas had better nodulation in St. Albert (11.4) compared to Barrhead (6.4). At Barrhead, faba bean nodulation was significantly greater than pea ($p<0.10$). At St. Albert faba bean and pea were significantly greater than lupin ($p<0.10$) (Table 2-7). Previous studies have indicated that nodulation success can be affected by soil pH (Tang and Robson 1995, Tang and Thomson 1996, French and Buirchell 2005) and this may have contributed to the low lupin scores at St. Albert. Moisture stress can also limit nodulation (Kurdali et al. 2002) which may have lowered overall nodulation scores of the pulse crops in this study. Soil organic matter generally increases the nutrient supplying power of a soil and the biological activity (Bullock 1992) which may influence the development and growth of nodules. Although soil organic matter content was much higher at St. Albert than at Barrhead there was no clear effect on nodulation in this study.

Grain Yields

Emergence counts early in the season indicated that target plant densities were only achieved for barley and pea crops. Canola plant density was 30 – 40% below target, faba bean was 20 – 25% below the target and lupin was 8% below the target (data not shown, targets in Table 2-3). Lower crop densities may affect crop yields. Crop grain yields were generally higher in St. Albert over the two years of study than in Barrhead, with the exception of the lupin treatment (Table 2-8). Environmental conditions at the two sites differed in precipitation, soil N, soil pH and soil organic matter. Lower lupin yield in St. Albert may be partially attributed to the higher pH of the soil at that site.

Both sites exhibited similar trends in crop yields between treatments but more significant differences occurred at St. Albert. Barley, faba bean and pea yields were numerically greater than canola and lupin yields at both sites (Table 2-8). Both sites exhibited a trend for '+N' treatments having higher yields than 'no N' treatments of barley and canola but the differences were not significant. Barley yields were significantly higher than canola yields at both sites ($p<0.05$) (Table 2-8). The 10-year average for barley and canola grown in Alberta was 3.1 Mg ha^{-1} and 1.7 Mg ha^{-1}, respectively (Su 2010). At St. Albert pea yields (5.9 Mg ha^{-1}) were significantly greater than faba bean yields (4.2 Mg ha^{-1}) ($p<0.01$), but there was no significant difference at Barrhead (Table 2-8). Strydhorst (2008) reported faba bean yields in this growing region to range from ~3.0 to 7.6 Mg ha^{-1} and peas from ~2.9 to 6.5 Mg ha^{-1}. Faba bean (2.6, 4.2 Mg ha^{-1}) and pea (3.2, 5.9 Mg ha^{-1}) yields were significantly greater than lupin (1.7, 1.7 Mg ha^{-1}) yields at Barrhead and St. Albert, respectively ($p<0.05$). Lupin yields in this study were lower than previously reported yields in this area (2.4 – 4.0 Mg ha^{-1}) (Strydhorst 2008). Soil pH, below normal moisture conditions, and differences in soil organic matter between sites may have affected the yields in this study.

Seed Quality

Thousand seed weight (TSW) and protein content are measures of seed quality that can affect the value of a crop. Thousand seed weight is a measure of seed size that varies between crop, variety and year (Alberta Agriculture and Food, 2007). Faba bean had the highest TSW of 453 g at Barrhead and 470 g at St. Albert (Table 2-9). Faba bean TSW was significantly greater than pea at both sites ($p<0.05$). The TSW of pea was 265 g at Barrhead and 286 g at St. Albert. The regional trials in Alberta reported TSW for ‘Snowbird’ faba bean (526 g) and ‘Canstar’ field pea (247 g) (Alberta Seed Industry Partnership, 2011). Lupin TSW (181, 163 g) was less then faba bean and pea at Barrhead and St. Albert, respectively ($p<0.05$). Lupin seed had a higher TSW at Barrhead due to more favourable soil pH conditions at Barrhead. Faba bean and pea had higher seed weights at St. Albert due to better soil moisture and more neutral soil pH of the St. Albert site.

Seed protein content was measured for each of the YR1 treatments (Table 2-9). Barley protein content at Barrhead was 156 mg g^{-1} (‘+N’) and 130 mg g^{-1} (‘no N’). At St. Albert barley protein content for the ‘+N’ treatment was 133 mg g^{-1} and ‘no N’ treatment 123 mg g^{-1}. For malt quality barley (two-row) the desired protein content is 105 – 125 mg g^{-1} (McLelland et al. 2009). The only barley treatment that fell within the malt barley range was the ‘no N’ treatment at St. Albert; all other treatments had protein levels that are too high for optimal malting. Environmental stress (moisture or temperature) or high N availability can increase protein content of seed (Zhang et al. 2001). Moisture stress in this study could have contributed to the higher protein levels in the seed.

Barley and canola produced with N fertilizer had higher protein levels than those treatments without N fertilizer but none of the differences were significant. Barley had lower protein content than canola ($p<0.0001$) (Table 2-9). The Canadian Grain Commission reported canola protein to be 215 mg g^{-1} (Barthet 2011). In this study canola protein was higher than the reported average and ranged from 331 to 386 mg g^{-1}. At Barrhead faba bean seed had a protein content of 274 mg g^{-1} which was numerically lower than at St. Albert (331 mg g^{-1}). These values of faba bean protein are within the range reported in previous research (270 – 340 mg g^{-1}) (Duc 1997). Lupin had a higher protein content at Barrhead (330 mg g^{-1}) than at St. Albert (304 mg g^{-1}) but protein content was consistent with previously reported values (273 – 385 mg g^{-1}) (Cowling and Tarr 2004, Fraser et al. 2005). Pea seed protein was 221 mg g^{-1} at Barrhead and 223 mg g^{-1} at St. Albert. These values were significantly lower than faba bean at both sites ($p>0.05$) (Table 2-9). Wang and Daun (2004) reported pea seed protein of 202 – 267 mg g^{-1}.

Nitrogen Fixation

Nitrogen fixation ranged from 41 to 201 kg N ha^{-1} with %Ndfa (nitrogen derived from the atmosphere) ranging from 26 to 66% (Table 2-10). These fixation values were similar to those reported by Strydhorst et al. (2008) for faba bean (70 – 223 kg N ha^{-1}), lupin (46 – 173 kg N ha^{-1}) and pea (78 – 146 kg N ha^{-1}). N fixation calculations for pulse crops are affected by research methodologies and environmental conditions. Many studies have indicated a high level of variability in N fixation with values ranging from 2 – 350 kg N ha^{-1} for faba bean, 26 – 283 kg N ha^{-1} for lupin and 0 – 183 kg N ha^{-1} for pea (Peoples et al. 2001, Rochester et al. 1998, Armstrong et al. 1997, Unkovich et al. 1995, Maidl et al. 1996, Strydhorst et al. 2008, Sparrow et al. 1995, Clayton et al. 2004, Soon and Arshad, 2004, Soon et al. 2004, Stevenson and van Kessel 1996).

At Barrhead, N fixation was not significantly different for faba bean, lupin or pea (Table 2-10). Lower levels of N fixation in faba bean and pea at Barrhead may be attributed to moisture limiting conditions (especially in 2009) and a lower soil pH at this site (Figure 2-1). Previous studies have indicated that moisture limiting conditions can reduce N fixation by reducing biomass growth, fixation efficiency and nodulation success (Kurdali et al. 2002, Abd-Alla and Abdel Wahab 1995). Faba bean and pea can exhibit reduced shoot and root growth when grown in environments with pH < 6 (Tang and Thomson 1996), unlike lupin that prefers acidic soil environments and has reduced performance on soils with pH ≥ 6 (French 2002, Tang and Thomson 1996).

At St. Albert, faba bean and pea had significantly higher N fixation than lupin ($p<0.05$). The neutral/basic soil (pH 7.1 – 7.6) at St. Albert may have reduced lupin fixation as demonstrated in previous studies (French and Buirchell 2005, Tang and Thomson 1996, French 2002). Numerically faba bean had the highest N fixation (201 kg N ha^{-1}) but this was not significantly different from pea fixation (123 kg N ha^{-1}). Soil organic matter may have also influence N fixation by influencing the availability of N and other nutrients in the soil. High soil organic matter may reduce available soil N through immobilization or increase soil N through mineralization. Low soil organic matter may increase the need for N fixation to supply N for plant growth. The effects of soil organic matter were not clear in this study in part due to the confounding effects of soil pH and available soil moisture.

Nitrogen fixation in this study was impacted by low moisture conditions, more prominently in 2009 and at the Barrhead site. Although lupin is commonly grown in low moisture environments, the literature does not appear to indicate a superior ability to deal with moisture stress (Grzeiak et al. 1996). All three pulses exhibit rapid development with early flowering and pod set to avoid low moisture stress and maximize yield (Siddique et al. 2001, Thomson et al. 1997, Palta et al. 2007). Yields of all three pulses can be limited by moisture stress that results in flower blasting and pod abortion (Park et al. 1999, Dracup et al. 1998). Flower blasting and pod abortion were observed for faba bean and pea, most commonly at Barrhead during the hot dry conditions of 2009 (personal observation).

Although there were no significant differences between the pulses for %Ndfa (N derived from the atmosphere) at Barrhead, 35 – 37% of the nitrogen in the above ground biomass of all three pulses was derived from atmospheric N (Table 2-10). Low moisture conditions and pH stress resulted in similar limited %Ndfa for all three pulse crops. At St. Albert, 66% of the N in the above ground biomass of faba bean was fixed nitrogen. Similarly pea fixed 55% of its above ground biomass N and lupin 26% at St. Albert. Faba bean and pea fixed a significantly greater percentage of their N than lupin ($p<0.05$) (Table 2-10). Previous research reports %Ndfa for faba bean (4 – 96%), lupin (42 – 93%) and pea (12 – 92%) (Beck et al. 1991, Peoples et al. 2001, Rochester et al. 1998, Armstrong et al. 1997, Unkovich et al. 1995, Strydhorst et al. 2008, Sparrow et al. 1995, Soon and Arshad, 2004, Soon et al. 2004, Stevenson and van Kessel 1996, Walley et al. 2007, McNeill and Fillery 2008, Smith et al. 1992). Stressful environmental conditions affect %Ndfa and N fixation of pulse crops resulting in highly variable responses.

Total N Yield

The total N yield is the amount of N measured in the above ground biomass of each YR1 crop. For barley and canola treatments, soil and fertilizer N were the nitrogen sources for N uptake. For the three pulses some of this N came from the atmosphere (26 – 66%) (Table 2-10). Total N yield for all YR1 treatments ranged from 89 to 299 kg N ha^{-1} (Figure 2-4). At Barrhead, the total N yield of canola was significantly higher than barley total N yield ($p<0.01$) due mainly to the difference in N yield of the seed. There were no significant differences between the pulse crops or when legumes were compared with non-legumes. Similarly, at St. Albert canola N yield was significantly greater than barley N yield ($p<0.01$). Faba bean and pea total N yield was not significantly different from one another but they were significantly greater than lupin total N yield ($p<0.05$). The N in the above ground biomass can be divided into 2 main components: N in the seed which was removed from the system at harvest (N removal), and N in the straw/pods/chaff which was returned to the soil for decomposition (N return) (Figure 2-4). Crops can partition N differently based on N concentration in different tissues and the biomass of different components. This will have an effect on the N removal and N return in the agricultural system.

N Removal

N removed from the system in harvested seed is the product of yield and seed N content. In this study significant differences were observed between the two non-legume crops (barley and canola) at both sites ($p<0.001$). Canola seed had significantly greater N content (average 57 mg g^{-1}) than barley seed (average 22 mg g^{-1}) (Table 2-11). This results in canola's total N removal exceeding that of barley even though barley yields are greater (Table 2-8). The '+N' treatments of barley and canola had greater N removal and N content than their respective 'no N' treatments but none of these differences were significant. Previously reported values for N removal by canola (49 – 71 kg N ha^{-1}) (Gan et al. 2010), were much lower than reported here.

Numerically the three pulse crops and canola had similar N removal but the pulses had slightly lower N content than canola (Table 2-11). Pulse crops removed more N in harvested seed and their seed had a greater N content than barley. Collectively, the three legume crops were only significantly different from the non-legume crops for N removal at Barrhead ($p<0.05$). At St. Albert, there were significant differences in the amount of N removed ($p<0.01$). Low lupin yields (Table 2-8) at the St. Albert site resulted in low levels of N removal by the lupin crop. Faba bean and pea were higher yielding and removed significantly more N than lupin ($p<0.01$) (Table 2-11). Previous studies have reported peas to remove 70 – 115 kg N ha^{-1} (Gan et al. 2010, Ayaz et al. 2004) and lupins 169 – 193 kg N ha^{-1}(Ayaz et al. 2004). The lower lupin N removal in this study reflects the lower lupin yields in this experiment. N content in seed was greater in faba bean (44, 50 mg g^{-1}) than pea (35, 36 mg g^{-1}) at Barrhead and St. Albert, respectively ($p<0.05$). Schulz et al. (1999) reported seed N content at 44 mg g^{-1} for faba bean and 42 – 45 mg g^{-1} for pea.

The N harvest index (NHI) is the measure of N yield of the seed as a percentage of the total N yield of in the above ground biomass. The NHI at Barrhead and St. Albert ranged from 0.65 to 0.73 for barley, 0.76 to 0.80 for canola and 0.75 to 0.85 for the three pulse crops (Table 2-12). At Barrhead there were no significant differences between treatments. At St. Albert, the barley NHI was less than canola ($p<0.01$), and faba bean (0.84) and pea (0.82) were greater than lupin (0.75) ($p<0.05$). The higher canola seed yields and lower lupin seed yields at St. Albert explain this difference. Gan et al. (2010) reported a NHI for pea of 0.56 – 0.69 and canola of 0.54 – 0.68 grown in Saskatchewan. These values are lower than those reported in this study. A high NHI indicates that a larger portion of the total N is being removed with harvested seed leaving less to contribute to the soil N pool (Carranca et al. 1999).

N return

The nutrients in crop residues are made available for use by subsequent crops through decomposition and mineralization. Crop residues were returned to the plots following harvest and some of the N in those residues will decompose into a usable form to be taken up by the subsequent crop. The amount of N return is determined by the dry matter biomass and N content of the returned residues. Total dry matter production of crop residues (straw and pods or chaff) ranged from 1.7 to 4.6 Mg ha^{-1} at Barrhead and 2.5 to 7.7 Mg ha^{-1} at St. Albert (Table 2-13). Canola produced the most dry matter biomass at both sites but also has the lowest N content. At Barrhead, the faba bean treatment had the lowest dry matter biomass and at St. Albert, lupin had the lowest dry matter biomass. Soon and Arshad (2002) reported straw dry matter of canola at 2.3 – 3.5 Mg ha^{-1} and pea 4.3 – 5.8 Mg ha^{-1}. In the present study canola dry matter yields were higher and pea dry matter yield was lower. N return for the seven treatments ranged from 22 to 44 kg N ha^{-1} at Barrhead and 28 to 62 kg N ha^{-1} at St. Albert. The canola +N treatment returned the most N to the system at both sites and the least was returned by faba bean at Barrhead and barley no N at St. Albert.

There were no significant differences in N return between the 7 treatments at either site but there were trends in the data that indicate some differences between the crops (Table 2-14). Generally, the ‘+N’ treatments for barley and canola returned more N to the soil in crop residues than the ‘no N’ treatments. Pulse crops all returned similar amounts of N to the soil when compared at each site year. Lupwayi et al. (2006) reported N return to rank: green manure pea > canola > pea = wheat in one year of study and then reported N return to rank: green manure pea > pea = canola > wheat in the second year of study. Soon and Clayton (2002) reported N return to be canola (50 kg N ha^{-1}) > pea (22 kg N ha^{-1}) > wheat (16 kg N ha^{-1}). These and other studies indicate that the environmental conditions can affect N accumulation, N return and decomposition of tissues (Lupwayi et al. 2006, Lupwayi et al. 2004, Lupwayi and Soon 2009).

Non-legume crops obtain their entire N yield from soil mineralization or N fertilizer addition. Pulse crops fix part of the N in their tissues from the atmosphere. In this study we report that pulse crops fix between 26 and 66% of their above ground N from the atmosphere. This results in them returning some fixed N to the soil in their residues instead of recycling existing N as non-legume crops do. Estimates of fixed N return for Barrhead are: 8.4, 11.6, and 10.6 kg N ha^{-1} for faba bean, lupin and pea, respectively. At St. Albert the amount of fixed N that was returned with residues was 31.0 kg N ha^{-1} for faba bean, 9.6 kg N ha^{-1} for lupin, and 21.5 kg N ha^{-1} for pea. This demonstrates that although the numerical values of N return are greater for canola, pulse crops are contributing more to the system because the percentage of fixed N is essentially new N in the system while canola is recycling existing soil N or N added through fertilization.

Nitrogen in below ground biomass was not accounted for in this study. Gan et al. (2010) estimated that at maturity 14% of the total plant N is in below ground biomass. Strydhorst (2008) reported root N accumulation for barley (37 kg N ha^{-1}), faba bean (36 kg N ha^{-1}), lupin (65 g N ha^{-1}) and pea (24 kg N ha^{-1}). Therefore, the above ground biomass values are likely an underestimation of total N returned to the soil in crop residues. Soon and Arshad (2002) reported C:N ratios for roots of canola (56 – 58) and pea (18 – 23), indicating that decomposition of the below ground biomass and N release from those tissues may occur at different rates for these crops.

Residue decomposition is another key component of these relationships. Crop residues that decompose more slowly may tie up N in the system in an unavailable form, limiting their benefit to subsequent crops. Decomposition rates for crop residues are affected by environmental conditions, N content of tissue, C:N ratio, and other chemical characteristics of the residue (Lupwayi et al. 2006). Soon and Arshad (2002) reported that decomposition of crop residues was pea ≥ canola > wheat.

Decomposition rates also impact the amount of N released back into the system in an available form for crop uptake. Previous studies indicate that only a small percentage (< 10%) of the N in crop residues is made available to a subsequent crop (Bremer and van Kessel, 1992, Jensen 1996). Strydhorst (2008) reported N released in a long term (12 month) decomposition study for barley (74 – 80 kg N ha^{-1}), faba bean (62 – 76 kg N ha^{-1}), lupin (118 – 134 kg N ha^{-1}), and pea (54 – 57 kg N ha^{-1}) residues. Lupwayi et al. (2006) reported N released from pea residue was 4 – 18 kg N ha^{-1} and canola 10 – 25 kg N ha^{-1} in 52 weeks. The variability of N return in crop residues and N released from the residues may be attributed to environmental conditions and crop residue quality and quantity (Strydhorst 2008, Lupwayi et al. 2006, Lupwayi and Soon 2009).

Generally, crops with lower C:N ratios decompose at a faster rate and N is mineralized into a plant available form. Crops with higher C:N ratios can reduce available soil N through immobilization. Above ground crop residue C:N ratios have been reported for barley (27 – 106) (Strydhorst 2008, Curtin et al. 2008, Beare et al. 2002), canola (71 – 89) (Soon and Arshad 2002), faba bean (26) (Strydhorst 2008), lupin (20) (Strydhorst 2008), and pea (26–66) (Soon and Arshad 2002, Lupwayi et al. 2006, Strydhorst 2008). Stevenson and van Kessel (1996) reported that the typical C:N ratio for pulse crops was 25 – 40: 1 and cereals 70 – 100: 1. Though previous studies indicate a large amount of variability in the C:N ratio of crop residues, generally pulse crops are lower indicating that residues will mineralize more quickly (Stevenson and van Kessel 1996).

Conclusion

A basic quantification of the differences between non-legume and legume crops can provide an understanding of how they will impact a crop rotation. Environmental conditions affected the yield, N dynamics and quality of seed of all YR1 treatments produced in this study. Pea was the highest yielding pulse treatment and barley +N the highest non legume treatment. N fixation was variable between the pulse crops but faba bean had the greatest potential for N fixation at St. Albert where it fixed 66% of N in above ground biomass (201 kg N ha^{-1}). In the more neutral soil of St. Albert pea fixed 123 kg N ha^{-1} (55% of the total N in the above ground biomass). Due to abiotic stress N fixation was limited at Barrhead for all three pulse crops.

Most of the N in the above ground biomass is removed from the system with harvested seed. In this study, N removal generally differed between treatments and ranged from 61 to 252 kg N ha^{-1}. Nitrogen return ranges from 25 to 62 kg N ha^{-1} with no significant differences between crops. Pulse crops fix 26 – 66% of their N from the atmosphere whereas non-legume crops receive their entire N from mineralization and fertilizer addition. Nitrogen fixation by pulse crops reduced the amount of soil N removed from the agricultural system. Due to N fixation in pulse crops, lower C:N ratios of pulse tissues and the contribution of below ground biomass N, an N treatment response in subsequent crops following a pulse crop is expected.

Table 2-1: Soil test nutrient analysis, soil properties and amount of fertilizer applied to plots in 2008 and 2009 at Barrhead and St. Albert, Alberta, Canada. Soil tests were done in the spring of 2008 and the fall of 2008 and fertilizer recommendations were determined for the growing season based on those results. P, K, and S fertilizers were applied to all plots. N was only applied to two treatments (barley +N and canola +N). Fertilizer was applied just prior to spring seeding with a pre-seeding run over the plots with the seeder.

