OPTIMAL AGRONOMIC CONDITIONS FOR SPRING AND WINTER CANOLA (*BRASSICA NAPUS* L.) PRODUCTION IN NORTHERN IDAHO

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Authorization to Submit Thesis

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Abstract

Small grain cereal crops dominate throughout dryland agricultural regions of the Pacific Northwest (PNW), where wheat is grown on 85% of the hectarge. The primary rotation crops such as dry peas, lentils, or garbanzo beans are only suited to the high rainfall areas where annual cropping is possible. Lack of economically viable alternative crops to grow in rotation with wheat has increased grower interest in growing spring and winter canola because these have shown beneficial effects on subsequent cereal productivity. Higher yielding canola cultivars combined with competitive prices have increased canola acreage in the PNW region. Although better adapted canola cultivars are now available to growers, few attempts have been made to optimize productivity through agronomic management of the crop. This experiment determines optimum agronomic conditions (nitrogen levels, seeding rates and seeding dates) to maximize growers' productivity and profitability of a range of adapted canola cultivars.

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Dedication

This thesis is dedicated to the farmers of the Pacific Northwest.

May you always have questions and may we always be looking for solutions.

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Chapter 1: Introduction

Global canola production has increased over the past forty years, rising from the sixth largest oil crop to second. Canola is produced extensively in Europe, Canada, Asia, and more recently in Australia. Two species, *Brassica napus* L. and *B. rapa* L., and to a lesser extent by the mustards *B. juncea* L. (Indian mustard) and *Sinapis alba* (yellow mustard) supply the world's commerce.

Within the United States (U.S.), rapeseed crops have been grown only on a very limited scale, and canola in the U.S. is still considered a new crop. U.S. domestic production was minimal until Generally Recognized as Safe (GRAS) status was granted by the Food and Drug Administration in 1985, allowing locally produced canola oil to be used in foods manufactured in the U.S. Since GRAS status approval U.S. canola production has increased dramatically from 62,775 hectares in 1992 to 545,940 hectares in 2014. However, the growth in U.S. demand for canola oil and seed meal for livestock feed has greatly outpaced domestic production. Canola oil demand has more than quadrupled from 369,573 Mt in 1992, to 1,474,666 Mt in 2014. Demand for canola meal has increased faster than for canola oil; it has drastically increased from 563 Mt in 1992 to 3,269 Mt in 2014.

Successful adoption of canola crops in the U.S. has so far been limited to one relatively small region in North Dakota, where 87% to 95% of all U.S. canola is grown each year. Perhaps it is not surprising that this region is adjacent to the major canola producing region in Canada, and has a very similar growing environment.

Canola is most adapted to U.S. production regions where wheat is the predominant crop. North Dakota produced 3,031,095 hectares of wheat in 2014, while Oklahoma produced 1,133,119 hectares and Montana grew 2,286,473 hectares in 2014. In the Pacific Northwest (PNW) specifically the states of Idaho, Oregon and Washington, wheat was grown on 1,725,579 hectares, accounting for more than 80% of all dryland production in 2014.

Many have suggested that canola would be an ideal rotation crop with wheat in the PNW, increasing agronomic sustainability in a mainly mono-culture wheat cropping system. Canola would add diversification to dry-land farmer's rotations. It has the same growing season as wheat, and growers can use the same equipment for planting and harvesting as for wheat. Adopting a suitable crop rotation can increase overall crop yields, decrease weed populations, reduce insect and disease infestations, improve soil health and fertility, and reduce soil erosion.

Although canola yields in the PNW are higher than in other U.S. regions, PNW canola hectarage has yet to meet the expectations many had predicted. This reluctance to adopt canola can be attributed to high wheat yields in the PNW, typically generating much higher returns than for canola. PNW dryland wheat yields on average produce higher yeidls (1,780 kg more per hectare) than in North Dakota, Oklahoma or Montana. Farmers are therefore hesitant to replace wheat, a crop with high economic returns crop that has been grown by their fathers and grandfathers for decades, with an unfamiliar rotational crop.

Variety testing; and genetic improvements of cultivars has significantly increased yield potential for spring and winter canola over the past 20 years. In recent years, the hectarage of canola in the Pacific Northwest has risen and continues to increase, albeit at a slow rate. Particularly for farmers in northern Idaho looking for a new rotation crop, canola is key. Information on canola production is limited among PNW growers. These growers have tended to adapt agronomic practices for canola based on those used in Canada or Europe.

The availability of new and adapted cultivars in combination with better understanding of the correct agronomic practices is needed for this region. Along with the combination of extension and outreach programs to educate new growers on the best management practices to maximize canola productivity will likely increase production in the region to meet the local demand to meet recently developed crushing capacity.

This project addresses some of the agronomic factors limiting larger hectarage adoption of canola in the PNW. Characteristics examined include planting date, nitrogen management, cultivars, tillage practices and seeding rate, and their impact on pre-harvest and post-harvest performance.

The specific objectives of this research were to:

1. Evaluate the performance of four adapted spring and two adapted winter canola cultivars under six variable nitrogen treatments, three seeding rates and two seeding dates.
2. Conduct a grower survey to identify advantageous and detrimental practices in order to optimize canola production.
3. Investigate the economic feasibility of canola.
4. Combine information from these studies to formulate best management practices for maximized productivity and profitability for spring and winter canola in the PNW.

Chapter 2: Literature Review

2.1 Brassicaceae crops

Brassicaceae oilseed crops are propagated worldwide and include cultivars from species including: *Brassica napus*; *B. rapa*; *B. juncea*; *B. carinata*; *Camelina sativa*; and *Sinapis alba.* Canola (synonymous with oilseed rape and rapeseed) is primarily produced from *B. napus, B. rapa,* and more recently, *B. juncea* (Rakow, 2004).

2.2 Origin

Brassica crops are among the oldest cultivated plants belonging to the Cruciferae (Brassicaceae) family, also known as the mustard family with records dating back to 1500 BC and archaeological evidence dating back to 5000 BC (Smartt and Simmonds, 1995)

B. napus evolved as the result of an interspecific cross between *B. oleracea* (n=9, CC genome) and *B. rapa* (n=10, AA-genome) (Olsson, 1960). *B. rapa* had the widest geographic distribution historically. There are several hypotheses as to where it evolved including the coasts of northern Europe and coastal cliffs of New Zealand or the Mediterranean region where the parents grow wild (Rakow, 2004). It is thought that *B. napus* could have formed at various places from crosses between different forms of *B. oleracea* and *B. rapa*. However, these recorded sightings may have been escapes from cultivation. Others believe *B. napus* is unlikely to exist in a wild form (Raymer, 2002).

Regardless of its evolutionary history, *B. napus* is the allotetraploid having the AACC-genome (n=19). It is largely self-fertile with outcrossing rates averaging 30%, ranging from 10% to 50% under field conditions. Outcrossing of canola is primarily by wind and insects (Olsson, 1960; Rakow and Woods, 1987; Lewis and Woods, 1991).

2.3 Canola development and oil production

Erucic acid, is a fatty acid that can comprise up to 50% of the total fats in rapeseed oil. Erucic acid is not metabolized well in human or animal diets, and is nutritionally undesirable. Consumers had a negative perception of the use of rapeseed oil in the household, as it was previously used to lubricate engines. Indeed, it was concern over the erucic acid content in rapeseed oil that prompted Canadian plant breeders to genetically reduce erucic acid content below 2% of total fats, production the first edible oil quality cultivars of *B. napus* and *B. rapa* in late 1960's and early 1970's, respectively, for each cultivar(Riggens, 1992). This breeding development provided the opportunity for rapeseed oil to be used in food products for human consumption. The high protein meal byproduct is primarily used for animal feed after the seed is crushed and the oil removed. Palatability and feeding efficiency are reduced due to glucosinolates in rapeseed meal. Genes that reduced the formation of glucosinolates to less than 30µmol g^{-1} of defatted seed meal, were introduced into the low erucic-acid cultivars. These became known as double-low cultivars and quickly became the most widely grown rapeseeds (Downy, 1990). In 1978, the rapeseed industry in Canada adopted the name 'canola' to identify these new double-low rapeseed varieties and distinguish them from industrial rapeseed. Seeds, oil and meal from canola can be produced from *B. rapa, B. napus* and more recently *B. juncea* crops (Downey, 1990). By definition canola oil must have less than 2% erucic acid and less than 30 µmoles of total glucosinolates in the defatted seed meal (Riggins, 1992). Canola cultivars had no deleterious adaptability effects from the removal of the erucic acid and glucosinolates (Downey, 1990).

Subsequently, breeding programs have further altered canola fatty acids to reduce polyunsaturated fats and hence increase shelf life of fry oil, to create an oil suitable for the plastics industry, to increase nutritionally neutral fatty acids and, decrease saturated fats.

2.4 Canola biology

Of the tribe Brassicaceae, *Brassica* is agronomically the most important genus, followed by *Raphanus*, valued for its edible roots, and *Sinapis*, a condiment crop (Rakow, 2004).

Worldwide *Brassica* crops are important vegetable crops. There are many species that are utilized, however *B. oleracea, B. napus, B. rapa* and *B.juncea* are the primary importance (Rakow, 2004). In temperate regions *B. oleracea* is widely grown but appears best suited where cool temperatures are prevalent in areas such as northwest Europe and former USSR territories (Hodgkin, 1995).

Brassicaceae produce a large tap root before flowering. Other vegetables in this genus include kales, collards, cabbages (Brussel sprouts), kohlrabi, inflorescence kales (broccoli and cauliflower), brush kales and Chinese kale. These vegetables are typically consumed locally; with production centers located in southern California and Brittany in France (Rakow, 2004).

Root and leaf products provided from *B. napus;* are used both as human feed and animal fodder. Part of this root production include swedes, known as neeps in Scotland and rutabagas in North America (McNaughton, 1955; Rakow, 2004). When used as fodder in northern Europe and New Zealand *B.napus* is either used for grazing or, stored and used as silage for winter feeding.

The roots leaves and seeds in *B. rapa* are utilized. Leaves are used in cattle forages, salad greens or pickling. Fodder crops using turnip greens are common in northern Europe and New Zealand; however, their importance is decreasing. The turnip, a root vegetable, is important in the Orient, North America, northern Europe and Australia due to its adaptability in these areas. It is often grown in home gardens but this is a minor use of the species and unlikely to increase in popularity. In China and Japan, using the leaves as a vegetable, known as the salad green Chinese cabbage, is common; this practice is becoming popular in northern Europe and North America as well (McNaughton, 1955). However, much of the production of this crop is also consumed locally (McNaughton, 1955; Rakow, 2004).

The germination of the canola's small rounded red, black or brown seed is epigeal (Auld *et al.,* 1977). The growing point of the plant is pushed a short distance above the soil level between the twin heart-shaped cotyledons of the canola seedling. Up to six waxy blue-green leaves develop as a rosette; environmental factors will determine the duration of this event (Gareau and Auld, 1992). Winter canola plants will not flower until the crops has undergone vernalization or cold treatment. Before the onset of winter weather the following year, the canola will have a long growing period to become well established with deep roots. Having satisfied its vernalization requirements, winter canola will flower and produce a seed crop. Canola has a substantial taproot with several small laterals. Canola has an extensive root system (Weiss, 1983) and root hairs (Hammac *et al.,* 2011) which gives it high root surface area and potential to remove nutrients from soil. The rooting depth for winter and spring canola has been reported as 65 and 46 inches, respectively (Johnston *et al.,* 2002).

Floral induction is dependent on photoperiod and temperature. These events are followed by stem elongation (bolting) and branching (Auld *et al.,* 1978) by plant height and degree of branching can vary variety and planting density. Borne terminally on elongated racemes of the main stem and branches bright yellow flowers will appear. Complete and perfect flowers form four sepals, four petals and six stamens (two outer and four inner) that surround the pistil. This pistil is receptive to pollen for about three days prior to and after anthesis (Auld *et al.*, 1980). About 40% to 50% of the flowers on the canola will develop a narrow pod or silique (Gareau *et al.*, 1990). These pods have two carpels containing 15-40 seeds which are separated by a false septum that can shatter readily when the pod is mature. The seed embryo is covered by a thin endosperm layer and thin reticulated seed coat. Of the conduplicate cotyledons the oil content ranges from 30% to50% (Kephart *et al.*, 1988). Two weeks prior to maturity most of this seed oil is laid. (Thomas, 1984). Canola also has an indeterminate growth habit, which means that the individual plants are capable of expanding to utilize available space. In fact canola is reported to be capable of producing near maximum yields with stand reductions of 50% of more (OMAFRA, 2011).

B. napus has become well adapted to high altitude temperature and cool moist climate growing regions and has also been grown successfully as a winter crop in some sub-tropical areas. In the Pacific Northwest (PNW) of the United States (U.S.) *B. napus* performance has ranged from poor to excellent depending on specific environmental conditions. Crop yield may also be influenced by plant adaptation, cultural practices and fertility regimes. The potential of canola as an alternate crop has showed promised enough to warrant further investigation.

2.5 World and local trade

Global canola production has grown rapidly over the past forty years, rising from the sixth largest oil crop to the second largest (USDA, NASS 2013). It is a major edible oil in China, India, Japan, Canada and many European countries which are also are the major importers. Major exporters include China, India and Canada. Second only to soybean, canola (oilseed rape) is now the most important source of vegetable oil in the world (USDA, NASS 2013).

2.6 U.S. canola

Canola is produced extensively in Europe, Canada, Asia, and Australia and to a limited extent in the U.S. Two species, *B. napus* L. and *B. rapa* L. and to a lesser extent by the mustards, *B.*

juncea L. (Indian mustard) and *Sinapis alba* (yellow mustard) supply the world's commerce (Raymer *et al.*, 1990).

Within the U.S. rapeseed crops have been grown on a limited scale, yet canola in the U.S. is considered a new crop, in the sense that its history is relatively short here (Raymer *et al.*, 1990). U.S. domestic production was minimal until GRAS (Generally Recognized as Safe) status was granted by the Food and Drug Association (FDA) in 1985, allowing locally produced canola oil to be used in foods manufactured in the U.S. (Raymer *et al.*, 1990).

Since GRAS status approval U.S. canola production has increased dramatically from 62,775 hectares in 1992 to 545,940 hectares in 2014. The growth in U.S. demand for canola oil (and seed meal for livestock feed) has continued to outpace the growth in domestic production. Canola oil demand has more than double from 369,573 Mt in 1992 to 1,474,666 Mt in 2014.

Over the past 10 years, the U.S. canola situation has changed. Between 2013 and 2014 growers in the U.S. planted nearly 511,902 to 644,160 hectares, respectively, producing 1,144,499,950 kg of canola seed in 2014 (USDA, NASS 2013). As in earlier years North Dakota accounted for by far the highest hectarage 477,529 hectares, but there is now little possibility of increased hectares in the North Dakota region. Instead, greater hectarage increases have been found the Oklahoma and the PNW regions. Oklahoma canola hectarage has increased from no canola to 66,773 hectares in the past few years. Similarly, the canola hectarage in the PNW has increased quite dramatically to 64,345 hectares, 16,187 hectares in Idaho, 4,856 hectares in Oregon, 18,210 hectares in Washington and 25,091 hectares in Montana (USDA, NASS 2013).

In 2014, average canola yield was 1,816 kg hectare^{-1}. Average canola yield in North Dakota was generally high at 2,038 kg hectare^{-1} compared to Montana at 1,724 kg hectare^{-1}, Idaho 1,792 kg hectare^{-1}, Oregon with 1,680 kg hectare^{-1}, and Washington at 1,904 kg hectare^{-1}. In contrast, canola yield in Oklahoma was markedly lower at only 1,568 kg hectare^{-1} (USDA, NASS 2013).

Successful adoption of canola crops in the U.S. has so far been limited to only one relatively small region in North Dakota where between 87 and 95% of all U.S. canola is grown. Perhaps it is not surprising that this region is adjacent to the major growing regional of Canada and has a very similar growing environment (NASS, 2001).

2.7 Economic importance

Canola (*B. napus*) is the most productive Brassicaceae oilseed crop with both winter and summer annuals grown worldwide. Seed oil is used for industrial (rapeseed) and culinary (canola) uses, as well as being a condiment in India (Downey, 1966). Canola meal is second largest protein meal produced in the world; although it is dwarfed in size by the production of soybean meal (USDA, NASS 2014). Canola hectarage in Idaho has risen in recent years as a result of higher yielding cultivars and higher pricing. The increase in popularity of canola is due to increased demand for healthy oil substitutes and caused a reduction in production of high erucic acid rapeseed.

Since 2,000 BC *Brassica* crops have been grown in Japan, China and India (Downey, 1966; Weiss, 1983). *B. napus* was used historically for lamp oil and often as a fuel, food, fooder, fertilizer, lubricant, and ink (Appelqvist and Ohlson, 1972; Downey, 1966; Bunting, 1986; Downey and Robbelen, 1989).

Around the 13th century European cultivation of *B. napus* began and the primary use of oil was for oil lamps. During the middle ages, seed crushing industries were established as rapeseed oil became the primary lighting oil and was used in northern Europe as a food source for lower classes (Bunting, 1986). The industrial revolution caused the expansion of rapeseed in Europe as the oil was ideal for lubricating steam engines. Rapeseed production declined by the end of the 19th century in Western Europe due to cheaper sources of mineral and petroleum oils while other oilseeds became available from areas in Asia and Africa. During World War II a resurgence in the cultivation of rape began due to a wartime supply shortage of oilseeds. Due to research developments in Canada cultivation in canola have accelerated to the current day levels (Downey, 1966; Downey *et al.,* 1974; Weiss, 1983; Bunting, 1986).

Before World War II North American production of *B. napus* and *B. rapa* did not begin until there were shortages of marine oils and lubricants (Downey, 1966). Canadian farmers were contracted to grow this oilseed for the allied effort, during this time they found it to be well adapted to numerous environments. Canadian farmers had previously grown the crop on previous oat land the oats were used to feed horses which were replaced by tractors (per. communication Jack Brown). They also found that it fit in nicely as a break crop in their grain production rotations. After the war Canadian researchers developed both *B. napus* and *B. rapa* into viable commodities for both edible and industrial uses (Downey, 1966; Daun, 1984; Downey and Rakow, 1987). Production began to increase dramatically due to early maturing new cultivars that were introduced improving both yield of seed and oil quality. Major advances in seed quality with reductions of erucic acid and glucosinolates content coupled with improved agronomic practices resulted in large hectarage increase for both *B. napus* and *B. rapa* by the late 1960's.

The Canadian government officially changed the name of rape to canola by the 1980's when the crops was established to be a billion dollar industry, and to distinguish canola products it from its earlier, less nutritionally acceptable rapeseed form and to make it a more marketable product by avoiding the sexually violent connotations of the word 'rape'.

Asian production is less well-documented. Most of the rapeseed production mainly of *B. rapa* and *B. juncea* species until recently was in China and the India subcontinent. Production of *B. napus* is known in parts of China (Singh, 1958; Liu, 1984). *B. napus* is currently the most important oilseed crop grown in Europe, Canada and Australia.

Canola quality oilseeds from a nutrition standpoint for human and livestock consumption makes this species an attractive alternative crop for the inland PNW and helped it to provide a wide acceptance. The wide variation that exists within *B. napus* and closely related Cruciferae species makes the development of better adapted cultivars bred specifically for the local growing areas possible.

2.8 Demand

Demand for canola products continues to rise in the U.S., and indeed worldwide. Canola and rapeseed has many edible and industrial uses (Downey, 1966). The edible types (canola) are primarily used as frying, salad oils, margarine, shortening, non-dairy fat substitutes, pet foods, and supplemental vitamin E (Downey, 1966). The industrial (rapeseed) uses include: lubricant oils and greases; plastics manufacture; floatation agents in potash mining; bio-fuel feedstock;

printing inks; lacquers; detergents; emulsifiers; fertilizers; pesticides; and as a component in asphalt (Downey, 1966).

Total domestic consumption of canola has been growing in the U.S., reflecting its common use in the home and especially in the fast-food establishments. Canola oil production 1,800 Mt for U.S. between 2013 through 2014. Major vegetable oils production totals from 2014 through 2015 are 10.73 million Mt for U.S. The U.S. is one of the largest buyers of Canadian canola seed, oil, and meal. With a total export value of 136,000 Mt of canola oil. (ERS, 2014). Total vegetable oil consumption in the U.S. exceeds 12 million Mt a year with canola currently ranked as the country's second most popular edible oil.

Potential canola hectares in the U.S. calculation assumes that domestic consumption and exports will remain the same over time, although domestic consumption of canola seed in the U.S. has been increasing, and canola seed exports have increased by greater than double from 1991 to 2014. It also assumes that domestic production of canola seed and oil in the U.S. could replace all imports if we could produce addition 3,719,566 hectares of canola.

In the PNW, there is a growing demand for determining agronomic practices that optimize canola production. Canola is a relatively new crop in the sense that is has not been readily adapted and grown in the region and there have been few research results on canola production available to growers. Current spring canola farmers in northern Idaho have adapted much of their practices from Canada and winter canola growers have adopted mainly European cultivars and practices. Neither the Canadian nor European environments mimic those in the PNW nor is it no surprise that developing appropriate agronomic practices along with adapted cultivars will make canola a more economically attractive crop for growers. Especially since canola grower can use the same small grain cereals equipment (i.e. planters, sprayers and harvesters), limiting the need for large investments in machinery. Grower input costs of canola are similar to those for winter wheat. The low investment costs and increasing consumer demand for canola oil make it a potentially good alternative crop for growers (Nelson, 1992).

Canola is here to stay in the PNW and farmers are now looking for information they can use to produce these crops economically. Farmers are looking to fine-tune management practices so that they will be able to make appropriate decisions on incorporating these factors into their current production systems.

2.9 Idaho and PNW dryland agriculture

Idaho agriculture represents a large portion of the state's economy and supports one of the nation's most diverse agricultural economies. Between famous potatoes and high quality wheat Idaho's agricultural products are known worldwide. The 2002 Census of Agriculture by the USDA reports that 22% of the land or 47,630 km^2 in Idaho is used for agricultural purposes. The average farm size is 1.9 km^2 and the average age of the farm operator is 54.1 years (ERS, 2010). Northern Idaho has some of the most favorable conditions for farming from sufficient rainfall and rolling hills covered with rich fertile land. The dryland farming region of the PNW has a long history of growing small grain cereal crops, such as wheat and barley. Soft white winter and soft white spring wheat are the predominant small grains grown in Idaho, and comprise about 99% of Idaho's total wheat production (USDA, NASS, 2014). Hard red winter wheat (1%) account for the remaining small grain crops (USDA, NASS, 2014). Barley is grown throughout Idaho, and is rank 1st in production in the nation (Idaho Farm Bureau Federation, 2013) with 206,389 hectares planted in 2014 (USDA, NASS, 2014). With such a high proportion of the PNW in continual cereal production it is not surprising that many growers have shown a willingness to increased crop diversity by including a legume crop (pea, lentil or garbanzo bean) or Brassicaceae crop (canola or mustard) into their rotations. Depending on annual precipitation, cropping systems in the PNW will vary. Approximately 1.7 million ha receive 200 to 350 mm of annual precipitation, and in these regions farmers traditionally rotate winter wheat (*Triticum aestivum* L.) with summer fallow although a small hectarage of winter canola (*B. napus* L.) is grown in this region (Schillenger, 2006). Widening crop diversity has been shown to have beneficial environmental and economic results compared to rotations with only cereal crops (Peterson and Rohweder, 1983).

In the PNW there is 1.3 million hectares of land in a grain-fallow rotation and less than 2% of this is planted into canola (Brown *et al.*, 2008). In 2013 and 2014 growers in the U.S. planted 22,725,526 and 22,854,216 hectares of wheat, respectively (USDA, NASS, 2013). Within the PNW in 2014 wheat was planted on 526,496 hectares in Idaho, 331,842 hectares in Oregon, and 918,636 hectares in Washington (USDA, NASS, 2013).

2.10 PNW topography, climate and rainfall restrictions

Topography in the dryland region of the PNW ranges from nearly flat to sloping uplands. About 70% of the cropland in the PNW has slopes of 8 to 30% with some areas exceeding 50% (Papendick *et al.,* 1983). These slopes are not only steep, but highly irregular.

Humid winters and hot dry summers characterize the Mediterranean climate of the inland PNW. Westerly winds predominate (Skidmore and Woodruff, 1968). Greater than 60% of the precipitation occurring from November to March while annual precipitation ranges from 200 to 600 mm (Papendick *et al.,* 1983). During most winters freezing weather and snow cover can be interrupted by rains and complete thawing. Storms within this region can provided from trace to 50 mm of precipitation.

2.11 Including Brassicaceae crop in crop rotations

Canola can germinate and grow in cool temperatures, it is one of the few oilseed crops that can be cultivated over wide areas of the temperate zone. Winter canola normally produces about twice the yield of spring canola in the same production area even though winter and spring varieties of canola have both been developed (Ehrensing, 2008). Canola can be grown in dryland situations and under irrigation systems.

Adopting a suitable crop rotation can increase overall crop yields (Classen and Kissel, 1984; Larney and Lindwall, 1994; Bourgeois and Entz, 1996), decrease weed populations (Liebman and Dyck, 1993), reduce insect and disease infestations (Krupinsky *et al*., 2004), improve soil health and fertility (Weinert *et al*., 2002; Vos and Van Der Putten, 2004) and reduce soil erosion (Peterson and Rohweder, 1983). Increased crop diversity often increase benefits. The use of a legume or an herbaceous dicot within a crops rotation can have beneficial result on wheat yields than rotation with a more closely related crop such as a barley (*Hordeum spp*.)(Peterson and Rohweder, 1983).

A survey conducted in 1997 by the University of Idaho on cropping systems found that 89% of the Idaho grain producers use crop rotation to control weeds, 69% to control insects and 70% to control disease (Fuchs, 1996). While 98% used herbicides and 61% used pesticides rotations to reduce the specific herbicides (Fuchs, 1996). 2% reported using insecticides and fungicides on a regular basis and another 73% used field scouting routinely to determine pest levels (Fuchs, 1996).

Very few alternative crops are adapted to PNW regions with less than 350 mm of annual precipitation suffer from a lack of summer rainfall. Within this system the limited choice of rotational crops makes it difficult to break disease, weed and insect cycles that result from a cereal monoculture.