	Barrhead				**St. Albert**			
	2008		**2009**		**2008**		**2009**	
Soil properties	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 Cm	15-30 cm
pH	5.3	5.8	5.6	5.6	7.6	7.3	7.4	7.5
	%				%			
Organic matter	2.7	1.4	n/a	n/a	11.6	8.0	n/a	n/a
	mg kg^{-1}				mg kg^{-1}			
Nitrate N	10	9	10	10	11	10	15	9
P	34	14	20	16	>60	21	>60	30
K	165	90	166	16	226	155	181	167
Sulphate S	21	12	14	13	7	10	8	7
Fertilizer Applications	kg ha^{-1}				kg ha^{-1}			
P_2O_5	43		45		0		0	
K_2O	0		0		44		84	
S	0		28		15		28	
N	101		101		101		101	

n/a: measurement was not available

Table 2-2: The seven YR1 treatments grown in 2008 and 2009 at Barrhead and St. Albert, Alberta, Canada.

Treatment	**Cultivar**	**N Fertilizer kg ha^{-1}**
Barley + N (BN)	Metcalf	101
Barley No N (BO)	Metcalf	0
Canola +N (CN)	71-45 RR	101
Canola No N (CO)	71-45 RR	0
Faba bean (Fb)	Snowbird	0
Lupin (Lu)	Arabella	0
Pea (Pe)	Canstar	0

Table 2-3: YR1 crops seeded at Barrhead and St. Albert, Alberta, Canada in 2008 and 2009. Seeding rates and depths were adjusted according to seed size and germination % to achieve optimal crop densities. Seed treatments were applied to seed before seeding and inoculants were seed placed at the recommended rate of 6.7 kg ha^{-1}.

Crop	**Target Plant Density (plants m^{-2})**	**Seeding Depth (cm)**	**Seed Treatment**	**Inoculant**	**Rhizobium species**
Barley	210	2-2.5	Raxil FL	n/a	n/a
Canola	120	1-1.5	Helix XTra	n/a	n/a
Faba bean	65	3-6	Apron Maxx	Faba bean	*Rhizobium leguminosarum* bv. *viciae*
Lupin	110	3-6	Apron Maxx	Lupin	*Bradyrhizobium* sp. (*Lupinus*)
Pea	75	3-6	Apron Maxx	Pea/Lentil	*Rhizobium leguminosarum* biovar *viceae*

n/a: not applicable

Table 2-4: Date of herbicide applications for barley, canola, faba bean, lupin and pea crops grown at Barrhead and St. Albert, Alberta, Canada in 2008 and 2009. Application dates were chosen according to crop maturity and environmental conditions. Herbicides were selected based on crop and weed problem.

		Barrhead		St. Albert	
Crop	**Chemical**	**2008**	**2009**	**2008**	**2009**
Barley	Sencor 75DF	June 4	n/a	June 4	n/a
	Achieve SC	n/a	June 10	n/a	June 8
	Refine SG	n/a	June 16	n/a	June 17
Canola	Roundup Transorb HC	June 11	June 10	June 10	June 10
Faba bean	Poast Ultra	June 2	June 10	June 3	June 8
	Basagran	June 11	June 16	June 10	June 17
Lupin	Poast Ultra	June 2	June 10	June 3	June 8
	Sencor 75DF	June 4†			June 17
Pea	Poast Ultra	June 2	June 10	June 3	June 8
	Basagran	June 11	June 16	June 10	June 17

† 1/2 rate

n/a: herbicide not applied

Table 2-5: Pesticides applied to plots at Barrhead and St. Albert, Alberta, Canada in 2008 and 2009. Application was according to recommended application rates at appropriate crop maturity.

Chemical	Application Rate	Surfactant	Target Pests
Herbicides:			
Achieve SC (*tralkoxydim)*	494 ml ha^{-1}	Turgocharge (1L/200L water)	Wild oats
Basagran (*bentazon)*	2249 ml ha^{-1}	Assist or Super Spreader	Chickweed, lamb's quarters, stinkweed, volunteer canola
Poast Ultra (*sethoxydim)*	470 ml ha^{-1}	Merge (1.0 L ha^{-1})	Quackgrass, volunteer barley, wild oats
Refine SG (*thifensulfuron-methyl + tribenuron-methyl)*	30g ha^{-1}	AgSurf (2L/10000L water)	Chickweed, hemp-nettle, lamb's quarters, stinkweed, volunteer canola, wild buckwheat
Roundup Transorb HC (*glyphosate)*	1.2 L ha^{-1}	No Surfactant	Hemp-nettle, lamb's quarters, stinkweed, volunteer barley, wild oats, Canada thistle, dandelion, quackgrass
Sencor 75DF *(metribuzin)*	272 g ha^{-1}	No Surfactant	Chickweed, hemp nettle, lamb's quarters, stinkweed, volunteer canola
Insecticides:			
Decis (*deltamethrin)*	198 ml ha^{-1}	n/a	Cutworms, grasshoppers, thrips
ECO Bran (*carbaryl)*	1.6 kg ha^{-1}	n/a	Grasshoppers
Desiccants:			
Reglone (*diquat)*	1.7 L ha^{-1}	n/a	n/a
Roundup Transorb HC (*glyphosate)*	1.2 L ha^{-1}	n/a	n/a

n/a: not applicable

Table 2-6: Harvest dates of barley, canola, faba bean, lupin and pea crops grown at Barrhead and St. Albert, Alberta, Canada in 2008 and 2009. Crops were harvested after they had been desiccated and had dried down.

	Barrhead		St. Albert	
Crop	**2008**	**2009**	**2008**	**2009**
Barley	August 19	August 27	August 18	September 2
Canola	September 17	September 17	September 18	September 25
Faba bean	September 4	September 3	September 10	September 16
Lupin	August 19	August 12	August 18	August 28
Pea	August 14	August 12	August 12	August 28

Table 2-7: Nodulation scores for faba bean, lupin, and pea averaged across 2008 and 2009 at Barrhead and St. Albert, Alberta, Canada. Scoring was out of 13 points which assessed overall plant health and nodule number, position, and colour as described by Zaychuk, 2006.

Treatment	Barrhead	St. Albert
Faba bean (Fb)	10.8	12.0
Lupin (Lu)	7.6	6.7
Pea (Pe)	6.4	11.4
F-Test (df)	0.0979 (2)	0.1503 (2)
SE[a]	1.1	1.7
Contrasts		
Fb vs Pe	0.0533	ns
Lu vs Fb, Pe	ns	0.0790

Significance was determined at $p<0.1$.

[a]Standard error of the difference between two least-square means.

ns: not significant at a probability level of 0.1

Table 2-8: Grain yields (Mg ha^{-1}) of YR 1 treatments (barley +N, barley no N, canola +N, canola no N, faba bean, lupin, and pea) grown at Barrhead and St. Albert, Alberta, Canada averaged across 2008 and 2009.

Treatment	**Barrhead** Mg ha^{-1}	**St. Albert** Mg ha^{-1}
Barley +N (BN)	3.4	4.8
Barley No N (BO)	3.3	3.8
Canola +N (CN)	2.0	3.6
Canola No N (CO)	1.7	2.9
Faba bean (Fb)	2.6	4.2
Lupin (Lu)	1.7	1.7
Pea (Pe)	3.2	5.9
F-Test (df)	0.0362 (6)	0.0010 (6)
SE[a]	0.5	0.4
Contrasts		
Fb, Lu, Pe vs BN, BO, CN, CO	ns	ns
BN vs BO	ns	ns
CN vs CO	ns	ns
BN, BO vs CN, CO	0.0046	0.0123
Fb vs Pe	ns	0.0078
Lu vs Fb, Pe	0.0276	<0.0001

Significance was determined at $p<0.05$.

[a]Standard error of the difference between two least-square means.

ns: not significant at a probability level of 0.05.

Table 2-9: Thousand seed weight (TSW, g 1000 seeds^{-1}) and protein content (mg g^{-1}) of barley +N, barley, no N, canola +N, canola no N, faba bean, lupin and pea treatments averaged across 2008 and 2009 grown at Barrhead and St. Albert, Alberta, Canada.

	Barrhead		**St. Albert**	
Treatment	**TSW** g 1000 seeds^{-1}	**Protein content** mg g^{-1}	**TSW** g 1000 seeds^{-1}	**Protein content** mg g^{-1}
Barley +N (BN)	n/a	156	n/a	133
Barley No N (BO)	n/a	130	n/a	123
Canola +N (CN)	n/a	387	n/a	359
Canola No N (CO)	n/a	358	n/a	331
Faba bean (Fb)	453	274	470	312
Lupin (Lu)	181	330	163	304
Pea (Pe)	265	221	286	223
F-test (df)	0.0153 (6)	<0.0001 (6)	0.0047 (6)	<0.0001 (6)
SE[a]	25	17	15	12
Contrasts				
Fb, Lu, Pe vs BN, BO, CN, CO	n/a	ns	n/a	0.0005
BN vs BO	n/a	ns	n/a	ns
CN vs CO	n/a	ns	n/a	ns
BN, BO vs CN, CO	n/a	<0.0001	n/a	<0.0001
Fb vs Pe	0.0167	0.0223	0.0066	0.0003
Lu vs Fb, Pe	0.0139	0.0015	0.0036	0.0113

Significance was determined at $p<0.05$

[a]Standard error of the difference between two least-square means.

ns: not significant at a probability level of 0.05.

n/a: data not available.

Table 2-10: Nitrogen fixation (kg N ha^{-1} and %Ndfa – nitrogen derived from the atmosphere) by faba bean, lupin and pea at Barrhead and St. Albert, Alberta, Canada averaged across 2008 and 2009. N fixation was determined using the N difference method with barley as a reference species.

Treatment	**Barrhead**		**St. Albert**	
	kg N ha^{-1}	**% Ndfa**	**kg N ha^{-1}**	**% Ndfa**
Faba bean (Fb)	55	37	201	66
Lupin (Lu)	58	35	41	26
Pea (Pe)	51	35	123	55
F-Test (df)	0.9295 (2)	0.9375 (2)	0.0990 (2)	0.0333 (2)
SE[a]	19	7.8	38	5.4
Contrasts				
Fb vs Pe	ns	ns	ns	ns
Lu vs Fb, Pe	ns	ns	0.0650	0.0181

Significance was determined at $p<0.10$

[a]Standard error of the difference between two least-square means.

ns: not significant at a probability level of 0.10.

Table 2-11: N removed from the system in the harvested seed (kg N ha^{-1}) and N concentration in seed (mg g^{-1}) averaged across 2008 and 2009 for each of the YR1 treatments (barley +N, barley no N, canola +N, canola no N, faba bean, lupin and pea) grown at Barrhead and St. Albert, Alberta, Canada.

	Barrhead		**St. Albert**	
Treatment	**N Removed (kg N ha^{-1})**	**N Content (mg g^{-1})**	**N Removed (kg N ha^{-1})**	**N Content (mg g^{-1})**
Barley +N (BN)	79	25	90	21
Barley No N (BO)	65	21	61	20
Canola +N (CN)	137	62	235	57
Canola No N (CO)	112	57	204	53
Faba bean (Fb)	123	44	252	50
Lupin (Lu)	115	53	102	49
Pea (Pe)	111	35	182	36
F-Test (df)	0.0024 (6)	<0.0001 (6)	0.0031 (6)	<0.0001 (6)
SE[a]	10	2.8	29	1.9
Contrasts				
Fb, Lu, Pe vs BN, BO, CN, CO	0.0174	ns	ns	0.0005
BN vs BO	ns	ns	ns	ns
CN vs CO	ns	ns	ns	ns
BN, BO vs CN, CO	0.0004	<0.0001	0.0004	<0.0001
Fb vs Pe	ns	0.0223	ns	0.0003
Lu vs Fb, Pe	ns	0.0015	0.0041	0.0113

Significance was determined at $p<0.05$

[a]Standard error of the difference between two least-square means.

ns: not significant at a probability level of 0.05.

Table 2-12: Nitrogen harvest index (NHI) for all YR1 treatments (barley +N, barley no N, canola +N, canola no N, faba bean, lupin and pea) produced at Barrhead and St. Albert, Alberta, Canada averaged across 2008 and 2009.

Treatment	Barrhead	St. Albert
Barley +N (BN)	0.73	0.65
Barley No N (BO)	0.72	0.69
Canola +N (CN)	0.76	0.80
Canola No N (CO)	0.78	0.80
Faba bean (Fb)	0.85	0.84
Lupin (Lu)	0.78	0.75
Pea (Pe)	0.79	0.82
F-Test (df)	0.1335 (6)	0.0080 (6)
SE[a]	0.04	0.03
Contrasts		
Fb, Lu, Pe vs BN, BO, CN, CO	0.0274	0.0089
BN vs BO	ns	ns
CN vs CO	ns	ns
BN, BO vs CN, CO	ns	0.0014
Fb vs Pe	ns	ns
Lu vs Fb, Pe	ns	0.0335

Significance was determined at $p<0.05$

[a]Standard error of the difference between two least-square means.

ns: not significant at a probability level of 0.05.

Table 2-13: The components of above ground biomass N return (dry matter (Mg ha^{-1}) production and N content (mg g^{-1}) of straw and pods/chaff), of all YR1 crops averaged across 2008 and 2009 at Barrhead and St. Albert, Alberta, Canada. Barley treatments (+N and no N) were divided into straw and chaff components, canola treatments (+N and no N) straw and pods were combined, and pulse treatments (faba bean, lupin and peas) straw and pods were separated.

	Barrhead				St. Albert			
	Dry matter		N content		Dry matter		N content	
Treatment	Straw	Pods / chaff	Straw	Pods/ chaff	Straw	Pods/ Chaff	Straw	Pods/ Chaff
	Mg ha^{-1}		mg g^{-1}		Mg ha^{-1}		mg g^{-1}	
Barley +N (BN)	2.4	0.6	10.9	12.4	2.8	0.8	13.4	15.4
Barley No N (BO)	1.9	0.6	10.1	12.7	1.8	0.7	10.7	13.6
Canola +N (CN)	4.6		9.8		7.7		8.1	
Canola No N (CO)	4.4		7.9		7.2		7.3	
Faba bean (Fb)	0.9	0.8	12.2	15.8	2.2	1.0	14.1	15.7
Lupin (Lu)	1.8	1.3	13.0	7.2	1.5	1.7	12.2	10.0
Pea (Pe)	2.0	0.7	12.7	7.3	3.0	0.9	10.8	7.2

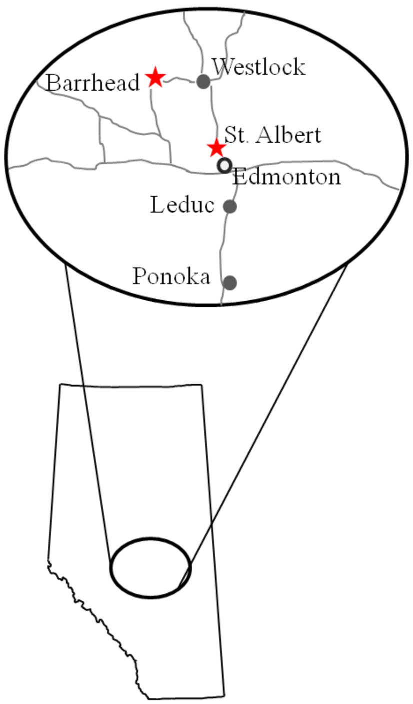
Table 2-14: Total N returned to the soil with crop residue of YR1 treatments (barley +N, barley no N, canola +N, canola no N, faba bean, lupin and pea) produced at Barrhead and St. Albert, Alberta, Canada averaged across 2008 and 2009.

Treatment	**Barrhead** kg N ha^{-1}	**St. Albert** kg N ha^{-1}
Barley +N (BN)	29.9	48.7
Barley No N (BO)	25.5	28.1
Canola +N (CN)	44.3	61.7
Canola No N (CO)	33.5	50.6
Faba bean (Fb)	22.3	46.7
Lupin (Lu)	33.4	36.3
Pea (Pe)	30.1	38.9
F-Test (df)	0.3450 (6)	0.4888 (6)
SE[a]	8.4	15.4
Contrasts		
Fb, Lu, Pe vs BN, BO, CN, CO	ns	ns
BN vs BO	ns	ns
CN vs CO	ns	ns
BN, BO vs CN, CO	ns	ns
Fb vs Pe	ns	ns
Lu vs Fb, Pe	ns	ns

Significance was determined at $p<0.05$

[a]Standard error of the difference between two least-square means.

ns: not significant at a probability level of 0.05.



Barrhead

Description: Commercial Farm (54°8'N, 114°14'W)
Soil Type: Orthic humic Gleysol (mesic Typic Endoaquoll) with heavy clay texture[1]
pH: 4.8-5.6[†]
Weather Station: Barrhead CS Environment Canada[3]
(14 km from site)

	2008	2009	Normal[‡]
Total Precipitation (mm)[*]	186.3	138.0	288.0
Average Daily Temperature (°C)[*]	15.1	14.0	13.8

St. Albert

Description: University of Alberta St. Albert Research Station
(53°41'N, 113°38W)
Soil Type: Malmo Eluviated Black Chernozem with silty clay loam texture[2]
pH: 7.1-7.8[†]
Weather station: Oliver ABDM Alberta Agriculture and Food [3]
(19 km from site)

	2008	2009	Normal[‡]
Total Precipitation (mm)[*]	174.6	153.2	272.9
Average Daily Temperature (°C)[*]	15.3	14.2	14.6

[†] Range across spring 2008 – fall 2009 soil tests [*]Growing Season (May – August) [‡]Estimates of long term normals as described by ACIS 2010 definitions.
[1]Strydhorst, 2008 [2]Browser et al 1962 [3]ACIS 2010

Figure 2-1: Description of study locations – Barrhead and St. Albert, Alberta, Canada where crops were produced in 2008 and 2009.

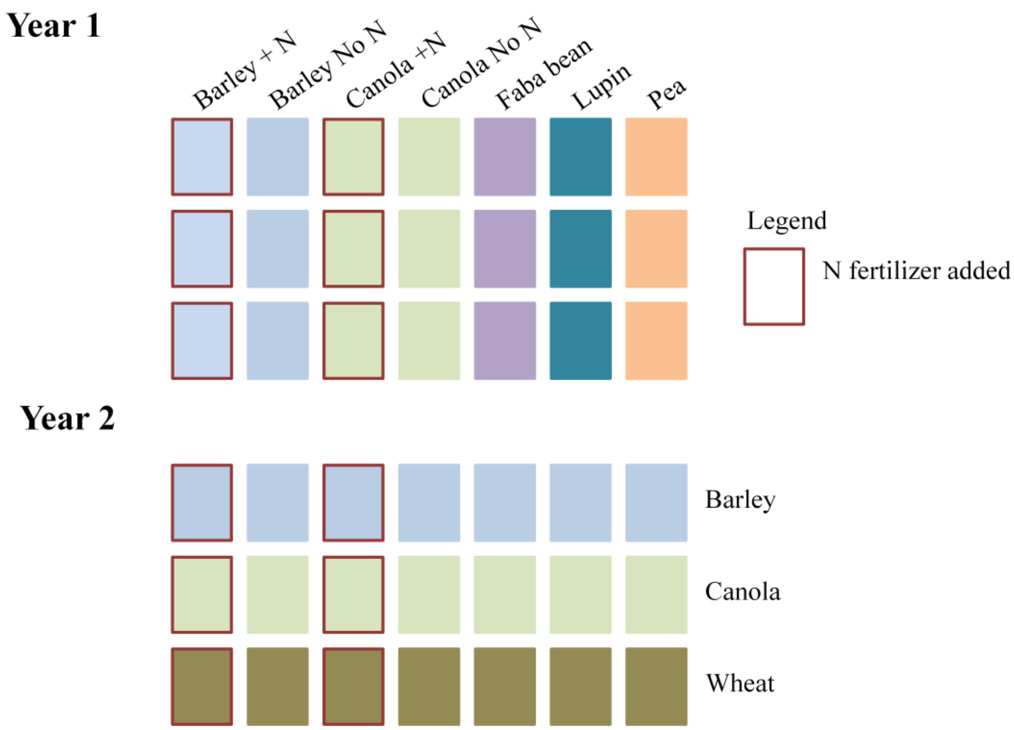


Figure 2-2: Plot plan for rotational study grown at Barrhead and St. Albert, Alberta, Canada in 2008, 2009 and 2010. YR1 crops were produced in vertical strips with 3 plots each and YR2 crops were produced horizontally on the YR1 stubble in the subsequent growing season. Four blocks of randomized treatments were grown at each site.

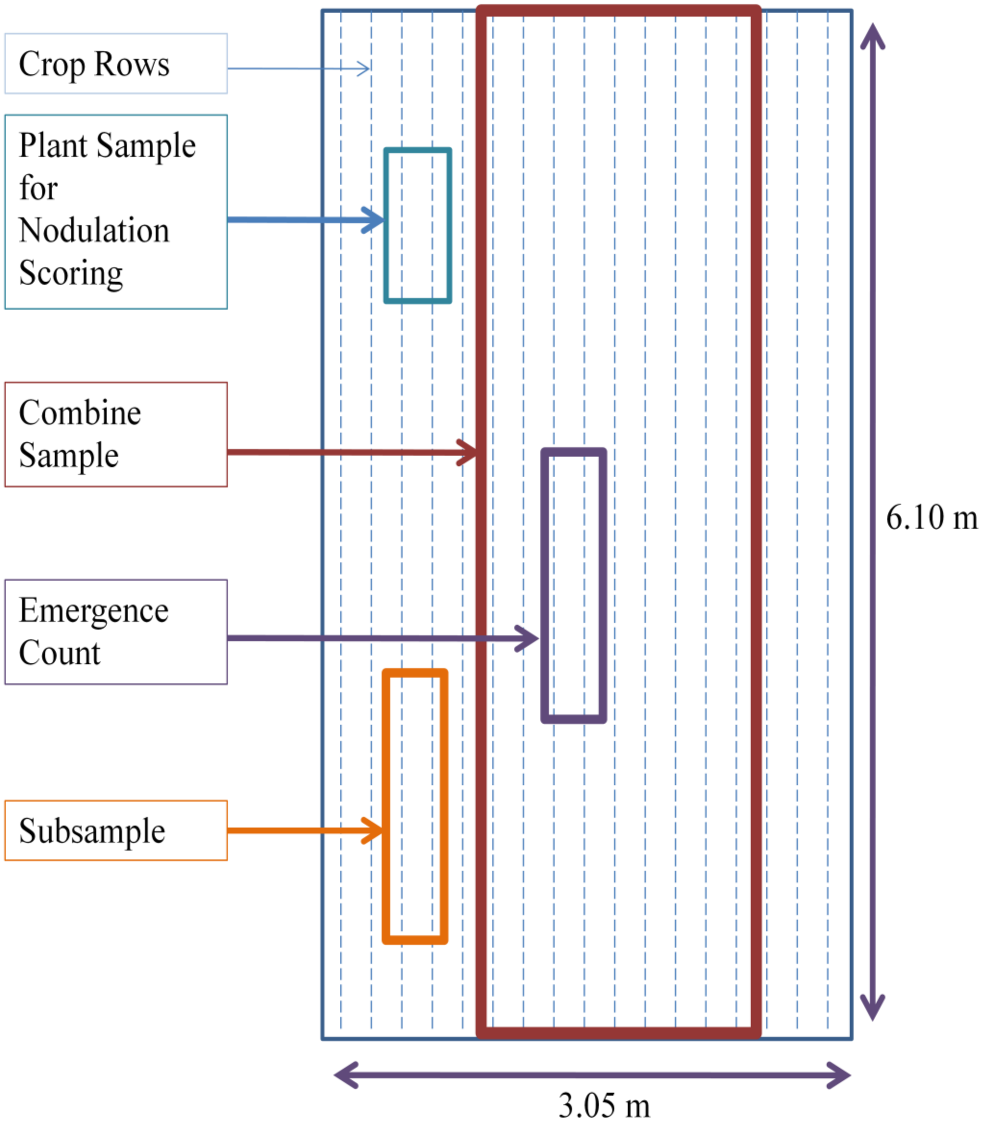


Figure 2-3: Plot diagram for YR1 crops grown in 2008 and 2009 at Barrhead and St. Albert, Alberta, Canada.

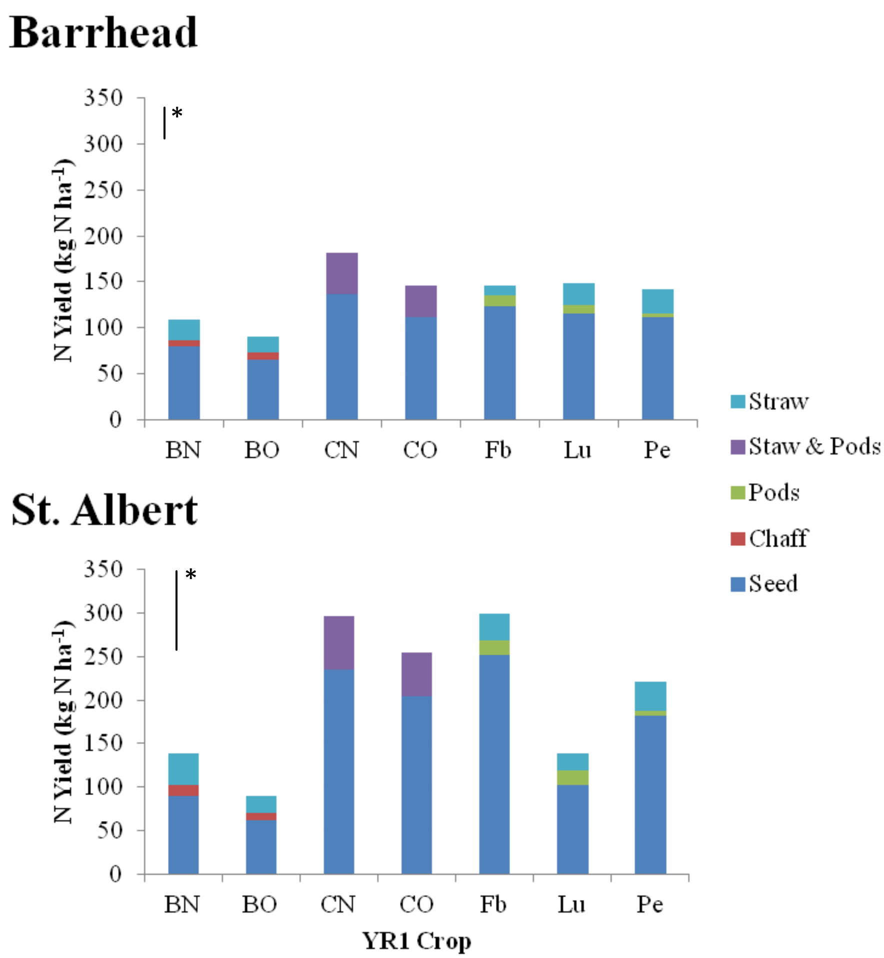


Figure 2-4: Total N Yield (kg N ha^{-1}) of above ground biomass components for all YR1 treatments – barley +N (BN), barley no N (BO), canola +N (CN), canola no N (CO), faba bean (Fb), lupin (Lu), and pea (Pe), grown at Barrhead and St. Albert, Alberta, Canada averaged across 2008 and 2009.

Statistical Analysis (Total N Yield):

	Barrhead	**St. Albert**
F-Test (df)	0.0221 (6)	0.0111 (6)
SE[a]	16.8	42.7
Contrasts		
Fb, Lu, Pe vs BN, BO, CN, CO	ns	ns
BN vs BO	ns	ns
CN vs CO	ns	ns
BN, BO vs CN, CO	0.0018	0.0015
Fb vs Pe	ns	ns
Lu vs Fb, Pe	ns	0.0151

Significance was determined at $p<0.05$, ns: not significant at a probability level of 0.05.

[a]Standard error of the difference between two least-square means.

*Bars represent the least significant difference (LSD) between treatments for each location

Literature Cited

Abd-Alla, M.H. and Abdel Wahab, A.M. 1995. Response of nitrogen fixation, nodule activities, and growth to potassium supply in water-stressed broad bean. Journal of Plant Nutrition. 18: 1391-1402.

ACIS (AgroClimatic Information Service) 2010. Alberta Agriculture and Rural Development. Alberta Government. [Online] Available: http://www.agric.gov.ab.ca/app116/stationview.jsp [8 November 2010].

Alberta Agriculture and Food. 2007. Using 1,000 kernal weight for calculating seeding rates and harvest losses. Government of Alberta. AGDEX 100/22-1. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex81 [31 March 2011].

Alberta Seed Industry Partnership. 2011. Alberta's Seed Guide Spring 2011. Issues Ink. Winnipeg, MB. [Online] Available: http://www.seed.ab.ca/news_and_events/news1.asp [30 March 2011].

Armstrong, E.L., Heenan, D.P., Pate, J.S. and Unkovich, M.J. 1997. Nitrogen benefits of lupins, field pea, and chickpea to wheat production of south-eastern Australia. Aust. J. Agric. Res. 48: 39-47.

Armstrong, E.L., Pate, J.S. and Unkovich, M.J. 1994. Nitrogen balance of field pea crops in south Western Australia, studied using the ^{15}N natural abundance technique. Aust. J. Plant Physiol. 21: 533-549.

Ayaz, S., McKenzie, B.A., Hill, G.D. and McNeil, D.L. 2004. Nitrogen distribution in four grain legumes. Journal of Agricultural Science. 142: 309-317.

Barthet, V.J. 2011. Quality of western Canadian canola – 2011. Grains Research Laboratory, Canadian Grain Commission, Winnipeg, MB. [Online] Available: http://www.grainscanada.gc.ca/canola/harvest-recolte/2010/hqc10-qrc10-eng.pdf [29 March 2011].

Beare, M.H., Wilson, P.E., Fraser, P.M. and Butler, R.C. 2002. Management effects on barley straw decomposition, nitrogen release, and crop production. Soil Sci. Am. J. 66: 848-856.

Beck, D. P., Wery, J., Saxena, M. C. and Ayadi, A. 1991. Dinitrogen fixation and nitrogen balance in cool-season food legumes. Agron. J. 83: 334-341.

Bowser, W.E., Kjearsgaard, A.A., Peters, T.W. and Wells, R.E. 1962. Soil survey of Edmonton Sheet (83-H). Bulletin No. SS-4 Report No. 21. Alberta Soil Survey. University of Alberta and Canadian Department of Agriculture.

Bremer, E. and van Kessel, C. 1992. Plant-available nitrogen from lentil and wheat residues during a subsequent growing season. Soil Sci. Am. J. 56: 1155-1160.

Bullock, D.G. 1992. Crop rotation. Critical Reveiws in Plant Sciences. 11: 309-326.

Carranca, C. de Varennes, A. and Rolston, D. 1999. Biological nitrogen fixation by fababean, pea and chickpea, under field conditions, estimated by the ^{15}N isotope dilution technique. European Journal of Agronomy. 10: 49-56.

Clayton, G.W., Rice, W.A., Lupwayi, N.Z., Johnston, A.M, Lafond, G.P., Grant, C.A. and Walley, F. 2004. Inoculant formulation and fertilizer nitrogen effects on field pea: Nodulation, N_2 fixation and nitrogen partitioning. Can. J. Plant Sci. 84: 79-88.

Cowling, W.A. and Tarr, A. 2004. Effect of genotype and environment on seed quality in sweet narrow-leafed lupin (*Lupinus angustifolius* L.). Australian Journal of Agricultural Research. 55: 745-751.

Curtin, D., Francis, G.S. and McCallum, F.M. 2008. Decomposition rate of cereal straw as affected by soil placement. Australian Journal of Soil Research. 46: 152-160.

Dracup, M., Turner, N.C., Tang, C., Reader, M. and Palta, J. 1998. Responses to abiotic stresses. Pages 227-262 *in* J.S. Gladstones, C. Atkins, and J. Hamblin, eds. Lupins as Crop Plants: Biology, Production, and Utilization. CAB International, New York, USA.

Duc, G. 1997. Faba bean (*Vicia faba* L.). Field Crops Research. 53: 99-109.

Fraser, M.D., Fychan, R. and Jones, R. 2005. Comparative yield and chemical composition of two varieties of narrow-leafed lupin (*Lupinus angustifolius*) when harvested as whole-crop, moist grain and dry grain. Animal Feed Science and Technology. 120: 43-50.

French, R.J. 2002. Soil factors influencing growth and yield of narrow-leafed lupin and field pea in Western Australia. Aust. J. Agric. Res. 53: 217-225.

French, R.J. and Buirchell, B.J. 2005. Lupin: the largest grain legume crop in Western Australia, its adaptation and improvement through plant breeding. Australian Journal of Agricultural Research. 56: 1169-1180.

Gan, Y.T., Campbell, C.A. Janzen, H.H., Lemke, R.L., Basnyat, P. and McDonald, C.L. 2010. Nitrogen accumulation in plant tissues and roots and N mineralization under oilseeds, pulses, and spring wheat. Plant Soil. 332: 451-461.

Grzesiak, S., Filek, W., Pienkowski, S. and Niziol, B. 1996. Screening for drought resistance: Evaluation of drought susceptibility index of legume plants under natural growth conditions. J. Agronomy and Crop Science. 177: 237-244.

Jensen, E. S. 1996. Nitrogen acquisition by pea and barley and the effect of their crop residues on available nitrogen for subsequent crops. Biol. Fertil. Soils. 23: 459-464.

Kurdali, F., Al-Ain, F. and Al-Shamma, M. 2002. Nodulation, dry matter production, and N_2 fixation by fababean and chickpea as affected by soil moisture and potassium fertilizer. Journal of Plant Nutrition. 25: 355-368.

Littell, R.C., Milliken, G.A., Stroup, W.W., Wilfinger, R.D. and Schabenberger, O. 2006. SAS® for mixed models. 2nd ed. SAS Institute Inc., Cary, NC, USA.

Lupwayi, N.Z., Clayton, G.W., O'Donovan, J.T., Harker, K.N., Turkington, T.K. and Rice, W.A. 2004. Decomposition of crop residues under conventional and zero tillage. Can. J. Soil Sci. 84: 403-410.

Lupwayi, N.Z., Clayton, G.W., O'Donovan, J.T., Harker, K.N., Turkington, T.K. and Soon, Y.K. 2006. Nitrogen release during decomposition of crop residues under conventional and zero tillage. Can. J. Soil Sci. 86: 11-19.

Lupwayi, N.Z. and Soon, Y.K. 2009. Nitrogen release from field pea residues and soil inorganic N in a pea-wheat rotation in northwestern Canada. Can. J. Plant Sci. 89: 239-246.

Maidl, F.X., Haunz, F.X., Panse, A. and Fischbeck, G. 1996. Transfer of grain legume nitrogen within a crop rotation containing winter wheat and winter barley. J. Agronomy and Crop Science. 176: 47-57

McLelland, M., Panchuk, K., Green, B., Campbell, D., Harvey, B., Rossnagel, B., Foster, J. and Kendall, N. 2009. Malting Barley. Government of Alberta. AGDEX 114/20-2. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex98 [29 March 2011].

McNeill, A.M. and Fillery, I.R.P. 2008. Field measurement of lupin belowground nitrogen accumulation and recovery in the subsequent cereal-soil system in a semi-arid Mediterranean-type climate. Plant Soil. 302: 297-316.

Palta, J.A., Turner, N.C., French, R.J. and Buirchell, B.J. 2007. Physiological responses of lupin genotypes to terminal drought in a Mediterranean-type environment. Annals of Applied Biology. 150: 269-279.

Park, B., Lopetinsky, K., Bjorklund, R., Buss, T., Eppich, S., Laflamme, P., Miller, N., Olson, M. and Piquette, K. 1999. Pulse crops in Alberta. B. Park and K. Lopetinsky, eds. Alberta Agriculture and Rural Development, Edmonton, Alberta. AGDEX 142/20-1

Peoples, M.B., Bowman, A.M., Gault, R.R., Herridge, D.F., McCallum, M.H., McCormick, K.M., Norton, R.M., Rochester, I.J., Scammell, G.J. and Schwenke, G.D. 2001. Factors regulating the contribution of fixed nitrogen by pasture legumes to different farming systems in eastern Australia. Plant and Soil. 228: 29-41.

Rennie, R.J. 1984. Comparison of N balance and ^{15}N isotope dilution to quantify N_2 fixation in field-grown legumes. Agronomy Journal. 76: 785-790.

Rochester, I.J., Peoples, M.B., Constable, G.A. and Gault, R.R. 1998. Faba beans and other legumes add nitrogen to irrigated cotton cropping systems. Australian Journal of Experimental Agriculture. 38: 253-260.

SAS Institute Inc. 2008. Version 9.2 SAS Institute Inc. Cary, NC, USA.

Schulz, S., Keatinge, J.D.H. and Wells, G.J. 1999. Productivity and residual effects of legumes in rice-based cropping systems in a warm-temperate environment I. Legume biomass production and N fixation. Field Crops Research. 61: 23-35.

Siddique, K.H.M., Regan, K.L., Tennant, D. and Thomson, B.D. 2001. Water use and water use efficiency of cool season grain legumes in low rainfall Mediterranean-type environments. European Journal of Agronomy. 15: 267-280.

Smith, C.J., Chalk, P.M., Hamilton, S.D. and Hopmans, P. 1992. Estimating N_2 fixation by field-grown lupins (*Lupinus angustifolius* L.) using soil and plant ^{15}N enrichment. Biol. Fertil. Soils. 13: 235-241.

Soon, Y.K. and Arshad, M.A. 2002. Comparison of the decomposition and N and P mineralization of canola, pea and wheat residues. Biol. Fertil. Soils. 36: 10-17.

Soon, Y. K. and Arshad M. A. 2004. Tillage, crop residue, and crop sequence effects on nitrogen availability in a legume-based cropping system. Can. J. Soil Sci. 84: 421-430

Soon, Y.K. and Clayton, G.W. 2002. Eight years of crop rotation and tillage effects on crop production and N fertilizer use. Can. J. Soil Sci. 82: 165-172.

Soon. Y.K., Harker, K.N. and Clayton, G.W. 2004. Plant competition effects on the nitrogen economy of field pea and the subsequent crop. Soil Sci. Soc. Am. J. 68: 552-557.

Sparrow, S.D., Cochran, V.L. and Sparrow, E.B. 1995. Dinitrogen fixation by seven legume crops in Alaska. Agron. J. 87: 34-41.

Steel, R.G.D., Torrie, J.H. and Dickey, D.A. 1997. Principles and procedures of statistics: A biometrical approach. 3rd Ed. McGraw-Hill, New York.

Stevenson, F.C. and van Kessel, C. 1996. The nitrogen and non-nitrogen rotational benefits of pea to succeeding crops. Can. J. Plant Sci. 76: 735-735.

Strydhorst, S.M. 2008. Faba bean and lupin: New grain legume crops to improve agricultural sustainability. PhD Thesis, Department of Agriculture, Food and Nutritional Science, University of Alberta, Edmonton, Alberta.

Strydhorst, S.M., King, J.R., Lopetinsky, K.J. and Harker, K.N. 2008. Weed interference, pulse species, and plant density effects on rotational benefits. Weed Science. 56: 249-258.

Su, C. 2010. Alberta 2009 crop year in review. Alberta Agriculture and Rural Development, Economics and Competitiveness Division, Statistics and Data Development Branch, Government of Alberta, Edmonton, Alberta.[Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd13100 [8 February 2011].

Tang, C. and Robson, A.D. 1995. Nodulation failure is important in the poor growth of two lupin species on an alkaline soil. Australian Journal of Experimental Agriculture. 35: 87-91.

Tang, C. and Thomson, B.D. 1996. Effects of solution pH and bicarbonate on the growth and nodulation of a range of grain legume species. Plant and Soil. 186: 321-330.

Thomson, B.D., Siddique, K.H.M., Barr, M.D. and Wilson, J.M. 1997. Grain legume species in low rainfall Mediterranean-type environments I. Phenology and seed yield. Field Crops Research. 54: 173-187.

Unkovich, M. J., Pate, J. S., Armstrong, E. L. and Sanford, P. 1995. Nitrogen economy of annual crop and pasture legumes in southwest Australia. Soil Biol. Biochem. 27: 585-588.

Walley, F. L., Clayton, G. W., Miller, P. R., Carr, P. M. and Lafond, G. P. 2007. Nitrogen economy of pulse crop production in the northern Great Plains. Agron. J. 99: 1710-1718.

Wang, N. and Daun, J.K. 2004. Effect of variety and crude protein content on nutrients and certain antinutrients in field peas (*Pisum sativum*). Journal of the Science of Food and Agriculture. 84: 1021-1029.

Zaychuk, K. 2006. Nodulation and nitrogen fixation field guide for the assessment of pulse crops. [Online] Available: http://pulse.ab.ca/LinkClick.aspx?fileticket=L2ECTm3zf14=&tabid=125 [30 March 2011].

Zhang, G., Chen, J., Wang, J. and Ding, S. 2001. Cultivar and environmental effects on (1→3, 1→4)-β-D-Glucan and protein content in malting barley. Journal of Cereal Science. 34: 295-301.

Chapter 3: The rotational response of barley, canola and wheat to cool season pulses in north central Alberta

Null Hypotheses

The yield and quality of barley (*Hordeum vulgare* L.) produced on YR1 treatments (barley +N, barley no N, canola +N, canola no N, faba bean, lupin and pea) will not differ between treatments.

The yield and quality of canola (*Brassica napus* L.) produced on YR1 treatments (barley +N, barley no N, canola +N, canola no N, faba bean, lupin and pea) will not differ between treatments.

The yield and quality of wheat (*Triticum aestivum* L.) produced on YR1 treatments (barley +N, barley no N, canola +N, canola no N, faba bean, lupin and pea) will not differ between treatments.

Introduction

Crop sequencing has an effect on yield and quality of crops (Cutforth et al. 2007). Previous research has focused on investigating the rotational benefits that lead to improved yields and quality of well rotated crops. Many of the rotational benefits can be attributed to improved soil fertility, increased nutrient availability, better water use efficiency and reduced disease and weed problems (Miller and Holmes 2005). Since decisions about cropping sequence are not only made based on plant relationships but in large are driven by marketability and profitability (Johnston et al. 2005) a solid understanding of rotational benefits is essential to encouraging producers to adopt such management practices within the context of unstable crop markets. Reports indicate that crop diversity can help to manage risks associated with crop markets and environmental conditions (Miller and Holmes 2005).