Crops of the *Brassica* species such as winter and spring canola and yellow mustard have proven to be advantageous crops when combined within cereal rotations (Johnston *et al*., 2002). Very few studies have quantified the exact rotational benefit of including canola with small grain cereals. From 2006 to 2009 a farm test was conducted near Ritzville Washington where it was shown that returns from winter canola was 34% less than winter wheat; however, winter wheat following canola yielded over 39% more than winter wheat following winter wheat (Esser, 2012). In addition, market price differential between the two crops can vary dramatically from year to year which can have a larger influence on profitability. However, canola needs to have a farm price value 26% higher per bushel over wheat to produce greater gross returns (Esser, 2012). Within Europe rapeseed and canola have long been valued as break crops for a primarily small-grain cereal rotation (Ward *et al.,* 1985). Wheat following canola has been discovered to have significantly less internode damage and take-all (*Gaeumannomyces graminis var. tritici*) symptoms than if wheat followed a plowed and burned stubble practice (Finnigan, 1994), and yielded better than when it followed another small grain crop (Kirkegaard *et al*., 1997; Guy and Karow, 1998). Spring wheat and barley following canola in a rotation showed an increase in seed quality and decline in disease incidence (Wilson, 1994). Within Europe the use of rapeseed/canola in crop rotation with small grain cereals has long been valuable part of their cropping rotations (Ward *et al.,* 1985). With the incorporation of rapeseed/canola in crop rotation pathogens in the soil and in straw residue can be dramatically reduced over time (Finnigan, 1994). An incidence on spring wheat and barley following canola in crop rotation reported an increase in seed quality and a decline in disease (Wilson *et al.,* 1994). It has also been shown that winter wheat that followed both winter and spring planted rapeseed also has greater seed yield than when following small cereal grains (Guy and Karow, 1998).

In the U.S. soil loss from water erosion is as severe in the PNW as anywhere (McCool *et al.,* 1976). On about 70% of the dryland cropland in the PNW water erosion is a major conservation problem. This issue is most severe in the steeply sloping area of the Palouse and Nez Perce Prairies in eastern Washington, eastern Oregon, and northern Idaho (CAST, 1975). In some areas soil losses may average 10 to 50 Mt hectare $^{-1}$ in a year and can exceed 450 Mt hectare^{-1} some years in particular fields (ECS-FS-SCS, 1978). The combination of winter precipitation, steep slopes, and management practices that leave the soil pulverized and unprotected during the rainy season results in a high soil loss. On course-textured soil sand where annual precipitation is less than 300 mm wind erosion is most serious (Leggett *et al.,* 1974). In early spring and fall when the soil surface is dry and unprotected wind erosion is most hazardous (Skidmore and Woodruff, 1968). Summer fallow fields proved to be the most vulnerable to blowing winds due to their surface residues and roughness. In areas of the dryland PNW that receives greater than 350 mm of annual precipitation have long included spring pea in with their small cereal grain rotations. Crop rotations of small grain cereals with pea and lentil, lacks sufficient crop residue for ground cover is at great risk of soil erosion. Winter canola crop residue can exceed 3,000 kg hectare^{-1} (Gareau and Guy, 1995) which reduces soil erosion, water run-off and nutrient leaching and can increase soil organic matter. Pea and lentil crops maintain less than 25% ground cover during the winter months and commonly produce only 450 to 900 kg residue hectare^{-1} (Gareau and Guy, 1995). For maximum seed yield and quality adequate weed and insect control is essential in pea and lentil crops (Murray *et al.,* 1987). In both cases grass and broadleaf weeds become problems controlled by multiple herbicide applications. Several insect pests can also infect peas and lentils that require insecticide applications for control.

In the near future availability of pesticides for pea, lentil, and canola may be a problem. The Environmental Protection Agency (EPA) has divided chemicals into groups according to risk to public health with those chemicals that are the greatest risk being placed in Priority Group I to meet the Food Quality Protection Act (FQPA) requirements (EPA, 1998). Organophosphates and carbamates are two current pesticides types classified as

Priority Group I. Presently, a large number of pesticides used on pea, lentil, and canola are part of those pesticide types. Production cost may potentially increase as more expensive chemicals may have to be used, or the possibility of not having a pesticide option to control pest may arise.

Within this region farmers rely heavily on a continuous application of group 2 herbicides. In this group include Beyond™, Maverick™, Olympus™, Olympus flex™, Osprey™, and Powerflex™. The over use of group 2 herbicides increase the potential for herbicide resistant populations of winter annual grassy weeds such as downy brome (*Bromus tectorum L.*) and jointed goat grass (*Aegilops cylindrical*) (Campbell, 2011). With a very limited history in this region and short term agronomic and economic risks in rotation winter canola (*B. napus* L.) can offer non-Group 2 grassy weed herbicide options such as RoundUp Ready® technology. With the potential to reduce Group 2 herbicide resistant weed population's winter canola has the ability to be a viable crop to incorporate into a winter wheat summer fallow rotation to compete economically with winter wheat (Esser, 2012).

2.12 Factors and constraints limiting growth of canola

Canola is currently grown on limited hectarage in the U.S. despite the benefits from including canola in a crop rotation. A major hurdle to increasing hectarage of canola in the PNW is inconsistent yields. Spring canola in the PNW often fares poorly because limited water availability combine with high summers temperatures interferes with flowering and reduce yield (Kirkland and Johnson, 2002). Winter canola, traditionally planted as a winter annual has twice the yield potential of spring canola but when planted after a summer fallow the soil is often too dry to permit good establishment.

There are very few non-cereal crops that are adapted to the growing conditions in the dryland region of the PNW. With this limited choice of rotational crops it makes it very difficult to break disease, weed, and insect cycles that result from cereal monoculture.

It has been noted that both winter and spring planted rapeseed/canola incorporated into crop rotation in the PNW will have provide some difficulties to growers despite the benefits of Brassicaceae crops in crop rotations. Stand establishment failure is the major risk for production of winter canola in the PNW. Winter Brassicaceae crops must be sown in mid-

August, requiring summer fallow and high seed zone moisture during a period of traditionally low moisture which could also lead to rotational problems. Delaying fall planting to allow for adequate seed zone moisture can result in overly cool soil temperatures causing poor stand establishment or small plants with poor winter hardiness (Ehrensing, 2008).

It can also be challenging to establish winter and spring *Brassica* crops in conservation tillage due to slow seedling emergence through the straw and poor juvenile winter survival (Wittman, 2005). Spring Brassicaceae crops must be sown in mid-April, requiring winter fallow and high seed zone moisture. Late planting of spring canola reduces the vegetative period before flowering combined with higher temperatures during flowering and seed set, which will most likely because a decreased yields Brassicaceae require higher soil moisture for germination than wheat or barley (Kephart and Murray, 1990).

Canola requires higher moisture levels than wheat and barley seedlings during germination and emergence (Kephart and Murray, 1990). In areas of the PNW that receive less than 350 mm of annual precipitation, moisture is often unavailable. Temperatures that were high shortly after seedling emergence can also damage and kill young canola plants by burning the stems at the soil surface (Ehrensing, 2008). Multiple insecticide applications are needed for spring and winter planted *B. napus* that lack resistance or tolerance to insect pests (Brown *et al.,* 1994).

Within the U.S. several other production regions have demonstrated good potential for canola production, however, very little growth has happen over the past 15 years (Raymer *et al.,* 1990). Most other regions In the U.S. are still struggling to develop or sustain viable canola industries. The introduction of canola anywhere besides the Northern Plains has largely been unsuccessful due to the host of problems that are all too familiar to those of us who work routinely with new corps (Raymer *et al.,* 1990). Some of these problems include the absence of local markets and the unavailability of locally adapted varieties along with the lack of registered crop protection chemicals and also the reluctance of farmers to adopt a new crop. Also various production challenges and the absence of infrastructure, meager research funds, limited crushing capacity and strong world competition combined with no incentives for domestic production have each played an individual role in stifling commercialization efforts in one or more regions (Raymer *et al.,* 1990).

The most common constraint is the formidable chicken to egg dilemma that is caused by the large initial production level that is required for profitable commercialization. Requirement of 20,000 ha or more of production by local crushers are in order to justify handling and to switch the facilities over to crush and market oil and meal (Raymer *et al.,* 1990). Within the local processing facility in Warden Washington it can take in 350,000 Mt of canola seed and process 136,200,000 kg of oil (PCC, 2014). Growers have no incentive without markets to grow the crop. Several successful years of production back to back are necessary to build up the grower confidence and the production of the crop to the size necessary to establish profitable and reliable local markets (Raymer *et al.,* 1990).

2.13 Optimizing canola

The seed yield is a function of interaction between genetic and environmental factors including soil type, sowing time and method, seed rate, fertilizers and time of irrigation among which, row spacing plays a vital role in getting higher yield (Hussain, 2003).

2.14 Tillage practices

Farm land in the PNW has traditionally been intensively tilled using moldboard plows, tandem disks or chisel plows. In this thesis this system will be considered conventional till. Difference between tillage systems have the potential to affect moisture availability and soil temperatures as well as other factors including infestations. As knowledge of the negative effects of this system on the environment becomes known producers have moved to lower disturbance systems know as conservation tillage. Approximately 36% of U.S. cropland is planted to eight major crops, or 36 million hectares of which were conservation tillage operations in 2009 (ERS, 2010).

2.15 Conventional tillage

Conventional tillage is defined as tillage that disturbs the entire soil surface resulting in less than 15% residue cover after planting, or less than 227 kg hectare^{-1} of small grain residue equivalent throughout the critical wind erosion period, which in the PNW is during the fallow period (CTIC, 2002). This particular tillage system commonly involves numerous tillage trips in the field to prepare the seedbed, and often begins with plowing. Historically conventional tillage was used to prepare seedbeds however in the PNW it has proven to have severe unintended consequences. Conventional tillage practices in steeply sloped dryland regions have led to increased soil erosion due to water runoff, flushing soil nitrates and other chemical residues into the surface water system (Borstlap and Entz, 1994) or through wind erosion (Skidmore and Woodruff, 1968).

2.16 Conservation tillage

Conservation tillage is defined as a tillage and planting system that leaves 30% or more of the soil surface covered with crop residue or has 454 kg hectare^{-1} of flat, small grain residue equivalent remaining on the soil surface throughout the critical wind erosion period. In the 1970’s conservation tillage began to gain in popularity. In 1991, 8 million hectares of 113 million cultivated hectares in the U.S. were planted using direct seed systems, the most restrictive of the conservation systems. From 1996 to 2002 the percent of the U.S. farmland being cultivated with conservation tillage was 36% (CTIC, 2002) Many farmers in highly erodible regions such as the PNW are currently adopting more conservation oriented tillage practices.

2.17 Nutrient requirements

2.17.1 Nitrogen

The plant nutrient needed in the greatest quantity is nitrogen since it is usually the most limiting factor for growth and seed production of *B. napus (*Ukrainetz *et al.,* 1975). Plants take the nitrogen and convert to protein and chlorophyll. Nitrogen supply has a larger influence on plant cell size and leaf area which is required for photosynthesis and growth *(*Ukrainetz *et al.,* 1975). Nitrogen promotes vigorous growth and has a strong impact on yield. It is nearly always deficient in agricultural soils due to repeated crop production. As canola plants mature plant nitrogen moves to the seed.

Nitrogen fertilizer materials that are equally able to supply nitrogen to annual crops include ammonium nitrate (AN; 34-0-0), anhydrous ammonia (AA; 83-0-0), ammonium sulfate (AS; 20-0-0-24), and urea (U; 45-0-0).

Most research completed on the fertility management for rapeseed/canola has been done in the PNW and Canada. The bulk of the previous work has been done on nitrogen and its interactions with other agronomic practices for canola. Significant increase in seed yield as additional nitrogen is applied to the crop is supported by many literature, with the best gain in yield coming from the addition of the first 40 kg N hectare^{-1} (Kutcher *et al.,* 2005).

For the soils in northern Idaho additional fertilizer N is required to supply spring canola with adequate N (Maher, and Guy, 1994). The N use efficiency of a cultivar is key since not all of the fertilizer N applied is actually taken up by canola. There have been very few nitrogen fertility studies conducted on canola in the U.S. and recommendations for northern Idaho are based on Canadian and North Dakota research local winter rapeseed nitrogen trials and spring cereal research (Grant and Bailey, 1990; Mahler and Guy, 1994).

To obtain optimum yields in the inland region of the PNW applying between 140 and 165 kg N hectare^{-1} was required (Gareau, 1996). It has been shown that spring canola requires between 120 to 150 kg N hectare^{-1} to produce a 2,000 kg hectare^{-1} seed yield (Ukrainetz *et al.,* 1975; Bailey 1990). It was reported that in northern Idaho spring canola requires 157 kg total N hectare^{-1} to produce a potential yield of 1,680 kg hectare^{-1} and 22 to 28 kg S hectare^{-1} if soil contains less than 10ppm SO_4-S (Mahler and Guy, 1994). There was a positive yield response reported in Canada. It was obtained with up to 270kg hectare^{-1} of applied nitrogen in regions with deficient N soils (less than 34 kg hectare^{-1}) and in most of the stubble trails economical yield responses were obtained by applying 130kg N hectare^{-1} (Thomas, 1984). Within this study it concluded that sulfur should be applied at 7:1 to 10:1 ratio with nitrogen. Maximum canola yields were reported from nitrogen rates of 71 to 88 kg N hectare $^{-1}$ (Kutcher *et al.*, 2005), 75 kg N hectare^{-1} (Hocknig *et al.,* 1997), 90 kg N hectare^{-1} (Cheema *et al.,* 2000) and 180 to 220 kg N hectare^{-1} (Jackson, 2000) of applied nitrogen to 193 to 209 kg N hectare^{-1} of available nitrogen (Lewis and Knight, 1987) while hybrid canola yields maximized at 165 kg applied N hectare^{-1} (Karmanos *et al.,* 2005; Mahler and Guy 2005).