In Alberta, barley, wheat, canola and tame hay dominate the production area (Su, 2010) resulting in high use of inputs (fertilizer, pesticides, etc.) and limiting access to many of the benefits of diverse crop rotations. Previous studies have indicated that pulse crops can provide both N and non-N benefits to subsequent crops which result in higher yields and improved crop quality (Wright 1990a, b). Nitrogen benefits have included improved N uptake (Soon and Arshad 2004, Maidl et al. 1996), increased seed protein (Wright 1990a) and increased soil N (Wright 1990a). Non-nitrogen benefits from pulses include: reduced disease (Stevenson and van Kessel 1996a, Lafond et al. 2006), decreased weed and pest problems (Stevenson and van Kessel 1996a, b), improved water use efficiency (Miller and Holmes 2005, Lafond et al. 2006), increased available soil moisture (Biederbeck et al. 1995), improved soil properties (Gan et al. 2003, Stevenson and van Kessel 1996b), increased nutrient availability (Stevenson and van Kessel 1996b) and a reduced carbon footprint (Gan et al. 2011). Studies have reported a range of yield responses in subsequent crops following pulses (Miller et al. 2002a). Yield responses have ranged from –12% to +58% for cereals grown on pulses in comparison to continuous cereal (Wright 1990a, Stevenson and van Kessel 1996a, Miller and Holmes 2005). Average yield of barley increased by 21% when grown on pulse stubble in comparison to barley stubble (Wright 1990a). Durum wheat had 10 and 15% higher yields when produced on mustard/canola and pulse stubble in comparison to wheat stubble (Gan et al. 2003). Miller et al. (2003) reported that canola yield increased by 29% when grown on pea or lentil stubble and decreased by 32% when grown on mustard stubble compared to a wheat stubble control. Different pulses can have different effects on wheat yields. Faba bean and pea stubble increased wheat yields in Alberta more than lupin stubble did (Strydhorst et al. 2008). In contrast, wheat grown on lupin stubble in Australia had higher grain yields than on pea or barley stubble (Armstrong et al. 1997). Faba bean and pea stubble also increased wheat seed protein (average 122 mg g^{-1}) to a higher level than did lupin stubble (average 118 mg g^{-1}) (Strydhorst et al. 2008). Studies report that protein content of barley was increased when grown on pulse residue (Wright 1990a). Wheat seed protein increased by 2 – 5.8% when grown on legume stubble instead of wheat stubble (Evans et al. 2003).

Depending on the crop and the intended use, certain quality characteristics become more important. Malt quality barley has a specific requirement for low protein. Environmental conditions and the influence of previous crops can determine if malt quality is reached by a crop (Zhang et al. 2001). In canola there are inverse relationships between protein and oil content (Karamzadeh et al. 2010) while desired wheat protein content is impacted by its intended use. These complex relationships between production and end use of crops impact the evaluation of quality parameters. Knowing the effects previous crops have on subsequent crops allows producers to optimize rotational benefits by designing crop sequencing to favour better yield and quality in the crop. Environmental conditions also have an impact on crop yield and quality and may change the interaction between crops in rotation. Johnston et al. (2005) indicated that drought conditions can reduce the benefit of pulse crops to the subsequent crop. An understanding of the relationships between crop rotation, environmental conditions, crop yield and crop quality can reduced producer risk and improve profitability.

A limited number of studies in Alberta have investigated the effects of pulses in rotation and most have only examined the effect of pulses on one subsequent crop. It is known that crops differ in their ability to access soil nutrients as well as their need for specific nutrients. The objective of this study was to examine the effects of faba bean, lupin and pea on multiple subsequent crops (barley, canola and wheat) and identify if the benefits of pulses to subsequent crops are universal or vary between different subsequent crops.

Materials and Methods

Experiment Design and Location

This study reports results from the second year of a two year crop rotation study where crops produced in the first year (YR1) of rotation are the treatments applied to the second year crops (YR2). The seven YR1 treatments were: 'Metcalf' barley (*Hordeum vulgare* L.) –with and without N fertilizer, '71-45 RR' canola (*Brassica napus* L.) – with and without N fertilizer, 'Snowbird' tannin-free faba bean (*Vicia faba* L.), 'Arabella' narrow-leafed lupin (*Lupinus angustifolius* L.), and 'Canstar' field pea (*Pisum sativum* L.). These treatments were followed by three different subsequent crops – 'Metcalf' barley (*Hordeum vulgare* L.), '71-45 RR' canola (*Brassica napus* L.), and 'Infinity' wheat (*Triticum aestivum* L.), in YR2. YR1 treatments were produced in 2008 and 2009, followed by YR2 production in 2009 and 2010.

The plots were produced in a randomized complete block design (Figure 3-1) with four replicated blocks at two locations – Barrhead and St. Albert in Alberta, Canada. Plots were 6.1 m by 3.1 m with 2.1 m alleys between all plots (Figure 3-2). The four blocks were separated by 12.2 m alleys. All alleys were seeded to barley which was mowed throughout the growing season.

The Barrhead site has an orthic humic gleysol soil (Browser et al. 1962) with a pH of 4.8 – 5.6 and organic matter content of 2.7% (0 – 15cm depth) (Figure 3-3). The St. Albert site has a Malmo eluviated black chenozemic soil (Strydhorst 2008) with a pH of 7.1 – 7.8 and an organic matter content of 11.6% (0 – 15 cm depth) (Figure 3-3). The differences in soil properties represent some of the variation seen in environmental conditions in agricultural systems in north-central Alberta. Growing season precipitation and average temperature data was collected from nearby weather stations (Figure 3-3)

Plot Management

In all years of the study plots received P, K, and S fertilizer as recommended by soil tests (Table 3-1, Appendix A). Nitrogen fertilizer was added in both years of rotation (YR1 and YR2), to 'barley +N' and canola +N' treatments in YR1 and to those same plots in YR2 (Figure 3-2, Table 3-1). The +N treatments received 100 kg N ha^{-1} in YR 1 and in YR2 fertilizer rates were based on soil N levels and soil test recommendations. Fertilizer was applied prior to seeding with a pre-seeding pass over the plots with the hoe-drill seeder.

Seeding rates were adjusted for each crop to account for seed size, % germination and target plant density. YR2 crops were seeded into YR1 stubble with a 3.05m wide John Deer hoe drill (9450 John Deer Hoe Drill, Deere & Company, Moline, IL) with 17.5 cm row spacing at recommended seeding rates and depths (Table 3-2). In 2009, YR2 crops were seeded on May 7 at Barrhead and on May 8 at St. Albert. In 2010, YR2 crops were seeded on May 14 at Barrhead and May 17 at St. Albert. Emergence was assessed when crop rows became visible; the number of plants in two rows by 1m was counted at one representative location within each plot (Figure 3-1). Weeds observed in the plots at St. Albert included wild oat (*Avena fatua*), volunteer barley (*Hordeum vulgare*), volunteer canola (*Brassica napus*), wild buckwheat (*Polygonum convolvulus*), lamb's quarter (*Chenopodium album*), hemp-nettle (*Galeopsis tetrahit*), sow thistle (*Sonchus asper*), dandelion (*Taraxacum officinale*), and stinkweed (*Thlaspi arvense*). At Barrhead weeds included volunteer canola, dandelion, stinkweed, chickweed (*Stellaria media*), and Canada thistle (*Cirsium arvense*). Herbicides were chosen based on crop and weeds present and applied according to recommended rates at the appropriate crop stages (Tables 3-3 & 3-4). Subsequent flushes of weeds were controlled with hand weeding throughout the growing season. Crop growth was monitored throughout the growing season and pest problems were addressed as needed. Insecticide (Decis) was applied on June 17, 2009 for cutworms and thrips at St. Albert (Table 3-4). Grasshopper bait was applied to the alleyways at Barrhead in 2009 to prevent crop damage (Table 3-4). No insecticides were applied in 2010.

Subsamples (2 rows x 1 m) of above ground biomass were collected from each plot just prior to desiccation (Figure 3-1). Crops were desiccated at physiological maturity. Reglone was used to desiccate canola at both locations in both years, and barley and wheat at St. Albert in 2010 due to a volunteer canola weed problem that developed on the YR1 canola plots. Roundup Transorb HC was used to desiccate barley and wheat at Barrhead in both years, and at St. Albert in 2009 (Table 3-4). Following dry down (1-2 weeks with Reglone and 2-3 weeks with Roundup Transorb HC), two combine seed samples were taken from each plot for at total harvested area of 9.1 m^2 (Figure 3-3), using a Wintersteiger plot combine (Elite Wintersteiger Plot Combine, Ried, Austria). Crops were harvested between August and October (Table 3-5).

Sample Analysis

Subsamples of above ground biomass were dried at 40^{o}C and then separated into plant components. Barley and wheat samples were divided into straw, chaff and seed components and canola was divided into straw/pod and seed. Each sample was weighed to determine total above ground biomass for each crop. Barley component samples and wheat seed samples were ground using a Wiley mill (to 1mm). Canola seed underwent a solvent oil extraction where ~6 g of seed was mixed with 20mL of n-pentane and ground for approximately one minute using a Polytron homogenizer (Model PT1035, Brinkmann Instruments, Rexdale, Ont., Canada). The ground canola-pentane mixture was filtered through #1 Whatman filter paper and the canola meal was collected and dried over night at room temperature. All ground seed samples were analyzed for N content using a Leco N analyzer (LECO CN-2000, LECO Corporation, St. Joseph, MI).

Statistical Analysis

Data was analyzed using SAS 9.2 (SAS Institute 2008). Each data set was tested for normality using PROC UNIVARIATE (SAS Institute 2008). Most data sets had normally distributed data and no transformations were used to improve normality.

Sites were analyzed separately because of the environmental differences between Barrhead and St. Albert (ie. moisture and soil type). An ANOVA analysis was performed using PROC MIXED (Littell et al. 2006) with YR1 treatment as a fixed effect and year and block as random effects. A set of orthogonal contrasts were used to make apriori comparisons of the responses of barley, canola and wheat crops to YR1 treatments. Significance was determined at $p \leq 0.05$.

Results and Discussion

Climatic Conditions

Moisture conditions in 2009 were limited at both sites; Barrhead received 48% of normal moisture and St. Albert received 56% of normal moisture (Figure 3-3). In 2010 moisture conditions were improved at both sites; Barrhead was 85% of normal and St. Albert 100% of normal. Temperatures at Barrhead were slightly above normal for the area and St. Albert was slightly below normal for the area in both years of study (Figure 3-3).

Yield

Barley

Year 2 barley yields were different between the two sites, with St. Albert yields being higher than barley yields at Barrhead (Figure 3-4). Generally '+N' treatments (barley and canola stubble) had higher YR2 barley yields than did 'no N' treatments (Figure 3-4). There was no significant difference in YR2 barley yields when produced on faba bean (3.0, 5.1 Mg ha^{-1}) or pea (3.0, 5.0 Mg ha^{-1}) stubble but yields were lower on lupin (2.3, 4.2 Mg ha^{-1}) stubble at Barrhead and St. Albert ($p<0.05$). A previous study in this area recorded similar results with subsequent wheat yields being similar on faba bean and pea stubble but generally lower on lupin stubble (Strydhorst et al. 2008). Wright (1990b) reported barley yields on faba bean stubble (3.4 Mg ha^{-1}), pea stubble (3.4 Mg ha^{-1}) and barley stubble (2.8 Mg ha^{-1}). Numerically, barley yields on '+N' treatments were close to faba bean and pea stubble treatments, indicating that pulse stubble provided a rotational benefit that maintained yields similar to N fertilization. Soon et al. (2004) reported that barley grain yield following pea was greater than following barley regardless of the N fertilizer treatment. In this study pulse stubble was similar to the '+N' treatments but numerically greater than the 'no N' treatments. Yield of YR 2 barley on lupin stubble was lower than on the '+N', faba bean and pea treatments, but slightly greater than on the 'no N' treatments. Lupin stubble may not provide as much rotational benefit as pea or faba bean stubble at these test sites. Evans et al. (2003) reported that yields of a subsequent wheat crop and soil N were strongly related. In YR1 there were no significant differences between treatments in the amount of N returned to the plots with aboveground crop residues (Table 3-6). N fixation by the pulse crops was only significantly different at St. Albert (Table 3-6) indicating that this yield reduction on lupin stubble in comparison to faba bean and pea is a more complicated relationship likely involving the rate of soil nitrogen release and other environmental factors. Previous studies have reported that crops differ in their water use efficiency (Lafond et al. 2006), decomposition rate (Soon and Arshad 2002) and N release (Strydhorst 2008); any of these factors could impact the yield of a subsequent crop.

Canola

Year 2 canola also had higher yields in St. Albert than Barrhead but in rotations where canola was continuously cropped site differences were reduced (Figure 3-5). At St. Albert in 2010 a flush of volunteer canola reduced the yield of the plots with continuous canola. There were no significant differences in YR2 canola yields between the seven YR1 treatments at Barrhead (Figure 3-5). The lower yields at this site can be attributed to soil properties and lower moisture conditions. At St. Albert, canola yields on legume stubble was significantly different than on non-legume stubble ($p<0.01$). Numerically St. Albert canola yields were similar on pulse stubble (3.5, 3.0, and 3.2 Mg ha^{-1} for faba bean, lupin and pea, respectively) to barley stubble (3.6 and 2.9 Mg ha^{-1} for '+N' and 'no N', respectively) but greater than canola stubble (2.4 and 2.0 Mg ha^{-1} for '+N' and 'no N', respectively). The 10-year average yield for canola grown in Alberta is 1.7 Mg ha^{-1} (Su 2010), canola yields in this study are generally greater than the 10 year average. Canola yields on '+N' treatments at St. Albert were greater than 'no N' treatments but the difference was only significant on barley stubble ($p<0.05$). Faba bean, lupin and pea stubble all produced similar canola yields.

Wheat

Wheat yields at Barrhead and St. Albert followed similar trends as barley and canola. Generally, '+N' treatments were significantly greater than 'no N' treatments with the exception of barley at Barrhead. The highest wheat yields were achieved on barley +N stubble followed by faba bean and pea stubble at both locations (Figure 3-6). Studies in western Canada have reported higher wheat yields (>20%) when wheat is grown on pulse stubble in comparison to wheat stubble when N fertilizer was added in to each wheat crop in rotation (Soon and Clayton 2002, Lafond et al. 2006). In Australia, wheat yields were lower following barley than lupin or pea when no N fertilizer was added to any of the treatments (Armstrong et al. 1997). The data from this study reports a similar trend where wheat grown on barley no N treatments had lower yields than that on faba bean or pea at both locations and lupin at St. Albert. The increase in wheat yields produced on pulse stubble has been attributed to increased soil N availability (Evans et al. 2003, Strydhorst et al. 2008), improved water use efficiency (Lafond et al. 2006), or decreased disease occurrence (Evans et al. 2003, Stevenson and van Kessel 1996b). In contrast, Johnston et al. (2005) reported that wheat yields under moisture limiting conditions could be reduced when grown on pulse stubble because of the low residue cover and dark colour of the stubble. The low moisture conditions of 2009 may have reduced some of the benefit pulses can provide to subsequent crops in more optimal conditions. St. Albert received more moisture in both years of study and subsequently had higher yielding crops than Barrhead. Strydhorst et al. (2008) reported wheat yields in this area of 4.5 Mg ha^{-1} when grown on faba bean stubble, 4.1 Mg ha^{-1} on lupin stubble and 4.6 Mg ha^{-1} on pea stubble. In this study wheat yields at Barrhead were lower than those reported by Strydhorst et al. (2008), 2.9 Mg ha^{-1} on faba bean stubble, 2.1 Mg ha^{-1} on lupin stubble, and 2.8 Mg ha^{-1} on pea stubble. Yields at St. Albert were more similar to reported values, 4.7, 4.3, and 4.6 Mg ha^{-1} for faba bean, lupin and pea stubble, respectively. Wheat yield following canola was generally lower than wheat following faba bean, lupin or pea (Figure 3-6).This result is similar to that reported by Soon and Clayton (2002) where wheat yields following canola were less than those following legumes but greater than yields following wheat. Canola is known to be a non-mycorrhizal crop whereas wheat associates with mycorrhizal fungi to increase nutrient acquisition (Gosling et al 2006, Ryan and Graham 2002). The lower wheat yields following canola could indicate a reduction in mycorrhizal associations due to a reduced mycorrhizae population cause by the preceding canola crop.

Harvest Index

Harvest index (HI) of subsequent barley, canola and wheat crops ranged from 0.46 to 0.59 for barley, 0.31 to 0.45 for canola and 0.42 to 0.51 for wheat across both locations (Table 3-7). Canola HI produced on legume and non-legume treatments at both sites were significantly different ($p<0.05$). At St. Albert canola grown on pulse stubble had a HI that was numerically higher than when grown on canola stubble but the same as when grown on barley stubble. At Barrhead canola grown on faba bean and pea stubble had a greater HI than all non legume stubble treatments. For wheat, barley no N treatment (0.51) had significantly higher HI than the barley + N treatment (0.44) ($p<0.05$). Wheat grown on canola stubble had a similar response to N fertilizer, with HI on canola no N stubble being 0.48 and canola +N stubble, 0.42 ($p<0.05$). At St. Albert wheat HI did not differ between treatments ($p>0.05$). The HI of barley did not significantly differ between treatments at either site ($p>0.05$) (Table 3-7). Zentner et al. (2003) reported that HI of wheat was more affected by environmental conditions (higher in dry years, lower in wet years) than it was by cropping frequency. They report HI for wheat of different classes ranging from 0.32 to 0.50 (Zentner et al. 2003).

Seed Quality

Barley

Thousand seed weight of barley produced on YR1 stubble only had significant treatment effects at Barrhead but trends between stubble types were generally consistent across sites (Table 3-8). Barley seed produced on barley stubble (with and without N) had a greater thousand seed weight (TSW) than barley seed produced on canola stubble (with and without N) ($p<0.05$ at Barrhead, not significant at St. Albert) (Table 3-8). The ‘no N’ treatments had higher TSW than the ‘+N’ treatments but the difference was only significant for barley (45.5 and 43.1 g for barley no N and barley +N) at Barrhead ($p<0.05$). Alberta Agriculture and Rural Development (2008) reported TSW for 'Metcalf' barley at 46 g. Values reported in this study were slightly lower than the agronomic trait average. Despite the less than optimal environmental conditions at Barrhead TSW was numerically higher than that at St. Albert where growing conditions were more favourable. It is commonly understood that seed weight is a relatively stable yield component whereas tillering is one way barley adjusts to environmental variability (Wych et al. 1985). At St. Albert, under better growing conditions it is likely that more tillering occurred which increased yields (Figure 3-4). The reduced seed weight and increased yield indicates an inverse relationship between these two yield components in this study. This is in agreement with the low or even negative correlations between TSW and yield reported by Evans et al. (1993) but in opposition to the positive correlation reported between these two parameters (Abera 2009). Thousand seed weight is dependent on many parameters including duration of grain fill, environmental conditions and plants photosynthetic ability (Petr et al. 1988, Evans et al. 1993). Better growing conditions increases tillering in barley. With more tillers, seed maturity becomes uneven as a result of differences in grain growth rate and duration. The lower seed weights at St. Albert could partially be due to uneven maturity of tillers resulting in smaller seed weights of less mature seeds. Studies that report a positive correlation between yield and TSW likely had conditions where tillers could fully mature before harvest. Overall barley TSW is affected by crop maturity and growing conditions but can be maintained on pulse stubble with no N fertilizer with similar yields to barley and canola stubble with the addition of N fertilizer.

Similar to TSW, seed protein content of Barley was higher at Barrhead than St. Albert. This increase in seed protein may be partially attributed to the moisture limiting conditions at Barrhead throughout the study. Seed protein can be affected by nutrient availability, disease and pest pressures and moisture conditions (Strydhorst et al. 2008, Doyle et al. 1988, Miller et al. 2006, Wright 1990a). Nitrogen fertilizer increased seed protein content. The '+N' treatments on barley stubble had significantly higher barley seed protein content (158 and 142 mg g^{-1}) at Barrhead and St. Albert than the 'no N' barley stubble treatments (140 and 123 mg g^{-1}) ($p<0.05$ and $p<0.01$) (Table 3-8). On canola stubble, barley seed protein was higher on '+N' treatments than 'no N' but the difference was only significant at Barrhead (163 and 140 mg g^{-1}, $p<0.01$). These results are higher than those previously reported by Johnston et al. (2005) in Saskatchewan, of barley grain protein ranging from 123 – 136 mg g^{-1} on barley stubble, 117 – 133 mg g^{-1} on canola stubble and 123 – 139 mg g^{-1} on pea stubble. Barley seed protein did not differ between pulse stubbles at either site. Seed protein ranged from 141 to 145 mg g^{-1} at Barrhead and 127 to 128 mg g^{-1} at St. Albert when grown on pulse stubble. Overall barley seed protein generally responded to Yr 1 treatments following the trend of '+N' > pulse > 'no N'. Wright (1990a) reported barley seed protein (99 – 148 mg g^{-1}) and indicated that protein was higher in dry years and following pulse crops. A slightly higher range of seed protein was measured in this study (114 – 163 mg g^{-1}) (Table 3-8). For two-row malting quality barley, the desired range for seed protein is 105 – 125 mg g^{-1} (McLelland et al. 2009). Only three treatments at St. Albert produced a barley crop within this acceptable range, barley no N, canola +N and canola no N. Results from this and previous studies (Wright 1990a, Johnston et al. 2005) indicate that barley seed protein may be increased when grown on pulse stubble in comparison to barley or canola stubble. Other environmental factors such as moisture availability can have a confounding affect on seed quality parameters.

Canola

Canola thousand seed weight ranged from 3.8 to 4.1 g at Barrhead and 3.3 to 3.6 g at St. Albert (Table 3-9). Similar to barley, canola yields were higher at St. Albert

(Figure 3-5) with an inverse relationship between yield and TSW. Karamzadeh et al. (2010) reported increased yields accompanied by increased TSW. Seed weight can be influenced by many factors and it is likely in this study that reduced seed maturity due to increased branching and later maturing second flushes of canola may have lowered seed weight at St. Albert. The previous crop had no significant affect on the TSW of canola seed.