At applied nitrogen rates ranging from 0 to 252 kg N hectare^{-1} (Jackson, 2000) the increase in canola yields from additional nitrogen was found to be both linear and quadratic. However, while others studies did not include the contrasts they did described similar trends (Kutcher *et al.,* 2005). Therefore environmental stresses affect both nitrogen use efficiency and optimal nitrogen rates which were all demonstrated by growing the crop under irrigation

(Taylor *et al.,* 1991) and by planting earlier to avoid drought and heat stress (Hocking and Stapper, 2001)

By applying the same nitrogen rates that maximized yield which were 90 kg N hectare^{-1} (Cheema *et al.,* 2000) or 180 to 220 kg N hectare^{-1} (Jackson, 2000), in some studies seed oil content was found to be maximized. Seed oil content decreased when nitrogen rates were increased (Taylor *et al.,* 1991; Grant and Bailey, 1993; Jackson, 2000; Kutcher *et al.,* 2005) or that oil content was unaffected by nitrogen fertility (Chamorrow *et al.,* 2002) were found by other experiments. Although the seed oil content decreased it was often found that the overall oil yield increased due to the increase in seed yield outweighing the lower oil content of the seeds (Taylor *et al.,* 1991; Jackson, 2000). The increase in nitrogen with the decrease in oil content is thought to be due the higher nitrogen levels delaying seed ripening causing immature seed with a lower oil content to be harvested (Grant and Baily, 1993)

It is found that the seed weight of canola is reported as either decreasing at high nitrogen rates (Hocking and Stapper, 2001; Kutcher *et al.,* 2005) remaining unaffected by nitrogen fertility (Taylor *et al.,* 1991) or increasing with increasing fertility (Mudholker and Ahlawat, 1981). A decrease in canola seed oil and seed weight at high levels of nitrogen was hypothesized due to excessive vegetative growth early in the growing season and depleted soil water reserves, resulting in greater water stress during flowering and seed fill (Hocking and Stapper, 2001) or due to a delay in crop maturity at excessive levels of nitrogen (Jackson, 2000; Kutcher, 2005).

2.17.2 Phosphorus

An essential nutrient phosphorus is especially needed during early growth stages and root development in canola. In amounts ranging between 40 and 80 kg hectare^{-1} phosphorus is needed by spring canola (Sheppard and Bates, 1980). Winter canola in Idaho has a moderate requirement ranging from 10 to 29 kg P hectare^{-1} (Mahler, 1990). Idaho spring canola has the same moderate requirement ranging from 10 to 29 kg P hectare^{-1} (Mahler, 1990). In soils that are deficient spring canola has been shown to respond to additions of phosphorus in western Canada. Seed yield responses to phosphorus additions have rarely been observed even though deficiencies can sometimes occur in northern Idaho soils (Mahler, 1990). *B. napus* is a non-mycorrhizal plant with proliferation of root hairs which may enable it to take up phosphorous more efficiently than cereal crops (Grant and Bailey, 1993). However, phosphorus is not mobile in the soil so it should be applied in the fall or spring by either banding with the seed at planting or incorporating it into the soil before planting depending on your management system.

Recommendations for phosphorus for maximizing canola yield and seed weight include 19.2 kg P hectare^{-1} (Brennan and Bolland, 2001) 26 kg P hectare^{-1} (Cheema *et al.*, 2000) and 20 kg P hectare^{-1} for conventional canola cultivars to 40 kg P hectare^{-1} for hybrid canola cultivars with a higher yield potential (Karamnaos *et al.*, 2005). Economically optimum phosphorus application of 68.9 kg P_2O_5 hectare^{-1} had showed a yield response to increased phosphorous when the crop was also fertilized with additional nitrogen (Mudholkar and Ahlawat, 1981). If soil test data shows soil to be P deficient, it is recommend to apply 49 to 68 kg P_2O_5 hectare^{-1} (Mahler and Guy, 2005).

2.17.3 Potassium

Canola requires potassium in relatively large amounts for optimum seed development. Even on soils that tested low for available potassium canola has demonstrated minimal or no response to potassium fertilization. K fertilization is only recommended on severely deficient soils (Grant and Bailey, 1993; May *et al.*, 1994). Recommendation for deficient K soils test from 0-75 ppm is applying 56 to 74 kg K hectare^{-1} (Mahler and Guy, 2005). Northern Idaho soils are rarely deficient enough in potassium to affect spring canola production (Mahler and Guy, 2005).

2.17.4 Sulfur

Sulfur is often the second most limiting nutrient for successful spring canola production. Brassicas have high levels of sulfur rich glucosinolates consequently meaning they require more sulfur than many other plants. It is necessary that canola levels of sulfur are adequate to maximize use of other nutrients including nitrogen, boron, and manganese and adequate levels of phosphorous and potassium are needed for efficient use for available sulfur (Malhi *et al.*, 2005). Sulfur is part of the structural and enzymatic components within canola plants. The key component of two essential amino acids, cysteine and methionine and is needed for protein and chlorophyll synthesis is sulfur. An important element for glucosionlates formation is sulfur which is part of an important group of secondary plant compounds. This element is available in the soil but can be extremely variable within fields. (Canola Council, 2014). When sulfur is taken up by plants as SO_4 it appears in proteins with methionine and cysteine representing up to 90% of total plant sulfur content (Holmes, 1980).

Sulfur fertilization is important for maximizing the canola yields in areas were soil is deficient. A large portion of agricultural soils in northern Idaho have been found to be sulfur deficient (Mahler *et al.,* 1985). This could be due to the absence of atmospheric sulfur additions from industrial sources such as oil, gas, and coal combustion. Canola crops require 0.45 kg of sulfur for each expected 112 kg hectare^{-1} of seed yield. Precautions should be taken since some S application are limited to no more than 28 kg S hectare^{-1} since it is highly prone to leaching deep into the soil profile away from the roots.

It was recommended that sulfur be applied if soil test values from the ammonium acetate-acetic acid-extractable sulfur procedure were less than the critical soil value for sulfur was determined to be 70 kg S hectare^{-1} in Montana. General fertilizer recommendations for spring canola are 20 to 30 kg S hectare^{-1} in soils that test less than 10 mg SO_4-S kg^{-1}. Application rates ranging from 20 kg S hectare^{-1} (Jackson, 2000; Karamanos *et al.,* 2005; Mahler and Guy, 2005) to 15-30 kg S hectare^{-1} (Malhi *et al.,* 2005) and up to 40 kg S hectare^{-1} for hybrid canola (Karamanos *et al.,* 2005). It was suggested that 20 kg S hectare^{-1} be applied to all canola at planting as a precaution (Jackson, 2000) as the SO_4-S extraction test for soil available sulfur is considered unreliable and that canola grown on soils known to be sulfur deficient be fertilized with up to 30 kg S hectare^{-1} (Grant and Bailey, 1993).

Increased oil content was created by the addition for 22 kg S hectare^{-1} at locations know to be sulfur deficient however, when soils contained adequate sulfur the addition did not affect the seed oil content (Jackson, 2000; Malhi *et al.,* 2005) and with excessive sulfur applications there was a decrease seed oil content (Malhi *et al.,* 2005).

The methods used to determine sulfur availability is soils have not proven precise, accurate or reliable (Beaton *et al.,* 1968). Along with the fact that the methods that exist tend to be expensive and time consuming sulfur still remains the major plant nutrient for no satisfying soil analysis exists (Blanchar, 1986).

2.17.5 Micronutrients

Canola must also be supplied with essential micronutrients in addition to macronutrients,(N,P, K, S, Ca and Mg) (Holmes, 1980). There has been little to no research done on the requirements for other micronutrients. Deficiencies of Fe, Mo, MN, Zn, Cu and Ni are unlikely or unheard of in northern Idaho soils. However, Boron is an exception since often it is deficient (Mahler and McDole, 1981). Canola requires more boron than most crops. It was reported in northern Idaho that if the soils is deficient canola has a strong response to boron therefore if soil tests below 0.5 ppm B, 1 to 2.2 kg B hectare^{-1} should be applied (Mahler and Guy 2005; Nutttal *et al.*, 1987). It was found that when boron was applied to canola forage, it did not affect yield (May *et al.*, 1994). This is probable due to the adequate plant available sulfur within the soil (Malhi *et al.,* 2005). In a sulfur limiting soil 2.2 kg B hectare^{-1} is an adequate amount to prevent sterile florets and increase pod development (Grant and Bailey 1993; Malhi *et al.,* 2005). Toxic symptoms will occur when excess B is applied (more than 2 kg hectare^{-1}) in canola. Boron should be applied before seeding in the fall however it should never be band since it can cause toxicity. For this reason care must be taken when recommending B additions for soils.

Canola is known to be more tolerant to copper deficiencies than other cereal crops and requires lower manganese than spring wheat (Grand and Bailey, 1993; Mahler and Guy, 2005). In low molybdenum soil, increases in yield and seed size can be obtained by applying Mo fertilizer (Grant and Bailey, 1993) however, another found that there was no yield increase form the increase of available molybdenum in the soil (Mahler and Guy, 2005). Soils treated with high levels of phosphorous increase in yield with zinc fertilization (Grant and Bailey, 1993) and in highly erode soils zinc application is recommended (Mahler and Guy, 2005). Canola should not respond to applications of chlorine copper and iron (Mahler and Guy, 2005).

A cropping history of a field can be helpful for growers to determine what the fertilizer needs of canola is; however, crop history alone is not as accurate or as reliable compared to using soil test and or with addition of a plant analysis.

2.17.6 Soil and tissue testing

An important tool to help make fertility decisions for profitable canola production is soil testing. Proper soil tests are necessary to develop a scientifically based fertility program for spring and winter canola. Soils can widely very even within a field in their ability to provide the available nutrients required for optimum growth and seed yield for canola. Yet, variability in climate, previous crops and management can also impact soil nutrient status. There are no absolute answers with soil testing but it does provide a baseline to make more accurate fertilizer decisions.

An effective method to evaluate soils for their ability to supply crops with sufficient nutrients is soil testing. Except for sulfur, there are reliable methods that exist for determining nutrient availability of the soil. The four objectives of soil testing outlined by Fitts and Nelson (1956) include: (1) group soils into classes so you can recommend fertilizer and lime; (2) predict profitablity of crop response due to fertilizer application (3) determine the productivity of the soil, and (4) evaluate if additional soil amendments or cultural practices may result in improved soil conditions. Avoidance should be made at sampling areas that may exaggerate the soil test reading. These avoidance spots include low spots, sandy ridges, old yard sites, hilltops, saline areas, and old burn piles. Some sampling patterns that can be use include random, benchmark, grid and smart. It is difficult to predict accurately the soil fertility changes over time with additions and removals.

Nutrient availability is affected by the release of essential elements from the organic matter and fertilizer materials can be affected by soil moisture and temperature. Root growth development and exploration along with mass flow and diffusion of the soil solution can often be moisture and/or temperature dependent and have intern been shown to have a great influence on nutrient availability. Plant nutrient concentrations are often a better indicator of available nutrients than soil samples under environmental stress. Due to the lack of a reliable soil test for S availability the use of plant tissue analysis has proved to be useful in detecting S deficiency in *Brassica* (Maynard *et al.,* 1983).

An important role in agricultural production and research are using plant tissues as indicators of soil nutrients (Munson and Nelson, 1974). Using the relationships between crop yield and plant tissue concentrations of the essential elements and soil nutrients can help establish critical levels and locate optimum concentrations of nutrients within the plant tissues. The critical level is defined as the plant nutrient concentrations below which significant decline in crop yield growth rate or quality occurs. The optimum concentration can be defined as the point which corresponds with the maximum economic or optimum yield (Ulrich and Hills, 1967). The critical level concept was later modified by Chapman (1967) into critical ranges to create critical and optimal concentrations rather than creating specific points.

Tissue concentrations can also be affected by management practices such as liming tillage pesticide application. Increase or decrease in tissue concentrations of certain elements can be caused by denser plant populations. Soil pH fluctuation can have direct influence on availability of nutrients such as Mg, Zn and Mn in canola as well as indirect influence on N and S.

The growth stage of the crop as well as with fertility level can cause tissue concentrations and some nutrients to change. As an example when N and K decreases and Ca and Mg increase little change to P was observed during the physiological aging of corn (Gorsline *et al.,* 1965). Further research into this led to the establishment of deficient intermediate ranges which change throughout the corns growing season. These seasonal plant diagnostics have been established for other crops. Variations in plant tissue nutrient concentrations, may be contributed by factors such as sampling time and physiological maturity concentration of other nutrients, soil moisture, soil pH, crop cultivar and management practices. Among cultivars and hybrids of the same crop differences in plant nutrient concentrations are known to occur. Research on corn was found that N, P, K, Ca and Mg in plant tissues hybrid difference were not great enough to be considered when interpreting plant analysis results for a given region (Munson, 1970). Among nutrients interrelationships may also influence concentrations in plants. As an example when K concentrations increase Ca and Mg concentrations will decrease in corn (Loue, 1963).

Field verifications to identify or confirm specific deficiencies may sometimes be done early enough to correct nutrient deficiencies, but is usually done on annual crops as a post mortem procedure and the information gained is used to prevent future problems. To define deficient soil areas and to determine the adequacy of fertilizer programs and schedules field surveys using plants in conjunction with soil tests are often used. Fields that fail to achieve optimal yield which show no visual diagnosed problem or areas in fields which show no visual deficiency symptoms can use plant analysis to diagnose problems (Munson and Nelson, 1974). High value crops are intensively grown, use plant analysis as a valuable tool for detecting hidden plant hunger and for developing crop logs in the progress of optimize crop production.

2.18 Planting date

To reach maximum potential yield of a canola crop, many factors must be balanced when making the decision when to start seeding. Factors to consider include soil temperature, frost, precipitation and timing with other crops within management system. Seeding dates may change the management of different weeds, insects and diseases (Canola Council, 2014).