Canola seed protein responded to the previous YR1 treatment. Barley +N treatments (383 and 334 mg g^{-1}) at Barrhead and St. Albert were greater than barley no N treatments (334 and 322 mg g^{-1}) but the difference was only significant at Barrhead ($p<0.01$) (Table 3-9). On canola stubble YR2 canola seed protein was significantly higher at Barrhead and St. Albert on the '+N' treatments (395 and 356 mg g^{-1}) in comparison to the 'no N' treatments (326 and 316 mg g^{-1}) ($p<0.01$). Canola seed protein response was similar following the three pulses, ranging from 342 to 356 mg g^{-1} at Barrhead and 326 to 328 mg g^{-1} at St. Albert (Table 3-9). Numerically, YR2 canola seed protein responded to the YR1 treatments in the following order: canola + N > barley +N > pulse crops > barley no N > canola no N. Soon and Arshad (2004) indicated previous crop and N fertilizer did not affect grain protein except in one case where N on canola stubble increased grain protein. In the current study, there is a response trend indicating that canola does respond to N fertilizer and previous crop. In Australia, canola seed protein following legume crops was significantly greater than seed protein following unfertilized wheat (Evans et al. 2006). Over the two years of that study canola seed protein ranged from 217 to 268 mg g^{-1} on pea stubble, 203 to 254 mg g^{-1} on lupin stubble and 181 to 220 mg g^{-1} on wheat stubble (Evans et al. 2006). In Saskatchewan, canola seed protein was reported following pea (185 – 252 mg g^{-1}), mustard (178 – 274 mg g^{-1}) and wheat (166 – 269 mg g^{-1}) (Miller et al. 2003). Previous studies report lower values for canola seed protein than those of the present study which may be due to different growing conditions (moisture conditions, soil

N, etc) and methodologies for measuring seed protein. Overall canola seed protein was higher at Barrhead in comparison to St. Albert. This site difference can be partially explained by the difference in precipitation between the two sites. Evans et al. (2006) reported a similar trend where mean canola seed protein was 269 mg g^{-1} in the drier year of their study and 219 mg g^{-1} in the wetter year.

Wheat

The TSW of wheat grown at Barrhead was 30.6 – 32.5 g and at St. Albert 31.3 – 33.6 g (Table 3-10). There were no significant differences between treatments at each site ($p>0.05$) and numerically the range of weights for both sites overlap indicating a lack of site response that occurred in both barley and canola. This may be a yield stabilizing result of wheat breeding (such as reduced tillering in comparison to barley) that hasn't occurred in other crops. Average thousand seed weight for 'Infinity' wheat grown in Alberta is 33 g (Alberta Seed Industry Partnership 2011).

Previous studies report variable responses of wheat seed protein to previous crop effects (Carr et al. 2008, Strydhorst et al. 2008, Miller et al. 2003, Soon and Arshad 2004). Doyle et al. (1988) indicated that seed protein responded to seasonal rainfall as well as soil N fertility. In the present study wheat seed protein was higher at the Barrhead site in comparison to St. Albert. The lower moisture conditions at Barrhead are likely a reason for the higher protein content at that site. Miller et al. (2006) reported wheat seed protein responding to the environmental conditions as well as previous crop. At a site with moisture limiting conditions wheat seed protein was 139, 159 and 169 mg g^{-1} on wheat, mustard and pea stubble, respectively. At the site where N was limiting wheat seed protein was lowest (132, 128, and 129 mg g^{-1}) and at the site with adequate moisture and adequate N wheat seed protein was highest (181, 177, and 180 mg g^{-1}) on wheat, mustard and pea stubble, respectively (Miller et al. 2006). In the present study wheat seed protein was increased by the addition of N fertilizer (Table 3-10). Barley '+N' treatments

(184 and 154 mg g^{-1}) at Barrhead and St. Albert had significantly higher seed protein than 'no N' treatments (150 and 135 mg g^{-1}) ($p<0.05$). Canola fertilizer treatments followed a similar trend but '+N' treatments were only significantly higher than 'no N' at Barrhead. Soon and Arshad (2004) report no significant effect of preceding crop or N fertilizer on subsequent wheat seed protein. In the two years of their study (1998 and 1999) wheat seed protein values were similar to the present study; 161 and 146 mg g^{-1} on canola stubble with N fertilizer, 145 and 141 mg g^{-1} on canola stubble without N fertilizer, and158 and 136 mg g^{-1} on pea stubble (Soon and Arshad 2004). Wheat grown on the stubble of any of the three pulses had numerically higher seed protein than did the 'no N' treatments of barley or canola. Many previous studies have reported an increase in seed protein when wheat is grown on pulse stubble (Miller et al. 2003, Strydhorst et al. 2008, Evans et al. 2003) Strydhorst et al. (2008) reported a wheat seed protein of 122 mg g^{-1} on faba bean or pea stubble and 118 mg g^{-1} on lupin stubble, these values were lower in the current study. Previous studies have determined a critical level of wheat seed protein (132 mg g^{-1}) that can indicate if sufficient levels of N were present during growth (Engel et al. 1999). All wheat seed protein levels in this study, except wheat grown on canola no N at St Albert (128 mg g^{-1}), were above the critical limit of 132 mg g^{-1}, indicating that N was not the limiting factor for the growth of wheat in any of the treatments.

Nitrogen Uptake

Barley

Total N uptake by the YR2 barley crop provides an estimate of the amount of available N that the barley crop could access throughout the growing season. Barley N uptake ranged from 61 to 98 kg N ha^{-1} at Barrhead and 73.7 to 172.8 kg N ha^{-1} at St. Albert. Higher yields due to increased moisture at St. Albert contributed to these site differences. Initial ANOVA analysis indicates there were no significant treatment effects at Barrhead. Lower yield potential due to environmental conditions seemed to reduce the treatment effects at this site. However, trends in treatment response at Barrhead are similar to the response differences in St. Albert. YR1 barley +N treatment had the highest YR2 barley N uptake and YR1 canola no N treatment had the lowest YR2 barley N uptake at both sites (Table 3-11). With the addition of N fertilizer it is expected that more N would be available for crop uptake throughout the growing season. At St. Albert total N uptake of barley grown on pulse stubble was significantly different than N uptake on non legume stubble ($p<0.05$). Generally, barley N uptake on pulse treatments was less than '+N' treatments but greater than 'no N' treatments (Table 3-11). Barley grown on faba bean (91.2, 143.2 kg ha^{-1}) or pea (96.6, 143.8 kg ha^{-1}) stubble had numerically lower N uptake than on barley +N (98.0, 172.8 kg ha^{-1}) stubble at Barrhead and St. Albert. This indicates that on pulse stubble N availability for YR2 barley growth was slightly lower than with the addition of N fertilizer on barley stubble. Faba bean and pea stubble produced numerically higher total barley N yields in YR2 than canola +N stubble at St. Albert. At Barrhead barley N yields on canola stubble were numerically equal to pea and slightly greater than faba bean stubble. Faba bean and pea stubble seems to provide a benefit toYR2 total barley N yield. Barley grown on lupin stubble was consistently lower than '+N' treatments. Considering that pulse stubble received no N fertilizer either year of the rotation a comparison to 'no N' treatments for N uptake is useful. Barley grown on faba bean (92.1, 143.2 kg ha^{-1}) and pea (96.6, 143.8 kg ha^{-1}) stubble consistently had higher total N uptake than canola no N (61.2, 73.7 kg ha^{-1}) and barley no N (78.6, 95.1 kg ha^{-1}). At St. Albert lupin (124.4 kg ha^{-1}) stubble had higher barley N uptake than barley (95.1 kg ha^{-1}) and canola (73.7 kg ha^{-1}) no N treatments. At Barrhead total barley N uptake on lupin stubble (69.6 kg ha^{-1}) was lower than on barley no N (78.6 kg ha^{-1}) stubble but higher than canola no N (61.2 kg ha^{-1}). With no addition of N fertilizer average barley N uptake increased when grown following pulse crops by 16.2 kg ha^{-1} at Barrhead, and 52.7 kg ha^{-1} at St. Albert, over the average of the 'no N' treatments. Pulse crops have the potential to provide more N for uptake by a subsequent crop than non legume crops. Soon et al. (2004) reported barley total N uptake on barley (48.2 – 81.5 kg ha^{-1}), canola (52.1 – 81.2 kg ha^{-1}), and pea (58.8 – 109.4 kg ha^{-1}) with N fertilizer and barley (29.4 – 42.7 kg ha^{-1}), canola (30.4 – 47.8 kg ha^{-1}) and pea (41.1 – 72.5 kg ha^{-1}) stubble without N fertilizer.

Each plant component (chaff, straw, and seed) of barley followed a similar pattern in response to previous crop. Barley seed N yield (calculated from grain protein and grain yield) in Saskatchewan ranged from 34 to 48 kg ha^{-1} on barley stubble, 43 to 67 kg ha^{-1} on canola stubble and 12 to 73 kg ha^{-1} on pea stubble (Johnston et al. 2005). Seed N yield is a parameter which integrates yield and nitrogen content and provides a combined view of N availability for grain production (Miller et al. 2002b).

Distribution of total N into plant components provides additional insight into the subsequent crops response to rotational benefits and environmental conditions. Generally, most of the total N in the plant is in the seed at maturity. For YR2 barley 56 to 70% of the total above ground biomass N was in the harvested seed at maturity (Figure 3-7). At St. Albert, N distribution between plant parts ranged from 67.4 to 70.4% of the total N in the seed, 5.6 to 7.9% in the chaff, and 21.6 to 27.0% in the straw. N distribution at Barrhead numerically varied more by YR1 treatment with 55.7 to 69.2 % of total N was in the seed, 9.0 to 12.8% in the chaff, and 21.3 to 31.6% in the straw (Figure 3-7). Different environmental conditions between the two sites and an understanding of N dynamics clarify these results. At St. Albert, soil N was relatively high and soil moisture was not limiting. Under these conditions barley did not mobilize and translocate additional N out of the straw and chaff tissues to fill the seed. Limiting moisture and lower soil N at Barrhead may be a reason why a higher percentage of total N was in the seed on the ‘no N’ treatments. Evans et al. (1975) indicated that high seed N can be due to increased mobilization of leaf N under limiting water conditions, high temperatures, or low soil N conditions. With the '+N' treatments, nitrogen from fertilizer may have provided enough N to the barley crop to reduce mobilization resulting in a greater percentage of total N remaining in the straw and chaff. Pulse treatments would rely on decomposition to convert N into a usable form for barley uptake. Under moisture limiting conditions decomposition is reduced, which may have limited N supply to the subsequent barley crop. This difference in N availability due to environmental conditions may partially explain the treatment response in N partitioning. This demonstrates one of the many ways in which crops can compensate for and adjust to adverse environmental conditions.

Canola

Seed N yield was calculated for canola grown across each of the YR1 treatments. Canola seed N yield ranged from 94.3 to 160.6 kg ha^{-1} at Barrhead and 135.7 to 267.5 kg ha^{-1} at St. Albert (Table 3-12). Gan et al. (2010) reported lower canola seed N in Saskatchewan; 48.5 kg ha^{-1} in low water conditions and 71.2 kg ha^{-1} in high water conditions. There were no significant treatment effects at Barrhead because of the lower yields due to moisture limiting conditions. The patterns in response to YR1 treatments were similar to barley responses. Generally, canola grown on faba bean or pea stubble had similar seed N yield to canola grown on barley +N, this was numerically greater than 'no N', canola +N and lupin treatments. The exception was seen at St. Albert with the barley no N treatment having greater seed N yield than pea. Canola is known to be a high nitrogen using crop and these results indicate that faba bean and pea residues can provide some of that needed N without the addition of N fertilizer. This indicates that pulses in rotation may be able to reduce fertilizer use in subsequent canola crops but further studies are needed to measure the rotational effect on oil content.

At St. Albert there was a significant difference between canola seed N yield on barley stubble (267.5 kg ha^{-1} with N fertilizer, 233.6 kg ha^{-1} without N fertilizer) and canola stubble (148.3 kg ha^{-1} with N fertilizer, 135.7 kg ha^{-1} without N fertilizer) (p<0.01). The lower seed N yield of canola grown on canola stubble with and without N indicates the negative impact of continuous canola in a cropping system. The effects of reduced yields due to overcrowding by volunteer canola, an increase in disease, and uneven maturity resulting in shelling out and green seed, all contributed to the reduced seed N yield in this study when canola was produced on canola stubble.

Wheat

Wheat seed N yield was lower at Barrhead than St. Albert across all YR1 treatments. Lower soil N and moisture conditions had an effect at this site. Seed N yield responding to soil moisture has previously been reported where wheat grown in high moisture yielded 100.7 kg N ha^{-1} and low moisture 62.5 kg N ha^{-1} (Gan et al. 2010). Increase in seed N yield in higher moisture conditions was mainly due to an increase in grain yield (Gan et al. 2010). In the present study higher seed N yields at the higher moisture site (St. Albert) were also accompanied by higher seed yields (Figure 3-6). Even with environmental differences, both sites exhibited similar patterns in treatment response but differences were only significant at St. Albert. Seed N yield of wheat was highest on faba bean stubble (78.4 kg ha^{-1}) and lowest on canola no N stubble (57.0 kg ha^{-1}) at Barrhead (Table 3-12). At St. Albert barley +N stubble (128.6 kg ha^{-1}) had the highest wheat seed N yield, followed by faba bean (115.8 kg ha^{-1}) and pea (111.1 kg ha^{-1}). Canola no N stubble (58.5 kg ha^{-1}) had the lowest seed N yield. Significant differences in wheat seed N yield occurred only between '+N' and 'no N' treatments of barley and canola stubble at St. Albert where fertilized treatments had higher seed N yield (p<0.05). Soon and Arshad (2004) reported seed N content of wheat grown on pea no N (70 kg ha^{-1}), pea +N (75 kg ha^{-1}), rape no N (50 kg ha^{-1}), rape +N (51 kg ha^{-1}), wheat no N (65 kg ha^{-1}) and wheat +N (66 kg ha^{-1}). The lack of fertilizer response in that study was attributed to moisture stress conditions.

Seed N yield can be affected by nitrogen availability (Egli 1998), moisture availability (Gan et al. 2010), water use efficiency (Miller and Holmes 2005, Miller et al. 2003) and pest or weed problems (Soon and Arshad 2004). Volunteer canola and barley were more prevalent at St. Albert and may have impacted crop yields. Soon and Arshad (2004) reported a decrease in wheat yield following oilseed rape which they attributed in part to volunteer oilseed rape growing in the wheat crop. Moisture availability and improved water use efficiency following broadleaf crops have previously been reported (Miller et al. 2003) but moisture limiting conditions at Barrhead may have reduced the impact of that rotational benefit reported by Miller and Holmes (2005).

In comparing treatments where no N fertilizer was added, generally pulse treatments have higher wheat N seed yield than ‘no N’ treatments, with the exception of lupin at Barrhead. In some cases the pulse treatments even had numerically higher wheat seed N yield than fertilized treatments. Maidl et al. (1996) reported an increase in N uptake by winter wheat when it was grown on legume stubble instead of oat stubble. With the addition of N fertilizer wheat seed N yield was 67 kg ha^{-1} on pea stubble, 47 kg ha^{-1} on wheat stubble and 54 kg ha^{-1} on mustard stubble in Saskatchewan (Miller et al. 2002b). Miller et al. (2002b) reported an increase in wheat seed N yield when grown on pulse or oilseed stubble, with pea stubble being 42% greater than wheat stubble and oilseeds 9% higher than wheat stubble. These and our results indicate that pulses provide a benefit to the subsequent wheat crop that is reflected in higher seed N yield.

Conclusions

Generally, the results of this study indicate that the yield and quality of barley, canola, and wheat are affected by the preceding crop. Yield and quality of crops are also impacted by environmental conditions. Under limited moisture conditions yields are reduced, and quality parameters are affected. Yields of subsequent barley, canola and wheat crops are generally increased with the addition of N fertilizer. Faba bean and pea stubble provide similar yield increases in subsequent crops as the addition of N fertilizer. Barley and wheat crops have higher yields following faba bean and pea than when following lupin, but canola crops respond similarly to all three pulse crops. Subsequent crops generally have higher yields following pulse crops than following barley or canola without the addition of N fertilizer. These results are in agreement with other research on pulse crops in rotation (Wright 1990b, Soon et al. 2004, Soon and Clayton 2002). Previous research attributes the increases in subsequent crop yield to improved soil N availability (Evans et al. 2003, Strydhorst et al. 2008), increased water use efficiency (Lafond et al. 2006), or reduction in diseases (Evans et al. 2003, Stevenson and van Kessel 1996a, b). Continuous cropping of canola reduces yields which can be attributed to an increase in disease and weed problems, particularly volunteer canola. Wheat also had lower yields following canola in comparison to following a pulse crop; this is in agreement with the results of Soon and Clayton (2002). This yield reduction in YR2 wheat could be a result of lower mycorrhizal populations in the soil following the production of canola, a non-mycorrhizal crop as described by Gosling et al. (2006).

Thousand seed weight was more affected by environmental conditions than by YR1 treatment. Environmental conditions affected crop maturity, which resulted in lower seed weights for barley and canola where seed maturity was uneven. Seed protein levels were increased by moisture limiting conditions but also had a response to fertilizer addition and stubble type. Barley seed protein was generally higher on pulse stubble than on barley or canola stubble without N fertilizer addition but lower than barley or canola stubble with N fertilizer. For malt quality barley environmental conditions need to be close to optimal to keep protein levels within the acceptable range. Production of barley on pulse stubble can increase seed protein levels (Wright 1990b, Johnston et al 2005). In this study barley seed protein levels were generally greatest with the addition of N fertilizer but also increased above “no N” treatments when grown on pulse stubble. An increase in seed protein is a benefit in the production of feed barley where high protein is valued. Similar to subsequent barley crops, canola and wheat crops exhibited an increase in seed protein on '+N' treatments as well as pulse stubble in comparison to 'no N' treatments. Depending on the use of the subsequent barley, canola or wheat crop this increase in protein may be a desired seed quality characteristic. Limited moisture conditions also increased the seed protein of all three subsequent crops.

Total N uptake is increased in barley crops with N availability. N fertilizer or pulse stubble can be the source of this N for barley uptake. N distribution between plant components is affected by environmental conditions and N supply. Under limiting conditions (low moisture or 'no N' treatments) a higher percentage of straw and chaff N is remobilized and moved into the seed during seed fill (Evans et al. 1975). Seed N yield of canola and wheat responds positively to nitrogen fertilizer and faba bean and pea stubble. This indicates that the inclusion of faba bean or pea in rotation could reduce the need for N fertilizer addition while still maintaining seed N yield in the subsequent crop. Previous research indicates that seed N yield is influenced by availability of soil N (Egli 1998), moisture conditions (Gan et al. 2010), water use efficiency (Miller and Holmes 2005, Miller et al. 2003), and pest or weed issues (Soon and Arshad 2004). Rotation effects of including pulse crops can influence many of the parameters which impact seed N yield in subsequent crop. Preceding pulse crops can maintain the yield and quality of subsequent barley, canola and wheat crops in rotation without the addition of N fertilizer.

Table 3-1: Soil test nutrient analysis, soil properties and fertilizer applications for plots produced in 2009 and 2010 at Barrhead and St. Albert, Alberta, Canada. Soil tests were done in the fall of 2008 and 2009 and fertilizer recommendations were determined for the growing season based on those results. P, K, and S fertilizers were applied to all plots. N was applied in both years of rotation (YR1 and YR2); in YR1 to plots where barley +N and canola +N treatments were grown and in YR2 to those same plots. Fertilizer was applied just prior to spring seeding with a pre-seeding run over the plots with the seeder.

	Barrhead				**St. Albert**			
	2009		**2010**		**2009**		**2010**	
Soil properties	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 Cm	15-30 cm
pH	5.5	5.4	5.1	n/a	7.7	7.7	7.2	n/a
	mg kg^{-1}				mg kg^{-1}			
Nitrate N	14	13	25	21	23	17	17	10
P	28		24		51		57	
K	229		163		234		293	
Sulphate S	16	13	17	14	13	12	18	13
Fertilizer Applications	kg ha^{-1}				kg ha^{-1}			
P_2O_5	45		22		28		0	
K_2O	28		0		0		0	
S	28		0		28		0	
N	101		78		78		90	

n/a: data not available

Table 3-2: YR2 crops seeded at Barrhead and St. Albert in 2009 and 2010. Seeding rates and depths were adjusted according to seed size and germination (%) to achieve optimal crop densities. Seed treatments were applied to seed before seeding.

Crop	**Target Plant Density (plants m^{-2})**	**Seeding Depth (cm)**	**Seed Treatment**
Barley	210	2-2.5	Raxil FL
Canola	120	1-1.5	Helix XTra
Wheat	250	3-4	Raxil FL

Table 3-3: Dates of herbicide applications for barley, canola and wheat grown at Barrhead and St. Albert, Alberta, Canada in 2009 and 2010. Application dates were chosen according to crop maturity and environmental conditions. Herbicides were selected based on crop and weed problem.

		Barrhead		**St. Albert**	
Crop	**Chemical**	**2009**	**2010**	**2009**	**2010**
Barley	Achieve SC	June 10	June 13	June 8	June 11
	Refine SG	June 16	June 17	June 17	June 16
Canola	Roundup Transorb HC	June 10	June 17	June 10	June 11
Wheat	Achieve SC	June 10	June 13	June 8	June 11
	Refine SG	June 16	June 17	June 17	June 16

Table 3-4: Chemical applications for plots at Barrhead and St. Albert in 2009 and 2010. Application was according to recommended application rates at appropriate crop maturity.

Chemical	Application Rate	Surfactant	Target Pests
<u>Herbicides:</u>			
Achieve SC (*tralkoxydim)*	494 ml ha^{-1}	Turgocharge (1L/200L water)	Wild oats
Refine SG (*thifensulfuron-methyl + tribenuron-methyl)*	30g ha^{-1}	AgSurf (2L/10000L water)	Chickweed, hemp-nettle, lamb's quarters, stinkweed, volunteer canola, wild buckwheat
Roundup Transorb HC (*glyphosate)*	1.2 L ha^{-1}	No Surfactant	Hemp-nettle, lamb's quarters, stinkweed, volunteer barley, wild oats, Canada thistle, dandelion, quackgrass
<u>Insecticides:</u>			
Decis (*deltamethrin)*	198 ml ha^{-1}	n/a	Cutworms, grasshoppers, thrips
ECO Bran (*carbaryl)*	1.6 kg ha^{-1}	n/a	Grasshoppers
<u>Desiccants:</u>			
Reglone (*diquat)*	1.7 L ha^{-1}	n/a	n/a
Roundup Transorb HC (*glyphosate)*	1.2 L ha^{-1}	n/a	n/a

n/a: not applicable

Table 3-5: Harvest dates of YR2 crops (following desiccation and dry down) at Barrhead and St. Albert in 2009 and 2010.

	Barrhead		St. Albert	
Crop	**2009**	**2010**	**2009**	**2010**
Barley	August 27	September 3	September 2	September 7
Canola	September 17	October 1	September 25	October 1
Wheat	September 14	September 28	September 22	September 25

Table 3-6: N return from YR1 crop residues (kg N ha^{-1}) and N fixation (kg N ha^{-1} and % Ndfa) by faba bean, lupin and pea averaged across 2008 and 2009 at Barrhead and St. Albert, Alberta, Canada.

	Barrhead			St. Albert		
Crop	**N Return kg N ha^{-1}**	**N Fixation kg N ha^{-1}**	**Ndfa %**	**N Return kg N ha^{-1}**	**N Fixation kg N ha^{-1}**	**Ndfa %**
Barley +N (BN)	29.9			48.7		
Barley no N (BO)	25.5			28.1		
Canola +N (CN)	44.3			61.7		
Canola no N (CO)	33.5			50.6		
Faba bean (Fb)	22.3	55	37	46.7	201	66
Lupin (Lu)	33.4	58	35	36.3	41	26
Pea (Pe)	30.1	51	35	38.9	123	55
F-Test (df)	0.3450 (6)	0.9295 (2)	0.9375 (2)	0.4888 (6)	0.0990 (2)	0.0333 (2)
SE[a]	8.4	19.1	7.8	15.4	37.6	5.4
Contrasts						
Fb, Lu, Pe vs BN, BO, CN, CO	ns			ns		
BN vs BO	ns			ns		
CN vs CO	ns			ns		
BN, BO vs CN, CO	ns			ns		
Fb vs Pe	ns	ns	ns	ns	ns	ns
Lu vs Fb, Pe	ns	ns	ns	ns	0.0650	0.0181

Significance was determined at $p<0.05$

[a]Standard error of the difference between two least-square means.

ns: not significant at a probability level of 0.05.

Table 3-7: Above ground harvest index (HI) of barley, canola, and wheat grown at Barrhead and St. Albert, Alberta, Canada averaged across 2009 and 2010.

	Barley HI		**Canola HI**		**Wheat HI**	
	Barrhead	St. Albert	Barrhead	St. Albert	Barrhead	St. Albert
YR1 Treatment						
Barley +N (BN)	0.50	0.55	0.41	0.43	0.44	0.47
Barley No N (BO)	0.55	0.58	0.42	0.42	0.51	0.47
Canola +N (CN)	0.46	0.56	0.41	0.31	0.42	0.50
Canola No N (CO)	0.55	0.59	0.43	0.35	0.48	0.48
Faba bean (Fb)	0.53	0.56	0.45	0.44	0.47	0.49
Lupin (Lu)	0.55	0.57	0.43	0.42	0.44	0.50
Pea (Pe)	0.55	0.57	0.45	0.42	0.45	0.49
F-test (df)	0.2238 (6)	0.6313 (6)	0.3367 (6)	0.0021 (6)	0.0473 (6)	0.2429 (6)
SE[a]	0.035	0.023	0.019	0.018	0.020	0.014
Contrasts						
Fb, Lu, Pe vs BN, BO, CN, CO	ns	ns	0.0451	0.0021	ns	ns
BN vs BO	ns	ns	ns	ns	0.0119	ns
CN vs CO	0.0363	ns	ns	ns	0.0314	ns
BN, BO vs CN, CO	ns	ns	ns	0.0003	ns	ns
Fb vs Pe	ns	ns	ns	ns	ns	ns
Lu vs Fb, Pe	ns	ns	ns	ns	ns	ns

Significance was determined at $p<0.05$

[a]Standard error of the difference between two least-square means.

ns: not significant at a probability level of 0.05.

Table 3-8: Seed quality characteristics for YR2 barley (thousand seed weight (TSW) (g 1000 $seeds^{-1}$) and seed protein content (mg g^{-1}) grown on the 7 YR1 treatments, barley +N (BN), barley no N (BO), canola +N (CN), canola no N (CO), faba bean (Fb), lupin (Lu), pea (Pe), at Barrhead and St. Albert, Alberta, Canada averaged across 2009 and 2010.

	Barrhead		**St. Albert**	
YR1 Stubble	**TSW g 1000 $seeds^{-1}$**	**Seed Protein mg g^{-1}**	**TSW g 1000 $seeds^{-1}$**	**Seed Protein mg g^{-1}**
Barley +N (BN)	43.1	158	41.3	142
Barley no N (BO)	45.5	140	40.9	123
Canola +N (CN)	41.9	163	42.6	122
Canola no N (CO)	43.5	140	40.8	114
Faba bean (Fb)	44.3	145	41.5	128
Lupin (Lu)	43.9	146	40.5	127
Pea (Pe)	44.9	141	41.9	127
F-Test (df)	0.0307 (6)	0.0188 (6)	0.2685 (6)	0.0097 (6)
SE[a]	0.72	5.14	0.80	4.02
Contrasts				
Fb, Lu, Pe vs BO, BN, CN, CO	ns	ns	ns	ns
BN vs BO	0.0159	0.0133	ns	0.0036
CN vs CO	ns	0.0039	ns	ns
BN, BO vs CN, CO	0.0204	ns	ns	0.0024
Fb vs Pe	ns	ns	ns	ns
Lu vs Fb, Pe	ns	ns	ns	ns

Significance was determined at $p<0.05$

[a]Standard error of the difference between two least-square means.

ns: not significant at a probability level of 0.05.

Table 3-9: YR2 canola seed quality characteristics (thousand seed weight (TSW) (g 1000 seeds^{-1}) and seed protein content (mg g^{-1})) at Barrhead and St. Albert, Alberta, Canada averaged across 2009 and 2010.

	Barrhead		St. Albert	
	TSW g 1000 seeds^{-1}	**Seed Protein mg g^{-1}**	**TSW g 1000 seeds^{-1}**	**Seed Protein mg g^{-1}**
YR1 Stubble				
Barley +N (BN)	4.0	383	3.5	334
Barley no N (BO)	3.9	337	3.5	322
Canola +N (CN)	3.8	395	3.3	356
Canola no N (CO)	3.8	326	3.4	316
Faba bean (Fb)	3.9	356	3.5	326
Lupin (Lu)	4.0	354	3.6	328
Pea (Pe)	4.1	342	3.5	327
F-Test (df)	0.5296 (6)	0.0061 (6)	0.3338 (6)	0.0553 (6)
SE[a]	0.14	10.9	0.10	8.8
Contrasts				
Fb, Lu, Pe vs BO, BN, CN, CO	ns	ns	ns	ns
BN vs BO	ns	0.0059	ns	ns
CN vs CO	ns	0.0008	ns	0.0042
BN, BO vs CN, CO	ns	ns	ns	ns
Fb vs Pe	ns	ns	ns	ns
Lu vs Fb, Pe	ns	ns	ns	ns

Significance was determined at $p<0.05$

[a]Standard error of the difference between two least-square means.

ns: not significant at a probability level of 0.05.

Table 3-10: Seed quality characteristics (thousand seed weight (TSW) (g 1000 seeds^{-1}) and seed protein content (mg g^{-1})) of YR2 wheat grown on YR1 stubble treatments at Barrhead and St. Albert, Alberta, Canada averaged across 2009 and 2010.

	Barrhead		St. Albert	
	TSW g 1000 seeds^{-1}	**Seed Protein mg g^{-1}**	**TSW g 1000 seeds^{-1}**	**Seed Protein mg g^{-1}**
YR1 Stubble				
Barley +N (BN)	32.0	184	33.6	154
Barley no N (BO)	32.5	150	32.4	135
Canola +N (CN)	30.6	186	32.2	145
Canola no N (CO)	32.3	155	31.3	128
Faba bean (Fb)	32.1	170	32.6	150
Lupin (Lu)	31.8	169	32.8	146
Pea (Pe)	32.0	166	33.0	141
F-Test (df)	0.1884 (6)	0.0024 (6)	0.1286 (6)	0.0820 (6)
SE[a]	0.60	4.99	0.61	6.57
Contrasts				
Fb, Lu, Pe vs BO, BN, CN, CO	ns	ns	ns	ns
BN vs BO	ns	0.0005	ns	0.0261
CN vs CO	0.0271	0.0008	ns	ns
BN, BO vs CN, CO	ns	ns	0.0273	ns
Fb vs Pe	ns	ns	ns	ns
Lu vs Fb, Pe	ns	ns	ns	ns

Significance was determined at $p<0.05$

[a]Standard error of the difference between two least-square means.

ns: not significant at a probability level of 0.05.

Table 3-11: N Yield (kg N ha^{-1}) of plant components (chaff, straw and seed) of YR2 barley averaged across 2009 and 2010 at Barrhead and St. Albert, Alberta, Canada.

	Barrhead				**St. Albert**			
	Chaff	**Straw**	**Seed**	**Total**	**Chaff**	**Straw**	**Seed**	**Total**
YR 1 Treatment	**kg N ha^{-1}**				**kg N ha^{-1}**			
Barley +N (BN)	9.8	31.0	57.2	98.0	9.6	46.9	116.3	172.8
Barley No N (BO)	6.9	19.8	51.9	78.6	5.6	23.2	66.3	95.1
Canola +N (CN)	12.1	30.9	53.5	96.5	10.2	34.6	95.8	140.5
Canola No N (CO)	5.6	12.8	42.7	61.2	5.8	16.1	51.8	73.7
Faba bean (Fb)	9.6	23.9	58.6	92.1	9.3	36.8	97.0	143.2
Lupin (Lu)	6.9	16.1	46.5	69.6	8.4	29.6	86.3	124.4
Pea (Pe)	9.4	24.3	62.9	96.6	9.7	35.0	99.1	143.8
F-Test (df)	0.0860 (6)	0.2411 (6)	0.0516 (6)	0.1047 (6)	0.0932 (6)	0.0272 (6)	0.0009 (6)	0.0013 (6)
SE[a]	1.7	7.3	4.8	12.2	1.5	5.9	6.8	11.1
Contrasts								
Fb, Lu, Pe vs BN, BO, CN, CO	ns	ns	ns	ns	ns	ns	0.0194	0.0329
BN vs BO	ns	ns	ns	ns	0.0382	0.0072	0.0003	0.0004
CN vs CO	0.0099	0.0475	ns	0.0276	0.0272	0.0208	0.0006	0.0010
BN,BO vs CN, CO	ns	ns	ns	ns	ns	ns	0.0109	0.0144
Fb vs Pe	ns	ns	ns	ns	ns	ns	ns	ns
Lu vs Fb, Pe	ns	ns	0.0145	ns	ns	ns	ns	ns

Significance was determined at $p<0.05$

[a]Standard error of the difference between two least-square means.

ns: not significant at a probability level of 0.05.

Table 3-12: Seed N yield (kg N ha^{-1}) of YR2 canola and wheat grown at Barrhead and St. Albert, Alberta, Canada averaged across 2009 and 2010.

	Canola		Wheat	
	Barrhead	**St. Albert**	**Barrhead**	**St. Albert**
YR1 Treatment	kg N ha^{-1}			
Barley +N (BN)	150.9	267.5	75.1	128.6
Barley No N (BO)	94.3	233.6	62.5	82.6
Canola +N (CN)	134.6	148.3	74.9	103.6
Canola No N (CO)	96.9	135.7	57.0	58.5
Faba bean (Fb)	160.6	266.9	78.4	115.8
Lupin (Lu)	105.0	184.5	53.2	107.0
Pea (Pe)	157.7	218.0	63.0	111.1
F-test (df)	0.2030 (6)	0.0269 (6)	0.1521 (6)	0.0506 (6)
SE[a]	29.0	31.8	8.9	15.7
Contrasts				
Fb, Lu, Pe vs BN, BO, CN, CO	ns	ns	ns	ns
BN vs BO	ns	ns	ns	0.0261
CN vs CO	ns	ns	ns	0.0322
BN,BO vs CN, CO	ns	0.0029	ns	ns
Fb vs Pe	ns	ns	ns	ns
Lu vs Fb, Pe	ns	ns	ns	ns

Significance was determined at $p<0.05$

[a]Standard error of the difference between two least-square means.

ns: not significant at a probability level of 0.05.

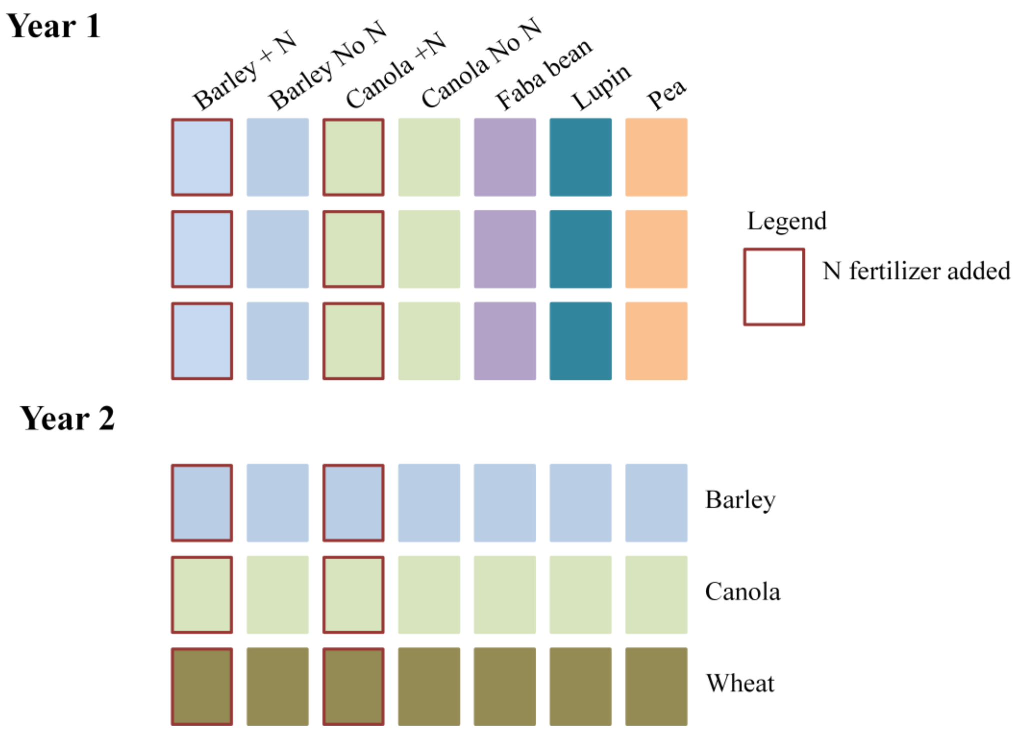


Figure 3-1: Plot plan for rotational study grown at Barrhead and St. Albert in 2008, 2009 and 2010. YR1 crops were produced in vertical strips with 3 plots each and YR2 crops were produced horizontally on the YR1 stubble in the subsequent year. Four blocks of randomized treatments were grown at each site.

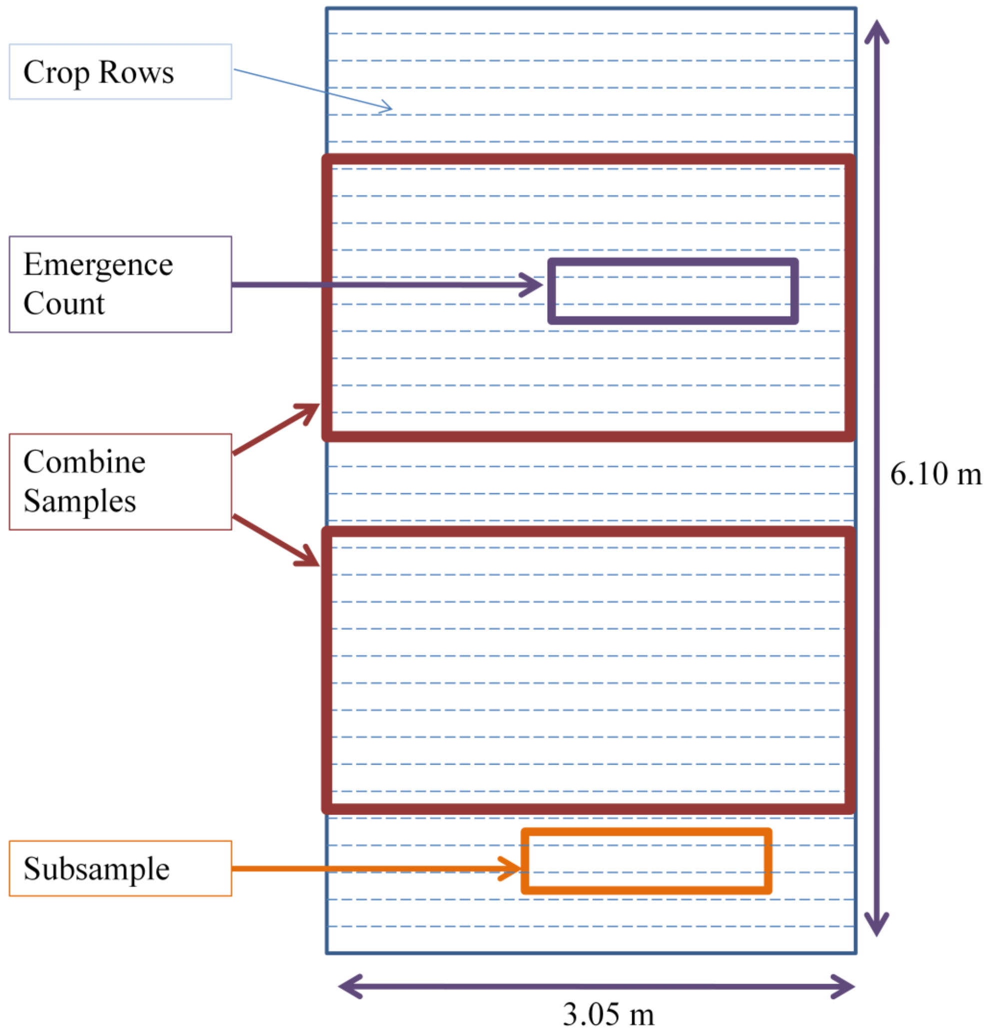
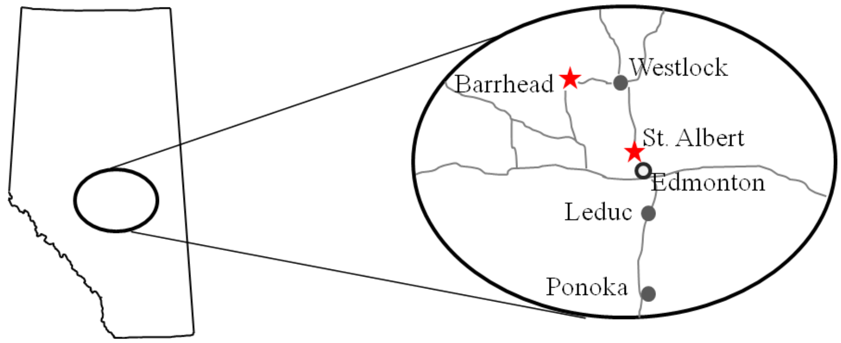


Figure 3-2: Plot diagram for YR2 crops produced in 2009 and 2010 at Barrhead and St. Albert. Rectangles representing the approximate location of the measurements and samples taken on the plots throughout the growing season.