Time of planting is very important for spring canola due to hot dry conditions during the summer months in the PNW. To avoid reduction in seed yield most spring planted alternative crops must be planted early in the spring. If planting of pea and lentil are delayed it can greatly reduce seed yield (Smittle and Bradley, 1966; Ali-Khan and Kiehn, 1989). In Canada delayed planting of canola often results in decreased seed yield (Hockings, 1993; Degenhardt and Kondra, 1981). With a narrow planting window, getting spring crop planted in time makes is difficult. Results have been variable in many studies looking at yield response to changing seeding rates with spring canola/rapeseed. Research has concluded that there is no significant yield difference due to seeding at 7 and 14 kg hectare^{-1} (Christensen and Drabble, 1984; Degenhardt and Kondra, 1981). Others found that higher canola seed yields could be initially be achieved when seeding rates were increased rates (Clarke and Simpson, 1978 and Clarke *et al.*, 1978).

The earliest possible seeding is advised since Brassicaceae crops are typically considered as potential break crops in regions with hot, dry summers (Angadi *et al.*, 2004). Decrease in germination does not occur with *B. napus*, however it is important to note that if *B. rapa* is planted into soils below 9°C germination decreases (Kondra *et al.*, 1983).

Several studies have indicated that despite the short growing season requirement of Brassicaceae crops an optimal planting date for the crop will vary by location (Brandt, 1994).

It is recommended that canola be planted before 15 May in North Dakota (Johnson *et al.*, 1995). In Montana planting canola after late march to mid-April resulted in a 43 to 63% yield loss (Chen *et al.*, 2005). It was found when planting mid – to late May you are able to maximize the yield of *B. rapa* and *B. napus* in Northwestern Alberta (Christensen *et al.*, 1985) While in western Canada seeding in the early part of May resulted in the highest yield (Degenhadt and Kondra, 1981).

Canola production in most regions of the Canadian prairies often is limited by a short frost-free growing season, hot, dry periods in July during flowering and seed set, and cool wet conditions at harvest in September (Kirkland, 2000).

The earliest you can get your spring canola in the ground will depend on when the farm machinery can get into the field which is related to snow cover, precipitation, soil type and gradient. Seeding should be delayed until soil temperatures exceed 10°C to reduce any slow uneven germination, thin stands and weed competition (Brown *et al.*, 2008). Within the PNW wheat is our primary crop. Canola will need to be planted in the short window after the fields of wheat are seeded.

Winter canola planting should be completed such that the crop achieves full ground cover before November to ensure suitable winter hardiness. When seeding of winter rapeseed is delayed time is limited for development to the rosette stage needed for reliable winter survival (Auld *et al.*, 1984). Plants that are established better in the fall months will have significantly less winter kill. Winter canola can be planted into summer fallow in the PNW from early August to the second week of September to decrease the risks from dry seedbeds or underdeveloped plants in the fall (Moore and Guy, 1997). In the PNW, late planting is possible in regions with less severe weather conditions. In mild winter region of the Willamette Valley in Oregon, planting is possible up to the first week of November. Generally winter canola should be planted six weeks before the first killing frost and four weeks before the killing frost in the southern states (Brown *et al.*, 2008).

Recommended planting dates in the Great Plains and Midwest vary according to latitude. Optimum planting dates for winter canola in Nebraska are from August 22 through September 12, August 26 to September 25 in Kansas and Missouri, August 20 to September

21 in Oklahoma and Arkansas, August 20 to September 28 in northern Texas and September 10 to October 25 in Alabama and Georgia (Brown *et al.,* 2008).

There are two types of Canola varieties: the Argentine type of the species *B. napus* and the Polish type of the species *B. rapa*. Argentine varieties have a higher yield potential and are also taller and have a higher oil content then polish varieties. Polish varieties need approximately 80 days to reach maturity while Argentine varieties require about 95 days to reach maturity (Berglund, 2007).

Fall seeded Argentine rapeseed (*Brassica napus* L.*)* yield was 22% (as high as 90%) greater than spring seeded rapeseed. Canola sown in the first 2 week of May rather than at the end of May increased *B. napus* seed yields from 24% (Degenhardt and Kondra, 1981; Kondra, 1977) to greater than 50% (Johnson *et al.,* 1995) and oil concentrations by 1% (Johnson *et al.,* 1995). Emerged canola seedlings tolerated temperatures down to as low as -6°C (Johnson *et al.,* 1995). They also found that canola seeded before mid-May avoided hot and dry periods during critical reproductive growth periods. Another study results confirmed that cooler and moisture growing conditions during flowering and seed set improved canola yield quality (Nuttall *et al.,* 1992).

There can be cultivar variability when it comes to winter hardiness however winter canola does need specific number of degree days above 4°C to provide enough organic material to survive winters (Brown *et al.,* 2008). In Idaho research suggests that a minimum of 6 accumulated degree days above 4°C are needed for germination, seedling emergence and to establish the 4 to 5 leaves to survive the PNW winter. The aim is to have at least 45 days of growth before the onset of winter conditions or to have plants with four to six fully opened leaves (in a rosette stage of growth) before winter (Brown *et al.,* 2008).

A decrease in dry matter production reduces the light intercepting efficiently of the crop during late plantings. A one day delay in planting was found to post-poned canola anthesis by 0.47 to 0.56 days therefore a later planted crop would have inferably fewer days between planting and flowering (Hocking and Stapper, 2001). This translates to reduce yields which caused a decrease in the number of pods per plant and then lower harvest index (Johnson *et al.,* 1995). This is due to a shortening of the pre-flowering as well as the period between flowering and senescence. This results in decreased amount of plant biomass and the grain fill occurring later in the growing season when there is more likely to be increased temperatures and photoperiodic stress (Degenhardt and Kondra, 1981; Hocking and Stapper, 2001). During reproductive phases canola is highly sensitive to heat stress therefore early planting is critical for flowering so it can then occur prior to the intense summer heat (Chen *et al.,* 2005).

Compensation for the delayed planting does not occur when adding additional nitrogen although it does take a late planted crop as much nitrogen to reach its lower yield potential as an early plated crop due to the difference in nitrogen use efficiency (Hocking and Stapper, 2001).

The potential seed oil content of canola decreases with late planting (May *et al.,* 1994 Hocking and Stapper, 2001). This is likely due to the increased temperature and water stress during grain fill, however it has been found that early planting can reduced seed oil content at some locations (Chen *et al.,* 2005). Researchers (Johnson *et al.,* 1995 and Degenhardt and Kondra, 1981) found that seed weights remained stable when the planting was delayed while others (Hocking and Stapper, 2001) found seed weights to decrease and hypothesized it was due to the increased environmental stress. In contrast one researcher found that the planting date did not significantly affect seed quality (Christensen *et al.,* 1985).

It has also been found that planting date can also impact insect damage in canola. Planting too early will increase the risk of insect infestation mainly from flea beetles (*Alticini*) that attack the canola at the seedling stage and cause a detrimental loss and may require insecticide treatments. Late planted canola had fewer flea beetles than early planted canola. This may be due to an aggregation pheromone produces by flea beetles while feeding on the earliest emerging plants (Milbrath and Weiss, 1995).

2.19 Seeding rate/plant density

First and foremost always plant certified seed free from seed-borne blackleg (*Phoma lingum*), Sclerotinia stem rot (*Sclerotinia sclerotiorum*) and Alternaria black spot (*Alternaria* species). It has become economically beneficial to use seed treatments containing insecticides and fungicides (Helix Xtra™ or Prosper 400™) to prevent damping off and flea beetle damage (Brown *et al.,* 2008). Canola seeds are small with approximately 90,000 to 115,000 (40,860 to

52,210 seeds kg^{-1}) seeds per pound and most drills used to plant small grains cereal can be used to plant canola with the aide of duct tape.

Many Brassicaceae crops are able to compensate for low plant densities by increasing branching excessively. Seeding rates that are low can result in uneven stands. These stands require more time to mature and can make the crop more susceptible to the effects of weeds, insects and diseases (SAF, 2004). Reduced stands can result due to poor germination and emergence therefore plant density is not as closely correlated with seeding rates as determined (Brandt, 1994).

In Western Australia the seeding rate recommend for canola is 5 kg hectare^{-1} to obtain about 155 seedlings m^{-2} (Lewis and Thurling, 1994) in Canada it is 4 to 6 kg seed hectare^{-1} (Kondra, 1977). The recommended seeding rate for spring canola in Montana is 32 to 65 seeds m^{-2} (Chen *et al.,* 2005). S. alba is tolerant to overly high seeding rates compared to *B.napus* and *B. rapa* as they are prone to lodging at high densities while yellow mustard is not (Brandt, 1994).

Current seeding rate recommendations for canola oy in North Dakota and Canada are to seed between 5.6 to 9 kg hectare^{-1}. Depending on the seedbed conditions at the time of seeding the aim of seeding is to establish a plant population of 40 to 200 plants m^{-2} (Berglund and McKay, 2002; Thomas, 2003). Among canola cultivars major differences in seed size can occur, with hybrid cultivars typically larger seeded than open pollinated cultivars (Hanson, 2008). Seed sizes for both types can overlap on another.

Spring canola in the PNW has been successfully planted using seeding rates that range from less than 4.48 kg hectare^{-1} to over 11.2 kg hectare^{-1} (Brown *et al.,* 2008). Winter canola crops have been successfully planted using seeding rates that range from less than 2.24 kg hectare^{-1} to more than 13.44 kg hectare^{-1} (Brown *et al.,* 2008). In both cases planting a seeding rate too low will result in poor crop establishment and more likely increased weediness. Planting too high a seeding rate will result in high plant populations with thin stemmed plants and high intra crop competition and crop lodging at maturity. The aim is use a seeding rate that results in 10 to 16 seedlings per square foot, achieving such plant stands will require a 5.6 to 6.7 kg hectare^{-1} seeding rate for winter canola. The aim in spring canola is to use a seeding rate that results in 105 to 170 seedlings m^{-2}, which should produce a plant stand count at harvest of about 52 to 105 plants m^{-2} (Brown *et al.*, 2008).

The optimal seeding rate for canola has not been agreed on among literature with some studies recommending low seeding rates (Morrison *et al.*, 1990), moderate seeding rates (Chen *et al.*, 2005) and others have demonstrated higher seeding rates all resulted in increased yields (Clarke *et al.*, 1978; Brandt 1994; May 1994). Some studies have shown that canola seed yields are not significantly reduced unless plant stand counts at harvest are less than 37 plant per m^{-2} or greater than 200 plant m^{-2} (Brown *et al.*, 2008). Other researchers found that seeding rates do not have a significant effect on yield (Degenhardt and Kondra, 1981; Chistensen and Drabble, 1984). Variation in the soil environment at planting at different locations may be why recommended seeding rates may vary. Through increased branching and the unusual plasticity of Brassicaceae crops low seeding rates often have the potential to yield comparably to higher rates (Kondra, 1975; Lewis and Knight, 1987; Morrison *et al.*, 1990; Brandt, 1994).

Suboptimal environmental conditions and unequal plant distribution limits the ability of the plants to compensate for lower seeding rate higher seeding rates are required for this (Angadi *et al.*, 2002). Water and nutrients are both limiting factors in Brassica crop production in stand density at high seeding rates due to interplant competition (Brandt, 1994) with severe summer droughts (Chen *et al.*, 2005) and late planting dates (Brandt, 1994) these issues exacerbate the situation leaving the crop unable to respond to the higher seeding rates. The natural competition between plants for limited resources suppresses all plants causing the high seeding rates to have lower yield potentials than low rates this was demonstrated by a linear increase in yield with increased seeding rates however this is not always the case (May *et al.*, 1994).

There is inconsistency in the effect of varying seeding rate on quality characteristics. A small linear decrease in canola seed oil concentrations was created by increasing the seeding rate (Chen *et al.*, 2005; May *et al.*, 1994). However, there was an inconsistently between the sites from oil content to seeding rate (Kondra, 1977; Chen *et al.*, 2005; Clarke *et al.*, 1978; Degenhardt and Kondra, 1981). There was no effect on seed weight when the seeding rates were varied.

Too low of seeding rates can delay canopy closure and therefore increases weed competition influencing the competitiveness of a crop (Martin *et al.,* 2001). Recommendations for rapeseed and other *Brassicaceae* seeding rates are often high (6 to 8 kg hectare^{-1}) they high seeding rates allow for an increase in competitiveness of the early plant growth stages (Morrison *et al.,* 1990). Since Brassicaceae crops have highly flexible growth patterns it can reduce the need for high seeding rates to maintain a competitive stand. If there is no need for weed control low density stands are not always the lowest yield (Martin *et al.*, 2001). Due to increased intraspecific competition high seeding rates are often found to decrease yield (Morrison *et al.,* 1990).

2.20 Seeding depth

Seeding depth for canola should be as shallow as allows the seed to be covered. Seeding recommendations are to plant 6.4 to 25.4 mm (Brown *et al.,* 2008). Seed must be placed into moisture, but too shallow can result in irregular germination and patchy stand. To deep can delay seedling emergence resulting in poor vigor.

The depth of seeding can greatly influence the number of seedlings that emerge. It has been observed that there was better crop establishment in field studies when canola was seeded at a depth of 6 to 12 mm compared with 38 to 50 mm (Thomas *et al.,* 1994). The seedling emergence was highly dependent on environments and ranged from 5 to 41% lower at the 50 mm seeding depth compared with the 25 mm seeding depth while effects on yield were inconsistent. Seeding depth of 12 to 25 mm resulted in statistically higher yields in 18 to 25 site-years compared with deeper seeding which were indicated by the western Canadian research (Thomas, 2003). An average yield decrease of 10% with up to a 40% yield decrease in two site-years was indicated at Seeding at a 51 mm depth. General seeding rates and depth recommendations are available to the public however, no published data is available for seeding rates for the Northern Great Plains. (Hanson, 2008).

2.21 Pest and Diseases

2.21.1 Weeds

In the PNW pest control in canola is difficult since few registered pesticides exist. The weeds can suppress the growth and productivity of the canola. Until the development, registration and release of herbicide-tolerant canola varieties, weed were a common limiting factor in canola production (Canola Council, 2014). However, it was possible to control the annual and perennial grassy weeds and certain broadleaf weeds such as wild oats (*Avena fatua*), volunteer cereals, Canada thistle (*Cirsium arvense*), and perennial sow thistle (*Sonchus arvensis*) and quackgrass (*Elymus repens*). Control of these weeds may take three or more herbicides plus other management techniques. Not only do weeds affect yield loss but hard to control weeds especially those within the *cruciferae* family can eventually reduce oil and meal quality by contamination. The introduction of new herbicide resistant varieties have allowed growers many options for variety and herbicide selection.

There are many problem weeds that are closely related to this species such as mustards (*Sinapis arvensis*), field pennycress (*Thlaspi arvense*), sheperd's purse (*Capsella bursa-pastoris*), flixweed (*Sisymbrium sophia*), common peppergrass (*Lepidium flavum*) and can even serve as alternate hosts to disease and pests (Thomas, 1984).

Weed control is necessary to maximize yield and quality of canola. Control of weeds can either be in the form of herbicides or cultural practices. Cultural practices that assist in weed management are the same ones that ensure a healthy crop: select a field with low population of Cruciferous weeds, manage weeds with cultivation prior to planting and establish an even stand (Oplinger *et al.,* 2000).

Prior to emergence of the crop herbicides applied keep the field weed free until the end of the critical period. Those herbicides applied after the crop has emerged must be applied as late as possible to kill as many of the weed flushes as possible with as few applications of the herbicide as possible (Martin *et al.,* 2001). Within the U.S., trifluralin is the only pre-plant herbicides registered for use in mustard or canola crops. It is nearly impossible to remove wild mustard (*Brassica kaber*), field pennycress (*Thlaspi arvense*) and shepard's purse (*Capsella bursa-pastoris*) from Brassicaceae crops because it does not select against other Brassicaceae species (Oplinger *et al.,* 2000). Within the U.S. the post emergent herbicide options for use on canola are limited. These post emergent herbicides include Assure II™ (Quizalofop P-Ethyl (Ethyl®-2-[4-(6-chloroquinoxalin-2-yloxy)-phenoxy]propionate)), Select™ (Clethodim €-2-[1-[[3-chloro-2-propenyl)oxy]imino]propyl]-5-[2-(ethylthio)ptopyl]-3-hydroxy-2-cyclohexen-1-one) and Stinger™ (clopyralid (3,6-dichloro-2-pyridine carboxylic acid) as well as non-selective herbicides used with herbicide resistant crops (Martin *et al.,* 2001).

Yellow mustard (*S. alba*) seed yields did not improve with the application of Trifluralin compared to no-herbicide treatment, indicating the application of Trifluralin is not necessary in yellow mustard production. When Trifluralin application was tested against canola yields the same results were found (Esser, 1998). Application of Trifluralin is recommended to maximize yield potential of the crop when overall weed competition of canola is considered, (*pers. comm. Jim Davis*).

The greatest negative affect on crops occur when weeds are allowed to compete in the first four to six weeks of crop growth in summer annual crops (Anderson, 1996). At early growth stages canola, like most crops, does not tolerate weed infestations (Martin *et al.,* 2001). However, Brassica crops due to their unusual growth plasticity are more able to recover from the early weed competition, even high levels of weed pressure. At the four leaf stage of growth canola can compensate for weed removal and still suffer less than 5% yield loss (Martin *et al.,* 2001).

Multiple studies have examined grass and broadleaf weed population's effect on seed yield and quality. Intermediate quackgrass (*Agropyron repens* L.) population was found to reduce canola (*B. rapa*) yield between 18-32% (O'Donovan, 1988). 1976 prediction module estimates that 100 wild oat (*Avena sativa*) shoots m^{-2} would reduce canola yield by 32%. It has been found that competition with oat can be highly variable from year to year (Lutman *et al.,* 1994). Other major grass weed problems in canola included volunteer barley and wheat (O'Donovan *et al.,* 1988). For 70 days, 75 tartary buckwheat (*Fagopyrum tataricum*) plants m^{-2} reduced canola yield by 20% if left in the crop (Remy and O'Sullivan, 1986). In lesser extent broadleaf weeds such as wild mustard and common lambsquarters can be detrimental to canola yield (Brennen, 1995; Blackshaw *et al.,* 1987).

To maintain end-product quality standards control of some weeds in canola are necessary (Rose and Bell, 1987). Contamination by field mustard (*B. rapa*) seed over 2% can cause oil quality in canola to exceed regulation requirement of 2% erucic acid. Contamination of 6.5% can increase glucosionlates content of the seed meal byproducts of canola to greater than 30umoles per gram (Davis *et al.,* 1994). If the contamination of field pennycress (*Thlaspi* *sativa*) seed was greater than 4% it is said that erucic acid content of spring canola would exceed the 2% limit (Brennan, 1995).

Weeds can be the most limiting factor in canola production and deciding when to control weeds is a complex decision. A critical question for growing canola is time of weed control because of the competitive nature of the crop. There is a high cost to leaving weeds in the earlier leaf stages. Weeds will win the competition for nutrients and soil moisture with young canola since it is not very non-competitive. In later stages the crop is more competitive letting less than 9% of full sunlight down to the soil surface where late-emerging weeds are in near darkness (Martin *et al.,* 2001).

The University of Manitoba has supported work on the benefits of early weed removal timing. Conducted at multiple locations over two years the trials showed that weeds emerged after the 4-6 leaf stage seldom impacted actual canola yields to 10% yield loss level (Martin *et al.,* 2001). After the 4 leaf stage of the crop few weeds emerged and the few that did were spindly and weak. Growers can concentrate on early emerging weeds and worry less about the later emerging weeds that come up after the crop has hit the 4-6 leaf stage in most instances (Martin *et al.,* 2000). The length of time weeds could be tolerated until they had caused a 5% or 10% yield loss varied greatly from site to site. When the weeds are allowed to remain in the field to the 4-leaf stage a 10% yield loss will happen (Martin *et al.*, 2001). Out of two fields weed control was actually not needed to avoid a 10% yield loss. Results showed a 3 bu acre^{-1} yield increase by spraying at the 1-leaf versus the 5-leaf stage (Clayton *et al.,* 2000). The belief that growers can make the maximum amount of money by knowing whether to spray as well as when to spray is supported by these findings. The most profitable timing for weed control was early and holds true for early-seeded or late-seeded crops.

2.21.2 Diseases

A number of diseases can attack *B. napus* at all growth stages, their effect on yield and quality can lead to an increase in production intensity. The intensity of damage can vary greatly depending on environmental factors. The major disease of *B. napus* that have been reported in north America are seed-rot seedling blight, a root rot complex caused by the soil borne fungi *Rhizoctonia solani*, *Fusarium sp* and *Pythium spp*; black leg or stem canker cause by the fungus *Leptoshaeria maculans* and its asexual stage *Phoma lingam*, Sclerotinia stem rot caused by the fungus *Sclerotinia sclerotiorum*. Minor disease include clubroot, powdery mildew, aster yellows and whit leaf spot (Thomas, 1984; Downy and Robbelen, 1989).

2.21.3 Insects

In the PNW yield reductions from insect damage may be the greatest limitation to spring *B. napus* (Auld *et al.,* 1980; Kephart *et al.,* 1988). In research trials specific problems with flea beetles (*Phyllotreta cruciferae (Goeze)*), aphids (*Aphidoidea*) and diamondback moths (Plutella xylostella) have been encountered and other insect populations are likely to increase with large scale production. Flea beetle (*Alticini*) is an early season pest that can be very detrimental to emerging rapeseed/canola seedlings in the PNW. Insects likely to cause a potential problem in canola include flea beetles (*Phyllotreta spp.),* the most serious insect attacking spring rapeseed which can completely devastate newly emerged stand (Lamb and Turnock, 1982), Red turnip beetle (*Entomoscelis americana*) specific to the brassicas are also damaging to newly emerged crops. Cut worms-red backed (*Euxoa ochrogaster*), pale western (*Agrotis orthogonia*), clover (*Scotogramma triflolii*) tend to show up in isolated outbreaks and cause serious plant losses. Diamond back moth (*Plutella xylostella*) larvae will feed at the flowering stage and cause yield losses especially in extremely dry years. Aphid-cabbage (*Brevicoryne brassicae*) and turnip (*Liaphis erysimis*) are usually abundant during late growth phases and can reduce yields. Lygus bugs (*Varios spp*.) have been known to cause damage to young flower buds but have not yet been of economic importance. Bertha armyworm (*Mamestra configurata*), alfalfa lopper (*Autographa californicus*), beet webworm (*Loxostege sticticalis*), and cabbageworm (*Pieris spp.)* are all defoliators of brassicas and have been known to have localized outbreaks in western Canada (Thomas, 1984); Root maggots (*Delia spp.)* are a problem only under cool wet conditions and have not been encountered in great numbers in the PNW (Kephart *et al.,* 1988). Cabbage seedpod weevil (*Ceutorhynchus assimillis*) are the major pest of the winter form of *B. napus* when grown in this area they have been observed on research trials of spring *B. napus*.

Weekly fields should be checked for the kind and number of insects present. Sweeps with a sweep net should be utilized to find insects high in the canopy, but inspection all plant parts (including roots) for damage should be conducted along with scouting for insects low in the canopy or on the ground. Daily sampling should be done when pests approach economic threshold levels. A minimum of five locations should be check in fields of less than 40.5 hectares. In fields greater than 40.5 hectares check minimum of 10 locations. There are several scouting patterns used when checking fields based on pest distribution and field configurations (Canola Council, 2004).

2.22 Abiotic stress factors

Weather conditions are unpredictable for the 11 to 12 month growing season and unforeseen circumstances can damage a portion of a field or hectares (Moore and Guy, 1997).

2.22.1 Frost

In any month frost can occur, however, it is usually those in the spring late summer and early fall that are critical (Kandel and Berglund, 2007). In minimum or zero-tillage situations frost can be greater since the soil is often cooler and less able to buffer cold air temperatures. (Canola Council, 2014). During seed development or seed maturation a killing frost is especially damaging.

There are limits to what the crop will withstand, however, canola can tolerate some frost damage. The temperature at which frost injury occurs varies with the plant's stage of growth moisture content and the length of time the temperature remains below freezing. Injury on the plant does not necessarily happen when frost cover (ice crystals) is found on a plant since the frost acts as an insulator decreasing the effect of freezing temperatures (Daun and Symons, 2000).

Fall sown and early spring seeded canola will undergo a gradual hardening process that will allow the plants to withstand freezing temperatures without serious damage after several days of near freezing temperatures. Low temperatures injure plants primarily by inducing ice formation between or within cells. Water that surrounds the plant cells freezes first (at about 0°C), while the water within the cell contains dissolved substances that, depending on their nature and concentration, depress the freezing point of water several degrees (Phelps, 2014). As the water around the cells becomes ice, more water vapor moves out of the cell and into the spaces around the cell where it becomes ice. The reduced water content of the cells further depresses the freezing point of the cell water. This could continue, up to a point, without damaging the cell, but below a certain point, ice crystals form within the cell, disrupt the cell membrane and injure the cell (Hall, 2010).

Plants growing under these conditions are slower growing, producing smaller cells that have a higher concentration of soluble substance more resistant to frost damage. Frost damage occurs when hardening does not occur and the plant at low temperatures induced ice formation between or within cells causing them to rupture (Kandel and Berglund, 2007).

Freezing temperatures length of time is important. While a light frost of a few degrees that lasts all night may cause severe damage a severe drop in temperature which only lasts a very short time may not damage canola plants (Kandel and Berglund, 2007).

Universities of Manitoba and Saskatchewan and at the Agriculture and Agri-Food Canada Beaverlodge Research Center have studies that have shown that fall sown and early seeded canola seedlings that undergone hardening could withstand -8 to -12°C temperatures (Canola Council, 2014). Volunteer canola and other weeds such as winter annuals have a high tolerance to cold temperatures in the spring would also be explain by this. Canola and mustards flowers and pods will freeze first before the leaves. The leaves of the canola plant can withstand -3.5 to 4.5°C while the flowers and pods can only tolerate -2 to -3°C (Phelps, 2014).

Canola seedlings that are rapidly growing are more susceptible to frost damage than plants that are growing slowly under cold conditions, especially when there is ample moisture. Warm weather exposure can cause cold hardened plants to lose frost tolerance. Similar to unhardened later sown canola can be killed by temperatures of only -5 to -8°C (Hall, 2010). Canola at the three to four leaf stage can usually withstand a couple of degrees more frost, while canola at the cotyledon stage is more susceptible to frost damage (Canola Council, 2014).

A light spring frost that does not damage the growing point of the plant seedlings will usually recover from it (Kandel and Berglund, 2007). If the growing points of the canola seedlings become destroyed by frost, the plants will die and re-seeding may be necessary. A frost that is light and that wilts the leaves but does not create some discoloration of the leaves, the plant will survive. If frost does blacken the cotyledons and or leaves no action should be taken for at least four to ten days. Waiting several days following the frost only determine the extent of killing (Kandel and Berglund, 2007). Fall frost damage usually occurs later with the results of green seed that develop in the later stages which can reduce the quality and oil content (Phelps, 2014). Green regrowth from the growing point should occur in four to five days under good growing conditions, while under poor conditions such as cold, and dry regrowth may take up to 10 days (Canola Council, 2014). At the growing point in the center of the frozen rosette if there is any green color the plant will recover and yields will be higher than if the field is worked and reseeded.