Barrhead

Description: Commercial Farm (54°8'N, 114°14'W)
Soil Type: Orthic humic Gleysol (mesic Typic Endoaquoll) with heavy clay texture¹
pH: 4.8-5.6†
Soil Organic Matter content: 2.7 %‡
Weather Station: Barrhead CS Environment Canada³ (14 km from site)

	2008	2009	2010	Normal**
Total Precipitation (mm)*	186.3	138.0	245.7	288.0
Average Daily Temperature (°C)*	15.1	14.0	13.9	13.8

St. Albert

Description: University of Alberta St. Albert Research Station
(53°41'N, 113°38W)
Soil Type: Malmo Eluviated Black Chernozem with silty clay loam texture²
pH: 7.1-7.8†
Soil Organic Matter Content: 11.6 % ‡
Weather station: Oliver ABDM Alberta Agriculture and Food ³ (19 km from site)

	2008	2009	2010	Normal**
Total Precipitation (mm)*	174.6	153.2	274.1	272.9
Average Daily Temperature (°C)*	15.3	14.2	14.1	14.6

† Range across spring 2008 – fall 2009 soil tests
‡ 2008 soil tests - depth: 0-15 cm .
*Growing Season (May – August)
**Estimates of long term normals as described by ACIS 2010 definitions.
¹Strydhorst, 2008
²Browser et al 1962
³ACIS 2010

Figure 3-3: Description of study locations – Barrhead and St. Albert, where crops were produced in 2008, 2009 and 2010.

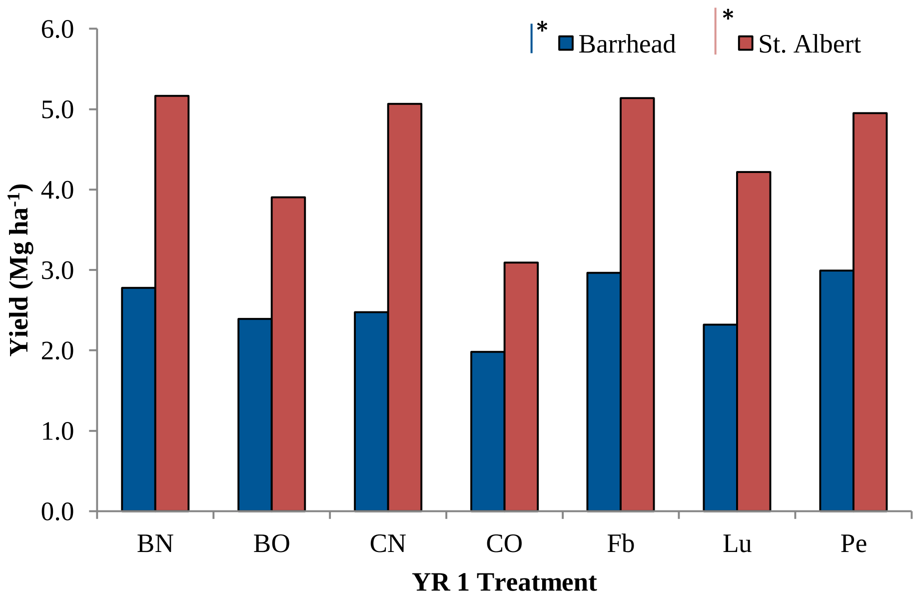


Figure 3-4: Barley yields (Mg ha^{-1}) produced on stubble from YR1 treatments (barley +N (BN), barley no N (BO), canola +N (CN), canola no N (CO), faba bean (Fb), lupin (Lu), and pea (Pe)) averaged across 2009 and 2010 at Barrhead and St. Albert.

Statistical Analysis:

	Barrhead	St. Albert
F-Test (df)	0.0151 (6)	0.0032 (6)
SE[a]	195.60	310.70
Contrasts		
Fb, Lu, Pe vs BN, BO, CN, CO	0.0157	0.0330
BN vs BO	ns	0.0066
CN vs CO	0.0455	0.0007
BN BO vs CN,CO	0.0426	ns
Fb vs Pe	ns	ns
Lu vs Fb, Pe	0.0081	0.0218

Significance was determined at $p<0.05$

[a]Standard error of the difference between two least-square means.

ns: not significant at a probability level of 0.05.

*Bars represent the least significant difference (LSD) between treatments for each location

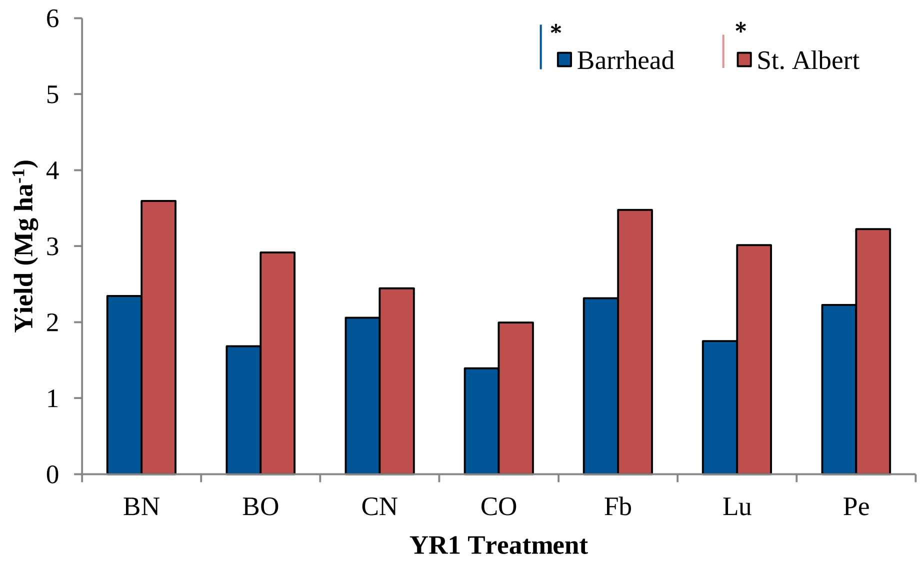


Figure 3-5: Canola yields (Mg ha^{-1}) grown on YR1 stubble treatments (barley +N (BN), barley no N (BO), canola +N (CN), canola no N (CO), faba bean (Fb), lupin (Lu), and pea (Pe)) averaged across 2009 and 2010 at Barrhead and St. Albert.

Statistical Analysis:

	Barrhead	St. Albert
F-Test (df)	0.0989 (6)	0.0029 (6)
SE[a]	293.70	217.98
Contrasts		
Fb, Lu, Pe vs BN, BO, CN, CO	ns	0.0054
BN vs BO	ns	0.0212
CN vs CO	ns	ns
BN BO vs CN,CO	ns	0.0005
Fb vs Pe	ns	ns
Lu vs Fb, Pe	ns	ns

Significance was determined at $p<0.05$

[a]Standard error of the difference between two least-square means.

ns: not significant at a probability level of 0.05.

*Bars represent the least significant difference (LSD) between treatments for each location

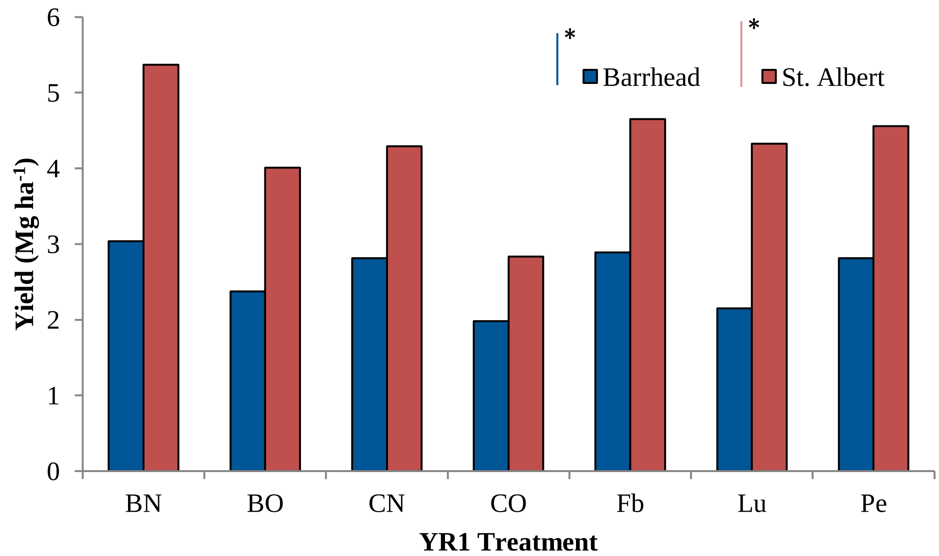


Figure 3-6: Wheat yield (kg ha^{-1}) on all seven YR1 treatments, barley +N (BN), barley no N (BO), canola +N (CN), canola no N (CO), faba bean (Fb), lupin (Lu), and pea (Pe), at Barrhead and St. Albert averaged across 2009 and 2010. Statistical analysis:

	Barrhead	St. Albert
F-Test (df)	0.0783 (6)	0.0200 (6)
SE[a]	310.37	430.78
Contrasts		
Fb, Lu, Pe vs BN, BO, CN, CO	ns	ns
BN vs BO	ns	0.0197
CN vs CO	0.0368	0.0149
BN BO vs CN,CO	ns	0.0101
Fb vs Pe	ns	ns
Lu vs Fb, Pe	0.0397	ns

Significance was determined at $p<0.05$

[a]Standard error of the difference between two least-square means.

ns: not significant at a probability level of 0.05.

*Bars represent the least significant difference (LSD) between treatments for each location

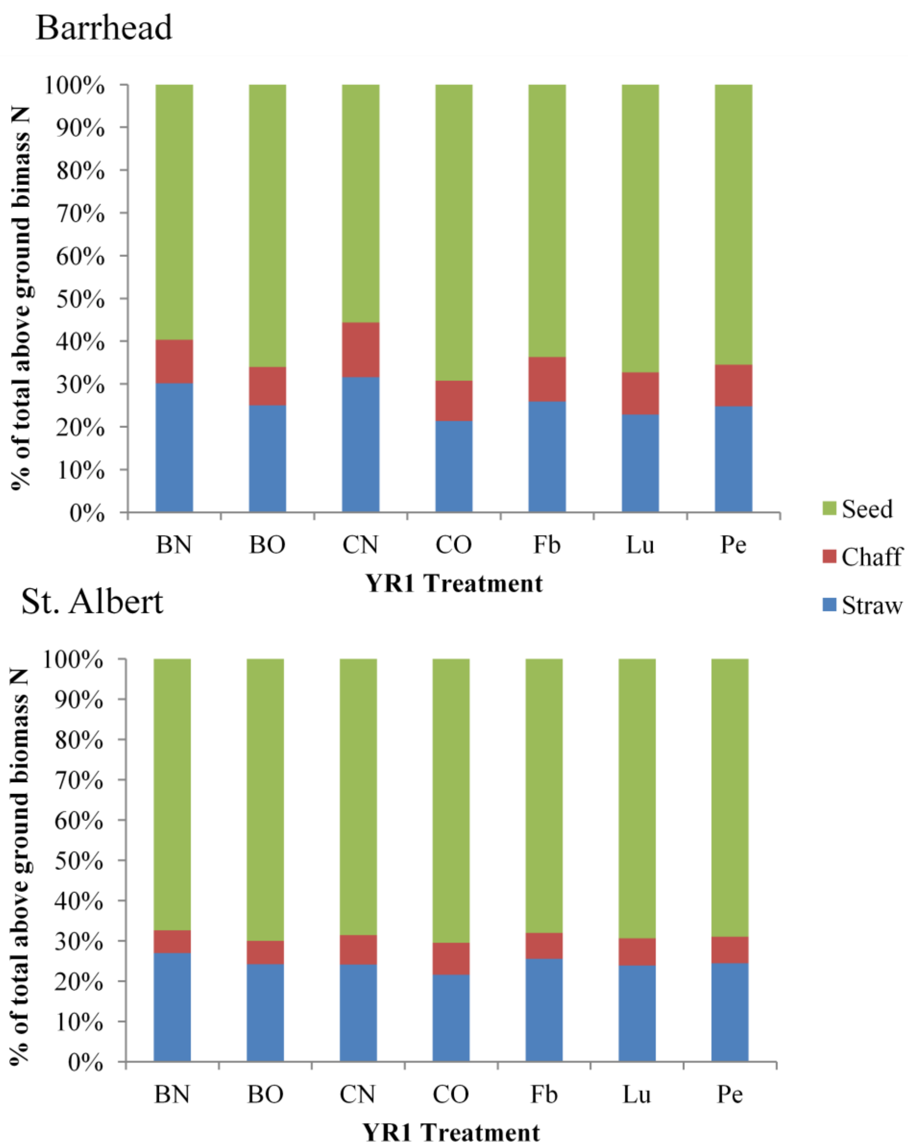


Figure 3-7: Nitrogen distribution of total N in the above ground biomass of YR2 barley grown on seven YR1 treatments (barley +N (BN), barley no N (BO), canola +N (CN), canola no N (CO), faba bean (Fb), lupin (Lu), pea, (Pe)) at Barrhead and St. Albert averaged across 2009 and 2010.

Literature Cited

Abera, K.T. 2009. Agronomic evaluation of Ethiopian barley (*Hordeum vulgare* L.) landrace populations under drought stress conditions in low-rainfall areas of Ethiopia. MSc Thesis. Swedish Biodiversity Centre, Uppsala, Sweden. [Online] Available: http://stud.epsilon.slu.se/641/1/abera_k_091125.pdf [5 May 2011].

Alberta Agriculture and Rural Development. 2008. AC Metcalfe Malting Barley. [Online] Available: http://www.agric.gov.ab.ca/app95/loadCropVariety?action=display&id=50 [April 29, 2011]

Alberta Seed Industry Partnership. 2011. Alberta's Seed Guide Spring 2011. Issues Ink. Winnipeg, MB. [Online] Available: http://www.seed.ab.ca/news_and_events/news1.asp [30 March 2011].

Armstrong, E.L., Heenan, D.P., Pate, J.S., and Unkovich, M.J. 1997. Nitrogen benefits of lupins, field pea, and chickpea to wheat production of south-eastern Australia. Aust. J. Agric. Res. 48: 39-47.

Biederbeck, V.O., Bjorge, H.A., Brandt, S.A., Henry, J.L., Hultgreen, G.E., Kielly, G.A., and Slinkard, A.E. 1995. Soil improvement with legumes: Including legumes in crop rotations. B.J. Green and V.O. Biederbeck, eds. Canada-Saskatchewan Agreement on Soil Conservation. Saskatchewan, Canada.

Bowser, W.E., Kjearsgaard, A.A., Peters, T.W., and Wells, R.E. 1962. Soil survey of Edmonton Sheet (83-H). Bulletin No. SS-4 Report No. 21. Alberta Soil Survey. University of Alberta and Canadian Department of Agriculture.

Carr, P.M., Martin, G.B. and Horsley, R.D. 2008. Wheat grain quality response to tillage and rotation with field pea. Agronomy Journal. 100: 1594-1599.

Cutforth, H.W., McGinn, S.M., McPhee, K.E. and Miller, P.R. 2007. Adaptation of pulse crops to the changing climate of the northern Great Plains. Agron. J. 99: 1684-1699.

Doyle, A.D., Moore, K.J. and Herridge, D.F. 1988. The narrow-leafed lupin (*Lupinus angustifolius* L.) as a nitrogen-fixing rotation crop for cereal production. III. Residual effects of lupins on subsequent cereal crops. Aust. J. Agric. Res. 39: 1029-1037.

Egli, D.B. 1998. Seed biology and the yield of grain crops. CAB International, New York, NY.

Engel, R.E., Long, D.S., Carlson, G.R. and Meier, C. 1999. Method for precision nitrogen management in spring wheat: I Fundamental relationships. Precision Agriculture. 1: 327-338.

Evans, J., Murray, G.M., Scott, G., Orchard, B., Brennan, J., Lemerle, D., Kaiser, A. and Armstrong, E.L. 2006. Impact of annual legume 'break' crops on the yield and quality of canola in comparison with the impact on yield of wheat. Australian Journal of Experimental Agriculture. 46: 1489-1497.

Evans, J., Scott, G., Lemerle, D., Kaiser, A., Orchard, B., Murray, G.M. and Armstrong, E.L. 2003. Impact of legume 'break' crops on the yield and grain quality of wheat and relationship with soil mineral N and crop N content. Australian Journal of Agricultural Research. 54: 777-788.

Evans, L.T. 1993. Crop evolution, adaption, and yield. Cambridge University Press, New York, NY.

Evans, L.T., Wardlaw, I.F. and Fischer, R.A. 1975. Wheat. Pages 101-149 *in* L.T. Evans, ed. Crop Physiology. Cambridge University Press, New York, NY.

Gan, Y.T., Campbell, C.A. Janzen, H.H., Lemke, R.L., Basnyat, P. and McDonald, C.L. 2010. Nitrogen accumulation in plant tissues and roots and N mineralization under oilseeds, pulses, and spring wheat. Plant Soil. 332: 451-461.

Gan, Y., Liang, C., Wang, X. and McConkey, B. 2011. Lowering carbon footprint of durum wheat by diversifying cropping systems. Field Crops Research. 122: 199-206.

Gan, Y.T., Miller, P.R., McConkey, B.G., Zentner, R.P., Stevenson, F.C. and McDonald, C.L. 2003. Influence of diverse cropping sequences on durum wheat yield and protein in the semiarid northern great plains. Agron. J. 95:245-252.

Gosling, P., Hodge, A., Goodlass, G. And Bending, G.D. 2006. Arbuscular mycorrhizal fungi and organic farming. Agriculture, Ecosystems and Environment. 113: 17-35.

Johnston, A.M., Kutcher, H.R. and Bailey, K.L. 2005. Impact of crop sequence decisions in the Saskatchewan parkland. Can. J. Plant Sci. 85:95-102.

Karamzadeh, A., Mobasser, H.R., Ramee, V. and Ghanbari-Malidarreh, A. 2010. Effects of nitrogen and seed rate on yield and oil content of canola (*Brassica napus* L.). American-Eurasian J. Agric. & Environ. Sci. 8: 715-721.

Lafond, G.P., May, W.E., Stevenson, F.C. and Derksen, D.A. 2006. Effects of tillage systems and rotations on crop production for a thin black chernozem in the Canadian prairies. Soil & Tillage Research. 89: 232-245.

Littell, R.C., Milliken, G.A., Stroup, W.W., Wilfinger, R.D. and Schabenberger, O. 2006. SAS® for mixed models. 2nd ed. SAS Institute Inc., Cary, NC, USA.

Maidl, F.X., Haunz, F.X., Panse, A. and Fischbeck, G. 1996. Transfer of grain legume nitrogen within a crop rotation containing winter wheat and winter barley. J. Agronomy & Crop Science. 176: 47-57.

McLelland, M., Panchuk, K., Green, B., Campbell, D., Harvey, B., Rossnagel, B., Foster, J. and Kendall, N. 2009. Malting Barley. Government of Alberta. AGDEX 114/20-2. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex98 [29 March 2011].

Miller, P.R., Engel, R.E. and Holmes, J.A. 2006. Cropping sequence effect of pea and pea management on spring wheat in the northern great plains. Agron. J. 98: 1610-1619.

Miller, P.R., Gan, Y., McConkey, B.G. and McDonald, C.L. 2003. Pulse crops for the northern great plains: II. Cropping sequence effects on cereal, oilseed, and pulse crops. Agron. J. 95:980-986.

Miller, P.R. and Holmes, J.A. 2005. Cropping sequence effects of four broadleaf crops on four cereal crops in the northern Great Plains. Agron. J. 97:189-200.

Miller, P.R., McConkey, B.G., Clayton, G.W., Brandt, S.A., Staricka, J.A., Johnston, A.M., Lafond, G.P., Schatz, B.G., Baltensperger, D.D. and Neill, K.E. 2002a. Pulse crop adaptation in the northern Great Plains. Agron. J. 94: 261-272.

Miller, P.R., Waddington, J., McDonald, C.L. and Derksen, D.A. 2002b. Cropping sequence affects wheat productivity on the semiarid northern Great Plains. Can. J. Plant Sci. 82: 307-318.

Petr, J., Černý, V., Hruška, L. et al. 1988. Yield formation in the main field crops. Elsevier Science Publishing Company, Inc. New York, NY.

Ryan, M.H. and Graham, J.H. 2002. Is there a role for arbuscular mycorrhizal fungi in production agriculture? Plant and Soil. 244: 263-271.

SAS Institute Inc. 2008. Version 9.2 SAS Institute Inc. Cary, NC, USA.

Soon, Y.K. and Arshad, M.A. 2002. Comparison of the decomposition and N and P mineralization of canola, pea and wheat residues. Biol. Fertil. Soils. 36: 10-17.

Soon, Y.K. and Arshad, M.A. 2004. Contribution of di-nitrogen fixation by pea to the productivity and N budget of a wheat based cropping system. 142: 629-637.

Soon, Y.K. and Clayton, G.W. 2002. Eight years of crop rotation and tillage effects on crop production and N fertilizer use. Can. J. Soil Sci. 82: 165-172.

Soon, Y.K., Harker, K.N. and Clayton, G.W. 2004. Plant competition effects on the nitrogen economy of field pea and the subsequent crop. Soil Sci. Soc. Am. J. 68: 552-557.

Stevenson, F.C. and van Kessel, C. 1996a. A landscape-scale assessment of the nitrogen and non-nitrogen benefits of pea in a crop rotation. Soil Sci. Soc. Am. J. 60: 1797-1805.

Stevenson, F.C. and van Kessel, C. 1996b. The nitrogen and non-nitrogen rotational benefits of pea to succeeding crops. Can. J. Plant Sci. 76:735-735.

Strydhorst, S.M. 2008. Faba bean and lupin: New grain legume crops to improve agricultural sustainability. PhD Thesis, Department of Agriculture, Food and Nutritional Science, University of Alberta, Edmonton, Alberta.

Strydhorst, S.M., King, J.R., Lopetinsky, K.J. and Harker, K.N. 2008. Weed interference, pulse species, and plant density effects on rotational benefits. Weed Science. 56:249-258.

Su, C. 2010. Alberta 2009 crop year in review. Alberta Agriculture and Rural Development, Economics and Competitiveness Division, Statistics and Data Development Branch, Government of Alberta, Edmonton, Alberta.[Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd13100 [8 February 2011].

Wright, A. T. 1990a. Quality effects of pulses on subsequent cereal crops in the northern prairies. Can. J. Plant Sci. 70: 1013-1021.

Wright, A. T. 1990b. Yield effect of pulses on subsequent cereal crops in the northern prairies. Can. J. Plant Sci. 70: 1023-1032.

Wych, R.D., Simmons, S.R., Warner, R.L. and Kirby, E.J.M.1985. Physiology and development. Pages 103-125. *in* D.C. Rasmusson, ed. Barley. Agronomy Series Number 26, American Society of Agronomy, Madison, Wisconsin.

Zentner, R.P., Campbell, C.A., Selles, F., McConkey, B.G., Jefferson, P.G. and Lemke, R. 2003. Cropping frequency, wheat classes, and flexible rotations: Effects on production, nitrogen economy, and water use in the Brown Chernozem. Can. J. Plant Sci. 83: 667-680.

Zhang, G., Chen, J., Wang, J. and Ding, S. 2001. Cultivar and environmental effects on (1→3, 1→4)-β-D-Glucan and protein content in malting barley. Journal of Cereal Science. 34: 295-301.

Chapter 4: Summary and Synthesis

Pulse Crops in Alberta

Pulses are not major crops in the Alberta cropping system but this research indicates that they would provide substantial economic and environmental benefits if they were included in more rotations. Faba bean, lupin and pea crops each have adaptations and benefits that may be better suited to particular environmental conditions or crop rotations. Pulse crops are known for their N fixing abilities and the N benefit that they provide to the agricultural system but this and other current research indicates that there are other benefits from pulse production that are not attributable to N alone.

This study demonstrated that faba bean has the highest potential for N fixation (55 – 201 kg N ha^{-1}) followed by pea and then lupin (Table 4-1). Faba bean in rotation would provide a different rotational break than pea or lupin as it has different disease pressures, weed concerns and nutrient use. Faba bean is the easiest to harvest as it stands erect and is not prone to lodging like peas and stands taller than lupin for ease of harvest.

Lupin exhibited the lowest potential for N fixation (41 – 58 kg N ha^{-1}) which was influenced by soil pH at St. Albert and low moisture conditions at Barrhead (Table 4-1). Lupin is sensitive to high soil pH and uniquely prefers more acidic soils. This characteristic is attractive for production in the Peace region of Alberta where acidic soils are more common and other pulses do not perform well. Lupin was not adapted to the two production sites of this study but may perform better in other areas of Alberta.

Pea is the most common pulse crop in Alberta due to its ability to adapt to diverse conditions. This study demonstrated that it has acceptable yields (3.2 – 5.9 Mg ha^{-1}) and N fixation (51 – 124 kg N ha^{-1}). Advances in breeding and the production of semi-leafless varieties have reduced disease and lodging problems, which reduces some of the risks of pea production. In the present study peas provided an equal rotational benefit to subsequent crops as faba bean even though N fixation was lower.

Peas have the most developed national and export market of all the pulse crops in Alberta. There is potential for an increase with the development of Canadian value added processing facilities such as fractionation or milling. With the expansion of research in the uses for pea flour, starch and protein, market demand should increase which may drive an increase in production. Further development of uses and markets for faba bean and lupin is needed to promote their production in Alberta. Demand for organic production has increased in recent years and pulse crops will play an important role in N management in organic production systems.

Pulse Benefits

The only N input into the faba bean, lupin and pea treatments in this study was from N fixation (Chapter 2). Averaged over the entire study, yearly N fixation was 128 kg N ha^{-1} for faba bean, 50 kg N ha^{-1} for lupin and 87 kg N ha^{-1} for pea. Average cost of urea fertilizer in 2011was \$559 tonne^{-1} or \$0.26 per kg of N (Alberta Agriculture and Rural Development 2011). The value of the N fixed by the pulse crop was \$33.28 ha^{-1} for faba bean, \$13.00 ha^{-1} for lupin and \$22.62 ha^{-1} for pea.

The harvested area of both pea and faba bean has generally increased in Alberta in recent years (Table 4-2). If all fixation rates and prices (2011) were kept constant the value of N fixed by faba bean in its lowest production year (2003) would have been \$26, 924 and in the highest production year (2004 and 2009) \$67,325. Similarly N fixation from pea production in its lowest production year (2002) would be valued at \$4,027,755 and in its highest production year (2009) \$6,865,491. If the land area dedicated to pea and faba bean production increased by 10% (from 2009 levels) the total value of N fixed annually according to above calculations would increase to \$74, 058 for faba bean and \$7,552,035 for pea.

Pulse seed is high in protein and can remove large amounts of N. In this study, on average, faba bean removed 188 kg N ha^{-1}, lupin 109 kg N ha^{-1} and pea 147 kg N ha^{-1} in the harvested seed. Most (~80%) of N in the above ground biomass of the pulses is exported in the seed which in some cases is more N than was fixed. Past and ongoing breeding efforts have focused on increasing yield and harvest index, developing adaptations for environmental stresses, producing disease resistant cultivars, reducing the effect of pests on growth and improving quality characteristics (Heyne and Smith 1967, Booth and Gunstone 2004). In some cases this focus may have reduced the potential benefit these crops could provide to subsequent crops in rotation. As an example, increasing harvest index reduces biomass returned to the soil and results in more nutrients being removed in harvested seed. With a holistic view of the agricultural system this may be seen as a disadvantage to subsequent crops in terms of nutrient availability in the soil. A determination of economic and environmental cost is needed to determine this balance. This may be a more important issue in organic systems than conventional because of the importance of crop residue breakdown as a nutrient source for subsequent growth.

In the present study N fixation differed between pulse crops; ranging from 41 to 201 kg N ha^{-1}. N returned in pulse crop residues was similar (22 – 47 kg N ha^{-1}) yet there was a yield response in the subsequent crops equal to N fertilization (78 – 90 kg N ha^{-1}) following faba bean and pea. The benefit to the subsequent crop was greater than that attributable to above ground biomass N. Below ground biomass was not measured and likely contributes to the N dynamics of this system. Future research needs to investigate the contribution of below ground N, but due to challenges in methodology development and funding this research has not occurred in Alberta. Identifying the N and non-N benefits of pulse crops will provide the knowledge to design and build a cropping system that is productive and sustainable. Research has indicated that there is a N benefit from the quicker break down of pulse residues in comparison to non legume residues (Strydhorst 2008, Lupwayi et al. 2004, Stevenson and van Kessel 1996), the additional N from the decomposition of pulse root systems (Strydhorst 2008, Gan et al. 2010), N released in the rhizosphere during pulse growth (Sawatsky and Soper 1991), or the stimulation of residue breakdown or subsequent crop growth from unidentified compounds (Stevenson and van Kessel 1996).

In our examination of nodulation, differences between pulse crop roots were observed which could contribute to the differences in subsequent crop growth. Faba bean roots were visually thicker with small nodules throughout, pea has similar roots and nodules but roots were much finer, and lupin generally had a single tap root with one large crown nodule (Figure 4-1). These root differences could affect nutrient acquisition, water use and root decomposition. Roots are generally difficult to study yet they may have a large effect on the growth of both the pulse crop and subsequent crops. There is currently a gap in our understanding of root structure and nodulation and its effect on pulse benefits.

This study demonstrated that N fertilizer could be eliminated in a subsequent barley, canola or wheat crop when preceded by a faba bean or pea crop. Non-legume crops generally require a large amount of N fertilizer. In the present study the soils were not severely deficient in N and soil tests recommended applications of 80 to 110 kg N ha^{-1} to produced a high yielding crop. The average area of barley, canola and wheat harvested in Alberta in 2008 and 2009 was 1,371,884 ha, 1,960,702 ha and 2,737,698 ha, respectively (Su, 2010). If 80 kg N ha^{-1} was applied as urea to these crops then the fertilizer expense would be $29 million for barley, $41 million for canola, $57 million for wheat. If pulse production increased and subsequent crops were grown on pulse stubble with the elimination of N fertilizer applications millions of producer dollars could be saved.

Optimal Cropping Sequences

The present study added to our knowledge about how crops interact with one another over multiple years. Pulse crops provide an N benefit to subsequent crops. Canola is a heavy user of N that can access the N provided by the pulses. Barley responds to available N with an increase in seed protein. This increase in seed protein reduces the value of a malt barley crop when malt quality standards are exceeded but an increase in seed protein increases the value of a feed barley crop. Wheat responds positively to pulse residue N and exhibits an increase in both yield and protein content when preceded by a pulse. With this knowledge it is clear that following a pulse with canola, wheat or feed barley may be more advantageous than a malting barley crop in utilizing the N most effectively.

In comparing cropping options we report an increase in barley, canola and wheat yields following faba bean or pea in comparison to barley no N, canola no N or canola +N treatments (Tables 4-3, 4-4, 4-5). Crops grown on pulse stubble had yields that were as high as 71% greater than no N treatments, and 29% higher than +N treatments. Wheat and canola had their highest yields on the barley +N stubble, but yields on faba bean stubble were only 10% lower for wheat (Table 4-5) and 2% lower for canola (Table 4-4). Barley had its highest yields on faba bean stubble which was 2% greater than barley +N stubble (Table 4-3).

This study demonstrates that pulses also affect the quality of subsequent crops. Protein content of seed following a pulse crop was generally lower than the '+N' treatments but higher that the 'no N' treatments (Table 4-1). Thus, pulse stubble increased protein content without the addition of N fertilizer.

Disease problems can be reduced by crop rotations. Increased crop diversity through growing different pulses such as faba bean or lupin will provide disease breaks. Also reducing the stacking of broadleaf crops or cereal crops for multiple years will help with disease problems. The conditions of this study were not such as to enhance disease development but including pulses in the rotation may provide a yield advantage when production conditions are optimal for cereal disease development. Diseases were observed when barley and canola crops were grown for 2 consecutive years, suggesting the need for diverse rotations.

Since there are few registered herbicides for pulse crops, care must be taken where they are located in the rotation. The largest weed problem in this study was volunteer canola in the year 2 crops grown on canola stubble. Producing barley or wheat following canola may offer more options for weed control. The disadvantage of monocropping was seen most clearly with glyphosate resistant volunteer canola in glyphosate resistant canola plots but volunteer barley was also a concern in YR2 cereal plots. This study clearly demonstrates that the benefits of diversifying rotations with pulse crops includes the control of volunteer crops, reduction in disease, and N and non-N benefits to subsequent crops.

Carbon Footprint

Rotations including pulses received no N fertilizer for 2 consecutive years in the present study. Production and application of N fertilizers is one of the major sources of greenhouse gas emissions from agriculture (Gan et al. 2011, Robertson et al. 2000). Effectively reducing the use of N fertilizers will improve the carbon footprint of agriculture. In this study we identified that by including pulse crops in rotation N fertilizer use can be reduced. Other research indicates that adding a pulse to a rotation can increase emissions from plant residue, but N fertilizer and other inputs can be reduced, which results in lower overall emissions for the rotation (Gan et al. 2011). Future studies investigating and quantifying the carbon footprint of different rotational practice will help improve the environmental sustainability of the agricultural system.

This research demonstrated the benefit of pulse crops in rotation. It investigated the effects of 3 cool season pulses on 3 subsequent crops. Differences were identified between the 3 pulses which indicate their unique characteristics and uses within the Alberta cropping system. This adds to the growing body of research on pulse N fixation and their response to different environmental conditions. Few studies have investigated more than one subsequent crop for response to production on pulse stubble. This study demonstrated that barley, canola and wheat all have increased yield when produced on pulse stubble. Quality of subsequent crops is also impacted by a preceding pulse; generally thousand seed weights were maintained and protein content was increased. Increasing the use of pulses in the Alberta cropping system would reduce production costs through decreasing N fertilizer, herbicide and pesticide use. Inclusion of pulses in the Alberta cropping system will improve sustainability through reducing environmental impact and increasing profitability of the production system.

Table 4-1: Summary of YR1 and YR2 data from the rotational study. Range of values from data averaged across years at Barrhead and St. Albert, Alberta, Canada.

	Faba bean	Lupin	Pea	Barley +N	Barley No N	Canola +N	Canola No N
Chapter 1 Data							
N Fixation (kg N ha^{-1})	55-201	41-58	51-124	0	0	0	0
% Ndfa	38-66	27-35	35-55	0	0	0	0
Seed Yield (Mg ha^{-1})	2.6-4.2	1.7	3.2-5.9	3.4-4.8	3.3-3.8	2.0-3.6	1.7-2.9
N removed (kg N ha^{-1})	123-252	102-115	111-182	79-90	61-65	137-235	112-204
Harvest Index	0.84-0.85	0.75-0.78	0.79-0.82	0.65-0.73	0.69-0.72	0.76-0.80	0.78-0.80
N returned (kg N ha^{-1})	22-47	33-36	30-39	30-49	26-28	44-62	34-51
Chapter 2 Data							
Subsequent Crop Yield	**(Mg ha^{-1})**						
Barley	3.0-5.1	2.3-4.2	3.0-5.0	2.8-5.2	2.4-3.9	2.5-5.1	2.0-3.1
Canola	2.3-3.5	1.8-3.0	2.2-3.2	2.3-3.6	1.7-2.9	2.1-2.4	1.4-2.0
Wheat	2.9-4.7	2.1-4.3	2.8-4.6	3.0-5.4	2.4-4.0	2.8-4.3	2.0-2.8
Subsequent Crop Protein	**(mg g^{-1})**						
Barley	128-145	127-146	127-141	142-158	123-140	122-163	114-140
Canola	326-356	328-354	327-342	334-383	337-322	395-356	317-326
Wheat	150-170	146-170	141-166	154-184	135-150	145-186	128-154

Table 4-2: Harvested area (ha) of faba bean and pea in Alberta from 2001 to 2009.

	Harvested area (ha)		
Year	**Faba bean**	**Pea**	**Reference**
2001	1214	246,858	Alberta Agriculture and Rural Development 2002
2002	1012	178,062	Alberta Agriculture and Rural Development 2003
2003	809	244,834	Alberta Agriculture and Rural Development 2004
2004	2023	265,069	Alberta Agriculture and Rural Development 2005
2005	1619	214,483	Alberta Agriculture and Rural Development 2006
2006	1619	228,647	Alberta Agriculture and Rural Development 2007
2007	1619	240,788	Alberta Agriculture and Rural Development 2009a
2008	1821	283,280	Alberta Agriculture and Rural Development 2009b
2009	2023	303,514	Alberta Agriculture and Rural Development 2010

Table 4-3: Response of subsequent barley yields to 7 stubble treatments in rotation averaged across Barrhead and St. Albert in 2009 and 2010.

	Stubble type						
	Barley +N	**Barley No N**	**Canola +N**	**Canola No N**	**Faba bean**	**Lupin**	**Pea**
Reference Stubble type				**%**			
Barley +N	-	-21	-5	-36	+2	-18	0
Canola +N	+5	-17	-	-33	+7	-13	+5
Barley No N	+26	-	+20	-19	+29	+3	+26
Canola No N	+56	+24	+49	-	+60	+29	+57

Table 4-4: Response of subsequent canola yields to 7 stubble treatments in rotation averaged across Barrhead and St. Albert in 2009 and 2010.

	Stubble type						
	Barley +N	**Barley No N**	**Canola +N**	**Canola No N**	**Faba bean**	**Lupin**	**Pea**
Reference Stubble type				**%**			
Barley +N	-	-23	-24	-43	-2	-20	-8
Canola +N	+32	+2	-	-25	+29	+6	+21
Barley No N	+29	-	-2	-26	+26	+3	+18
Canola No N	+75	+35	+32	-	+71	+40	+60

Table 4- 5: Response of subsequent wheat yields to 7 stubble treatments in rotation averaged across Barrhead and St. Albert in 2009 and 2010.

	Stubble type						
	Barley +N	**Barley No N**	**Canola +N**	**Canola No N**	**Faba bean**	**Lupin**	**Pea**
Reference Stubble type				**%**			
Barley +N	-	-24	-15	-43	-10	-23	-12
Canola +N	+18	-10	-	-32	+6	-9	+4
Barley No N	+32	-	+11	-25	+18	+1	+15
Canola No N	+74	+32	+47	-	+57	+34	+53

Figure 4-1: Faba bean (A), lupin (B) and pea (C) roots with N fixing nodules examined at mid flower.

Literature Cited

Alberta Agriculture and Rural Development 2002. Alberta 2002 specialty crop report. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd4671/$file/specialty02.pdf?OpenElement [8 July 2011].

Alberta Agriculture and Rural Development 2003. Alberta 2003 specialty crop report. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd6834/$file/specialtycropreport2003.pdf?OpenElement [8 July 2011].

Alberta Agriculture and Rural Development 2004. Alberta 2004 specialty crop report. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd8416/$file/2004specialtycropresults.pdf?OpenElement [8 July 2011].

Alberta Agriculture and Rural Development 2005. Alberta 2005 specialty crop report. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd9840/$file/2005-special-crops-results.pdf?OpenElement [8 July 2011].

Alberta Agriculture and Rural Development 2006. Alberta 2006 specialty crop report. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd11117/$file/specialcropsreport.pdf?OpenElement [8 July 2011].

Alberta Agriculture and Rural Development 2007. Alberta 2007 specialty crop report. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd11803/$file/report2007.pdf?OpenElement [8 July 2011].

Alberta Agriculture and Rural Development 2009a. Alberta 2008 specialty crop report. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd12490/$file/specialty_crops_final.pdf?OpenElement [8 July 2011].

Alberta Agriculture and Rural Development 2009b. Alberta 2009 specialty crop report. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd12862/$file/report2009.pdf?OpenElement [8 July 2011].

Alberta Agriculture and Rural Development 2010. Alberta 2010 specialty crop report. [Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd13340/$file/specialty_crop_report_2010.pdf?OpenElement [8 July 2011].

Alberta Agriculture and Rural Development 2011. Alberta Farm Input Survey Prices. [Online] Available: http://www.agric.gov.ab.ca/app21/rtw/surveyprices/graph.jsp?groupId=5&dataId=40 [8 July 2011].

Booth, E.J. and Gunstone, F.D. 2004. Rapeseed and rapeseed oil: Agronomy, production and trade. Pages 1-16. *in* F.D. Gunstone, ed. Rapeseed and canola oil: Production, processing, properties and uses. Blackwell Publishing Ltd., Oxford, UK.

Gan, Y.T., Campbell, C.A. Janzen, H.H., Lemke, R.L., Basnyat, P. and McDonald, C.L. 2010. Nitrogen accumulation in plant tissues and roots and N mineralization under oilseeds, pulses, and spring wheat. Plant Soil. 332: 451-461.

Gan, Y., Liang, C., Wang, X. and McConkey, B. 2011. Lowering carbon footprint of durum wheat by diversifying cropping systems. Field Crops Research. 122: 199-206.

Heyne, E.G. and Smith, G.S. 1967. Physiology. Pages 269-306. *in* K.S. Quisenberry and L.P. Reitz, eds. Wheat and wheat improvement. Agronomy Series Number 13, American Society of Agronomy, Wisconson, USA.

Lupwayi, N.Z., Clayton, G.W., O'Donovan, J.T., Harker, K.N., Turkington, T.K. and Rice, W.A. 2004. Decomposition of crop residues under conventional and zero tillage. Can. J. Soil Sci. 84: 403-410.

Robertson, G.P., Paul, E.A. and Harwood, R.R. 2000. Greenhouse gases in intensive agriculture: Contributions of individual gases to the radiative forcing of the atmosphere. Science. 289: 1922-1925.

Sawatsky, N. and Soper, R. J. 1991. A quantitative measurement of the nitrogen loss from the root system of field peas (*Pisum avense* L.) grown in the soil. Soil Biol. Biochem. 23:255-259.

Stevenson, F.C. and van Kessel, C. 1996. The nitrogen and non-nitrogen rotational benefits of pea to succeeding crops. Can. J. Plant Sci. 76:735-735.

Strydhorst, S.M. 2008. Faba bean and Lupin: New grain legume crops. University of Alberta, Edmonton PhD thesis.

Su, C. 2010. Alberta 2009 crop year in review. Alberta Agriculture and Rural Development, Economics and Competitiveness Division, Statistics and Data Development Branch, Government of Alberta, Edmonton, Alberta.[Online] Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd13100 [February 8 2011].

Appendix A: Soil Tests

Soil test analysis at Barrhead and St. Albert, Alberta, Canada for crop production in 2008, 2009 and 2010.

	Total Soil Nutrients			
	N	**P**	**K**	**S**
	kg ha^{-1}			
Barrhead				
YR1				
Spring 2008	42.6	75.0	369.6	76.2
Fall 2008	45.9	44.8	373.0	59.4
YR2				
Fall 2008	59.9	61.6	512.4	65.0
Fall 2009	103.0	53.2	36.4	70.6
St. Albert				
YR1				
Spring 2008	49.3	134.4	506.2	38.1
Fall 2008	52.6	134.4	405.4	33.6
YR2				
Fall 2008	89.6	114.8	523.0	54.9
Fall 2009	59.9	127.7	656.9	69.4