Frost at flowering will delay maturity but only causes minor reductions in yield by causing flower abortion (Kandel and Berglund, 2007; Phelps, 2014). Frost after flowering can result in significant yield reductions and grade loss. Researchers have found that the flowers there were open at the tie of flowering are affected (Kandel and Berglund, 2007; Phelps, 2014). Pods lower on the plant and un-open pods will continue to develop normally.

Think twice before applying high rates of nitrogen top dress even if soils do dry up quickly and the crop recovers. Nitrogen will stimulate growth, and can make a delayed crop even later, increasing the risk of grade and yield loss from fall frost. (Canola Council, 2014)

A Canola Council study in 2004 on reseeding of canola showed a 7.4 bushel loss compared to leaving the frosted crop to produce seed (Canola Council, 2014). An economic loss of $29.16 hectare^{-1} would happen in this reseeding situation (Canola Council, 2014).

2.22.2 Heat and drought

Canola is more sensitive to heat stress at flowering than wheat since flowering and seed initiation occur over long period of time and a long duration of flowering is directly related to high seed yields (Koenig, 2011). When high temperatures occur during flowering and early pod set heat stress becomes a problem, it is more severe when plants are growing under drought conditions. Heat stress on plant development and yield during early flowering than at pod set may have a more negative effect. When in the blooming stages heat blasting and or flower abortion is a strong possibility (Berglund, 2007). During the stage of flowering, heat combined with extreme drought will severely affect the pod and seed development including formation of seeds seed size and oil content. High temperatures during seed maturation result in reduced oil content. High temperatures drought and long days hasten maturity and in combination can reduce yield through fewer pods with fewer and lighter seeds per pod (Berglund, 2007).

Often mistaken for nutrient deficiencies sunscald has appeared in many fields across the southern Great Plains. During periods of heat stress ripening sunscald can occur, purpling on the stems and pods, which is an abiotic stress response is the main symptom to appear (Canola Council, 2014). The purpling is likely due to higher levels of the anthocyanin pigment and a lack of chlorophyll in the naturally senescing tissue (Great Plains Handbook, 2012). Sunscald is cultivar dependent since some cultivars show more sunscald than others. Check the underside of the pods or branches (areas not exposed to the sun) for normal color to confirm the observance of sunscald (Great Plains Handbook, 2012).

If moisture is received before ripening then the plant may compensate by setting new buds, flowers, and pods on secondary branches however, dry soil conditions can limit pod set (Great Plains Handbook, 2012). Increase in overall yield may occur but it could also delay harvest. After initial ripening if conditions improve under severe drought the crop may continue to grow. If the primary pod set is ripe, then the new growth will in-tune delay harvest (Great Plains Handbook, 2012). The canola plant usually dies after harvest yet the stubble may continue to grow or remain green if the crop was severely stressed before harvest and normal conditions return.

Research done in the Central Great Plains documented that yield is not significantly affect by water stress at any particular growth stage however canola did exhibit a linear response of seed yield to water use, with approximately 196 kg hectare^{-1}of seed produced for every inch of water used after the first 152 mm of water use (Nielson, 1997). Canola produced seed yields of 1,008 kg hectare^{-1} with 203 mm of water use and seed yield increased by 151 kg hectare^{-1} for each additional inch of water used in Alberta (Anonymous, 1985). It was reported by Stoker and Carter (1984) that irrigation following flowering was the most critical factor affecting seed yield of rapeseed. However Nutall *et al.*, (1992) discovered that canola yields were reduced in his study by 406.56 kg hectare^{-1} for every 15°C increase in mean maximum daily temperature during July and August. It was noted that greatly reduced canola yields under high temperatures and severe drought stress during July in severe environmental stresses during the rapeseed growing season caused pod abortion and seed loss (Johnson *et al.*, 1995).

2.22.3 Wind and hail

Under dry conditions and in lighter textured soils wind can blow seed and seedlings out of the ground or create a sandblasting effect causing plants to tip over or break at the point of injury. This abiotic stress can also be worse on hilltops and side slopes facing into the wind (Canada Canola, 2014). The whole field should be assessed before making a decision to reseed. Leaving the stand is likely better than reseeding if the wind damage is patchy or if the plant stand is still 20 to 40 plants m^{-2} (Canada Canola, 2014).

Injuries inflicted by hail to rapeseed (*B. campestris* L. and *B. napus* L.) crops in the seedling or early vegetative stages of development frequently result in loss of plants and thinning or plant population (McGregor, 1980). If hail breaks off both cotyledons or snaps the stem, in the early season these plants usually do not survive. Even though individual plants may perish, a whole canola crop is fairly resilient to early season hail when it comes to overall yield potential. Before yield losses exceed 10% an average stand can be reduced to fewer than 40 plants per m^{-2} (Canada Canola, 2014). The yield potential is recovered by the crop because the remaining seedlings take advantage of the reduced competition for light, moisture and nutrients. A study conducted in canola indicated that the thinning of the plant population by hail at the seedling or early vegetative stages of development would reduce seed yield by more than 20% only if the plant population were reduced to below 40 plants m^{-2} (McGregor, 1987). As a result compensating for lost plants, plants grow larger, produce more branches, and develop more pods and seeds per pod. However, maturity of the crop can be delayed with fewer plants (Canola Council, 2014).

Over irrigation along with heavy rains can knock flowers from stems and reduce pollination. Plants often recover from this damage with later forming flowers (Great Plains Canola production handbook, 2012).

2.23 Harvest and post-harvest

All harvest methods can be used successfully however whether to swath, push or direct combine comes down to being a management decision. For winter canola harvest swathing is generally recommended if harvest cannot be competed in a timely manner (3 to 7 days). No additional equipment for wheat growers when using the method to direct combine. Harvesting canola is a slower process than harvesting wheat. Since pre-harvest shattering happens frequently ripe canola should be harvested immediately. Holes within harvest equipment such as combines, trucks, or trailer should be plugged with tape or caulk to ensure the small seed of the canola is not lost (Boyles, 1914).

Consequently, crop maturity is seldom uniform due to many fields in the PNW being located on variable slopes, elevation, and soil depths (Douglas *et al.,* 1990). Canola fields at harvest are typically a mix of immature and mature areas which lead to harvest problems in canola. Plants within these mix fields can show pod shattering, while others or too green to harvest. It can be costly to wait for “dry down” to direct combine canola especially if pre-harvest winds shatter the seed pods. Also direct combining of canola can be very slow. Swathing prior to full maturity reduces the potential for pod shatter and helps hasten maturity, but adds about \$10 hectare^{-1} in costs and can result in reduced oil content and inferior oil quality if done too early (Wysocki, 2006). The recommended crop stage for swathing is to wait till one third brown seed. At this growth stage there is sufficient photosynthate in the plant to carry seed to maturity (Wysocki, 2006). If seed is too green (less than 1/10th brown) seed yield can be reduced by 10% and quality reduced from immature seed at harvest (Wysocki *et al.*, 1996).

Low yield and poor seed quality may result from harvesting too early, shattering and reduced seed yield may result from harvesting too (Oplinger *et al.,* 1989). It is preferred for better threshing and storability to harvest at full maturity (when seed moisture content is near 100 g kg $^{-1}$) because of the suitable moisture content of both pods and seeds (Elias, 2001). It may be advisable to harvest the crop at physiological maturity rather than at harvest maturity if the crop is excessively weedy to avoid bird damage or unfavorable weather conditions during late maturation and harvest (possible frost damage or excessive rain) (Salunkhe and Desai, 1986; Fenwick, 1988). Therefore it is important to determine when physiological maturity is reached in canola. The proper period for harvesting canola is short as a result identification of harvesting maturity is important. Crop loss can be expected if canola is harvested past the appropriate time, as a result of over ripening, which causes pods to shatter easily, especially under adverse weather conditions (Oplinger *et al.*, 1989; Salunkhe and Desai, 1986). Some researchers have defined harvest maturity as when seed moisture content is low enough to allow effective threshing with a mechanical harvester (Delouche, 1980).

The optimum stage to swath that research indicates is up to an average of 60% seed color change. Delayed swathing of any canola variety up to this stage content while avoiding economic shattering losses prior to or during swathing, can lead to improve in yield and quality through increased seed size, reduced green seed, and higher oil. Growers with large canola hectarage are able to wait for at least a 30% seed color change before they swath their first field and still finish their last field within the optimum swathing stage. At about 40% moisture seed in all pods on a plant reach physiological maturity and complete filling. Moisture in amounts of 1 to 3% per day are loss in physiological mature seed. Depending on the weather and variety seeds during maturation will slowly turn from green to light yellow reddish brown to brown or even black. About 10% every two to three days seed color change will typically increase. Under hot, dry conditions it can occur more rapidly while it may take much longer with good moisture and cool temperatures due to delayed seed dry down. Under good drying weather the crop is at the optimum swathing stage for only three to five days. (Canola Council, 2014)

2.24 Advancements, and breeding

Research in canola has helped to advance canola varieties around the world. In Canada, canola was the first genetically modified (GM) crop to reach commercial markets (Fulton and Keyowski, 1999). In 1998 herbicide-resistant (HR) canola comprised 44% of total canola production. In 2012, there were 31 million hectares of canola grown world-wide, and from that 30% or 9.2 million hectares were GM (herbicide resistant) and grown in Canada, U.S., Australia and Chile (ISAA, 2013), and this was a one million ha increase compared to 2011 (ISAA, 2013). Many commercial winter and spring canola varieties are available. Most of the recently developed spring canola varieties have been genetically modified to induce herbicide resistance. These include Liberty Link® and Roundup Ready®. Herbicide resistant winter canola varieties are also beginning to appear on the market (Ehrensing, 2008).

The longest running canola breeding program in the U.S. is at the University of Idaho. A breeding program at the University of Idaho was established over 35 years ago, before Genarally Accepted As Safe status (GAAS) was granted to canola in the U.S. This still remains the only University based breeding program developing both spring and winter canola in the U.S. Over the past eighteen years this program has released several winter canola cultivars (‘Ericka’, Brown, *et al.,* 1997; ‘Athena’, Brown, *et al.*, 2004; and ‘Amanda’, Brown, *et al.,* 2012) and spring canola cultivars (‘Premier’, Brown, *et al.,* 2005; ‘Clearwater’, Brown, *et al.,* 2011; ‘Arriba’, Brown, *et al.,* 2012; ‘Empire’, Brown, *et al.,* 2015; ‘Cara’, Brown, *et al.,* 2015) grown commercially in the PNW. This program also released ‘Durola’ winter industrial rapeseed (Brown *et al.,* 2014) and the first U.S. spring rapeseed cultivars (‘Sterling’, Brown, *et al.,* 1997; ‘Gem’, Brown, *et al.,* 2011). The University of Idaho has not only worked on breeding but also agronomic studies to provide growers with the best knowledge on growing canola within the PNW.

Over the 20 year period of cultivar testing, the most adapted (top 3 lines) winter canola cultivars yields have increased from 3,400 kg hectare^{-1} to over 4,400 kg hectare^{-1}, an average increase of 52 kg hectare^{-1} each year (Pakish, 2014). The winter rapeseed cultivar ‘Bridger’ also showed increased productivity from 2,601kg hectare^{-1}to 3,070 kg hectare^{-1}; a rate of 23 kg hectare^{-1} per year. The observed yield increase for Bridger can be attributed to improvements in agronomic practices throughout the region which include new pesticides (herbicides, insecticides, and seed treatment) and better fertility management. Comparison of the genetic and non-genetic yield gains show that winter canola genetic improvements were responsible for yield increases of 604 kg hectare^{-1}(or 55% of the total increase), while agronomic improvements only attributed 483 kg hectare^{-1}(or 45% of total increase) (Pakish, 2014). Yield of the most adapted cultivars entered into the spring variety trials have made similar large gains from 1,950 kg hectare^{-1} to over 2,500 kg hectare^{-1}. ‘Westar’ spring canola also showed yield gains of 1,665 kg hectare^{-1} to 1,844 kg hectare^{-1}. Again, comparing genetic with non-genetic yield gain spring canola cultivars showed improvement in genetics of 470 kg hectare^{-1} (70% of the total increase), while agronomic improvements in spring canola production accounted for an increase in yield of 188 kg hectare^{-1} (30% of the total increase) (Pakish, 2014). The larger genetic yield gains of spring canola cultivars compared to winter varieties is perhaps due to a comparatively larger financial investment of commercial breeding programs. This is also reflected in the number of commercial cultivars entered into the different trials, where an average of 31 cultivars each year have been entered into the PNW-SVT and only 23 cultivars a year in the PNW-WVT; a 25% difference (Pakish, 2014).

Within the variety testing, genetic improvements of cultivars has increased yield potential for spring and winter canola significantly over the past 20 years (Pakish, 2014). In recent years, the hectarage of canola in the PNW has risen and continues to increase. The availability of new and adapted cultivars in combination with better understanding of the correct agronomic needs of the crop in the region, and the availability of local crushing has resulted in higher canola seed prices to the farmer (Pakish, 2014). These advances within canola have helped to cultivate the industry in the PNW. Future breeding, research and agronomic trials will continue to aid canola production as it prospers throughout the coming years.

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Chapter 3: Optimal agronomic practices (planting date, seeding rate, and N fertilization) for maximized yield performance of spring canola (*Brassica napus* L.) in northern Idaho.

3.1 Abstract

Lack of economically viable crops to grow in rotation with small grain cereals in the Pacific Northwest (PNW) region has increased interest in growing spring canola (*Brassica napus* L.). Higher yielding canola cultivars combined with competitive prices has resulted in an increase of canola hectarage in the PNW region. Although adapted spring canola cultivars are now available to growers, few attempts have been made to optimize productivity through agronomic management of the crop. The objective of this research is to determine optimum agronomic conditions (nitrogen levels, seeding rates, and seeding dates) to maximize grower's productivity and profitability of a range of adapted canola cultivars. The experimental design at each site was a four replicate, split-split-plot, with planting dates as main-plots, nitrogen (N) application assigned as split-plots and cultivars and seeding rates as sub-sub-plots. In 2013 and 2014 identical trials were planted at two different locations in northern Idaho; Craigmont (no-till) and Genesee (tillage). The early seeding date was as soon as the weather permitted, and the late planting was 14 d later. Four spring cultivars were examined ('DKL 30-42-RR', 'InVigor-L.130-LL', 'Empire', and 'Cara') each planted at 3 seeding rates (900,000 seeds hectare^{-1}, 1,125,000 seeds hectare^{-1}, 1,350,000 seeds hectare^{-1}), and with six N application rates (0, 33, 67, 100, 134 and 168 kg N hectare^{-1}). In general, all canola cultivars produced higher yields when planted early, at intermediate seeding rates and with moderate to high N availability; although cultivars did respond differently to N availability. Highest spring yield was 3,153 kg hectare^{-1} for the cultivar DKL 30-42-RR with 168 kg N hectare^{-1} in 2014. Information from this project will allow growers to make decisions on choice of cultivar and management practices to optimize profitability.

3.2 Introduction

Industrial rapeseed has been grown on a limited scale in Idaho for over 100 years, yet canola in the United States (U.S.) is still considered a new crop. Prior to Generally Recognized as

Safe (GRAS) status was granted by the Food and Drug Association in 1985 there was no U.S. canola production (Raymer *et al.*, 1990).

Current U.S. canola production is dominated by spring type's (*B. napus*) and hectarage is mainly in North Dakota where Canadian developed cultivars were adapted and Canadian agronomic practices have worked well for production. If U.S. canola hectarage is to increase then canola production must expand to other states. In the Midwest and the Great Plains it is winter canola that has greatest yield potential. Indeed spring canola only has potential in the U.S. in the northern states (including the PNW), but outside of North Dakota, Canadian developed cultivars are not as well adapted and it has taken some time to develop new cultivars that would fit these environments.

Agriculture in the PNW is intensely monolithic predominated by small grain cereals, with over 60% of land planted to wheat (*Triticum aestivum*), and with very few alternative crops available for rotations. The PNW region has some of the most erosion sensitive soil in the world with an estimated 40% of the Palouse regions topsoil already lost to erosion (Pimentel *et al.*, 1995). In the higher rainfall regions, crop rotations of small grain cereals with pea and lentil, lacks sufficient crop residue for good ground cover and soil erosion is severe. Pea and lentil commonly produce only 450 to 900 kg residue hectare $^{-1}$, which results in less than 25% ground cover during the winter months (Gareau and Guy, 1995).

Monoculture wheat or when wheat is grown in rotation with closely related crops (i.e. barley) can cause increases in disease, pests and particularly grassy weeds (Krupinsky *et al.*, 2004).

Canola would be an ideal crop when grown in rotation with wheat, and it would diversity to dry-land farmer's rotations within the PNW (Pakish, 2014). Spring canola has a similar growing season to spring wheat, and uses the same equipment for planting and harvesting (Johnson, 2009). However, canola is a relatively new crop to PNW growers, and few varieties have been specifically developed for environments with cool winters and hot summers (Perry, 2011).

Including canola crops in rotation with cereals can increase overall crop yields (Classen and Kissel, 1984; Larney and Lindwall, 1994; Bourgeois and Entz, 1996), decrease weed populations (Liebman and Dyck, 1993), reduce insect and disease infestations (Krupinsky *et al.*, 2004), improve soil health and fertility (Weinert *et al.*, 2002; Vos and Van Der Putten, 2004) and reduce soil erosion (Peterson and Rohweder, 1983). Wheat or barley following a canola crop can result in increased cereal grain yield (Guy and Karow, 1998) and quality, and a decline in cereal disease (Wilson *et al.*, 1994). Growing canola provides an opportunity to clean up grassy weeds that are difficult to control in a continuous cereal production system (Johnson, 2009). The deep taproot of canola also can improve soil structure and allow for greater water infiltration, further reducing runoff.

Low investment costs to grow canola crops, and increasing consumer demand for canola oil make canola a potentially good alternative crop for PNW wheat growers (Nelson, 1992).

Seed yield of canola is a function of genetic (cultivars) and agronomic factors, including: planting date; row spacing; seeding rate; fertility; and pest control strategies, all which are vital in obtaining higher yield (Hussain, 2003)

A major hurdle to increasing hectarage of canola in the PNW is inconsistent yields. Spring canola in the PNW often fares poorly because limited water availability combined with high summers temperatures interferes with flowering and reduces yield (Kirkland and Johnson, 2003). To achieve maximum yield potential many factors have to be considered in decision making. These include soil temperature, frost, precipitation and timing with other crops within management system. Different seeding dates may change the management of weeds, insects and diseases (Canola Council, 2014).

Late planted spring canola reduces the vegetative period before flowering, when combined with higher temperatures during flowering and seed set, reduces seed yield. Canola crops require higher soil moisture for germination than wheat or barley (Kephart and Murray, 1990). Therefore, time of planting is very important for spring canola in the PNW due to hot dry conditions which are common during the summer months. Several studies have shown that optimal canola planting dates will vary by location (Brandt, 1994).

The time of planting spring crops in the PNW will depend on snow cover, precipitation, soil type and gradient, which combined will determine when farmers can get machinery into the field. However, even in dry springs, seeding should be delayed until soil temperatures exceed 10°C to reduce slow uneven germination, thin stands and increased weed competition (Brown *et al.,* 2008). Farmers will tend to plant crops that are most sensitive to planting date and have highest profitability, which is usually spring wheat, and to plant the rotation crops, with perhaps lesser value, later. However, little is known about the impact of delayed planting of spring canola in the PNW and how this affects the economic feasibility of the crop.

Canola stand establishment and seedling survival in the inland PNW is more variable than cereals (Koenig, 2011). This is largely attributed to its epigeal emergence whereby the cotyledons and the shoot growing point emerge above the soil surface, increasing the plants exposure to environmental stress (Koenig, 2011). In contrast cereals exhibit hypogeal emergence resulting in the shoot growing point remaining below ground and therefore more protected from extreme aerial climatic conditions (Koenig, 2011). Seeding during favorable temperature and moisture conditions is therefore more critical for canola than for wheat stand establishment.

Many Brassicaceae crops are able to compensate for low plant densities by increased branching. However, seeding rates that are too low result in uneven stands, which mature later making crops more susceptible to infestation from weeds and damage from insects and diseases (SAF, 2004). Spring canola in the PNW has been successfully planted using seeding rates that range from less than 4.8 kg hectare^{-1} to over 11 kg hectare^{-1} (Brown *et al.*, 2008). The optimal seeding rate for canola has not been agreed on among literature with some studies recommending low seeding rates (Morrison et al 1990), moderate seeding rates (Chen et al 2005), and others have demonstrated higher seeding rates all resulted in increased yields (Clarke *et al*., 1978; Brandt 1994; May 1994). Some studies have shown that canola seed yields are not significantly reduced unless plant stand counts at harvest are less than 37 plant per m^{-2} or greater than 200 plant m^{-2} (Brown et al., 2008). Other researchers found that seeding rates do not have a significant effect on yield (Degenhardt and Kondra 1981; Chistensen and Drabble 1984).

Reduced stands due to poor germination and emergence must be considered by growers when setting seeding rates (Brandt 1992). Seeding canola at rates that are too low will result in poor crop establishment and increase weed problems. Conversely, planting canola at too high a seeding rate will result in high plant populations with thin etiolated stemmed plants due to excessive intra plant competition, resulting in lodging and reduced yield.

Canola crops are highly competitive with weeds after bolting and flowering, allowing less than 9% of full sunlight down to the soil surface for late-emerging weeds (Martin *et al.*, , 2001). However, canola seedlings are not competitive with weeds, which will deplete soil nutrients and soil moisture. After the 4 leaf stage of the crop few weeds emerged and the few that did were spindly and weak. Growers can concentrate on early emerging weeds and worry less about the later emerging weeds that come up after the crop has hit the 4-6 leaf stage in most instances (Martin *et al.*, 2001).

Canola is more sensitive to heat stress at flowering than wheat since flowering and seed initiation occur over long period of time, and long duration of flowering is necessary for high seed yields (Koenig, 2011). When in bloom heat blasting and flower abortion is common (Berglund, 2007). After the end of flowering high temperatures combined with drought will reduce pod and seed development, and result in smaller seeds with lower oil content. (Berglund, 2007).

Usually the most limiting nutrient factor for growth and seed production of canola is availability of N (Ukrainetz *et al.*, 1975). Plants uptake N and convert it to protein and chlorophyll (Ukrainetz *et al.*, 1975). N has a larger influence on plant cell size and leaf area both which influence plant growth and photosynthesis and has a strong impact on yield (Bailey, 1990). Significant increase in seed yield as additional N is applied to the crop is supported by many literature, with the best gain in yield coming from the addition of the first 40 kg N hectare $^{-1}$ (Kutcher *et al.*, 2005).

There was a positive yield response reported in Canada. It was obtained with up to 270kg hectares^{-1} of applied N in regions with deficient N soils (less than 34 kg hectares^{-1}) and in most of the stubble trails economical yield responses were obtained by applying 130kg N hectares^{-1} (Thomas 1984). A complicating factors is that cultivars different in their response to N uptake and N use efficiency. There have been few N fertility studies conducted on spring canola in the U.S. and recommendations for northern Idaho are based on Canadian and North Dakota research (Grant and Bailey, 1990; Mahler and Guy, 1994), and both have a markedly different rainfall pattern to that in the PNW.

For the soils in northern Idaho additional fertilizer N is required to supply spring canola with adequate N (Maher and Guy, 1994). To obtain optimum yields in the inland region of the PNW, applying between 140 and 165 kg N hectares^{-1} was required (Gareau, 1995). It was reported that in northern Idaho spring canola requires 157 kg total N hectares^{-1} to produce a potential yield of 1,680 kg hectares^{-1} and 22 to 28 kg S hectares^{-1} if soil contains less than 10 ppm SO_4-S (Mahler and Guy 1994). It also should be noted that response to N studies in the PNW have been conducted using un-adapted cultivars which may have limited yield potential compared to the newer varieties that have more specific regional adaptability.

The objective of this research is to examine the response of canola under early and late planting conditions and determine the effect of planting density and N fertilizer application on yield and oil quality of four spring canola grown at two locations in northern Idaho.

Specific objectives of this research are:

1. Evaluate the performance of four adapted spring canola cultivars under six variable N, three seeding rates and two seeding dates.
2. Determine the optimum agronomic conditions to maximize productivity of spring canola, and hence increase hectarage of canola in the PNW.

3.3 Materials and methods

3.3.1 *Site and trial specifications*

Conventional till trials were planted in 2013 and 2014 at University of Idaho Kambitch Research Farm near Genesee, Idaho. The Genesee site is located 15.3 km south of Moscow (46°55’N, 116°92’W) and has an elevation of 815 m with an annual precipitation of 60 cm. The soil type at the Kambitch Farm is Naff Palouse silt loam complex consisting of fine-silty, mixed, mesic Typic Argixerolls. Genesee trials were always planted following a cereal, either wheat or barley. Fields were chisel plowed in the fall and then lightly cultivated in the spring. After cultivation, herbicide treatments were applied and fields were cultivated and harrowed once more. Prior to planting the trial area was treated with 79.36 oz. ai hectare $^{-1}$ of the herbicide Trust™ which was incorporated with two perpendicular cultivar passes, to control broadleaf weeds and mayweed chamomile.

The direct seeded trials were planted in 2013 and 2014 at Craigmont, Idaho. Craigmont (46°14′N, 116°28′W elevation 1,140m) trials were in a cooperators field. The average annual precipitation is 51.5 cm for Craigmont. The soil type at the cooperators farm is Uhlorn-Nez Perce. It is very deep, well drained and moderately well drained, warm soils with a high content of organic matter in the surface layer that formed in loess. Craigmont trials were always planted into cereal stubble, either wheat or barley. Prior to planting, plots were treated with 0.96 L hectare $^{-1}$ of the herbicide Roundup RT3™, a broad spectrum herbicide to control weeds.

The planting dates at Genesee in 2013 were April 25 (early) and May 8 (late), and May 5 (early) and May 16 (late) in 2014. Planting dates at Craigmont were April 25 (early) and May 8 (late) in 2013, and April 19 (early) and May 2 (late) in 2014.

3.3.2. *Factors examined*

Four spring canola (*B. napus* L.) cultivars with proven adaptability to the PNW environments from Regional Variety Trials were chosen for this experiment (Table 3.1, 3.2) were examined and included the Round-up Ready® variety DKL 30-42-RR, the imidazoline tolerant variety ‘Cara’ (Brown *et al.*, 2015a), a LibertyLink® variety tolerant to glufosinate herbicide ‘InVigor L.130-LL’, and a traditional herbicide susceptible variety ‘Empire’ (Brown *et al.*, 2015b). Cara and Empire are both open-pollinated cultivars developed at the University of Idaho, while DKL 30-42-RR was developed by Monsanto, and InVigor L.130-LL by Bayer Crop Science. The latter two cultivars are hybrid varieties.

The seeding rates examined were 900,000; 1,125,000 and 1,350,000 seeds hectare^{-1}, according to seed size which varied between years and cultivars (approximately equivalent to 4.5, 5.6, and 6.7 kg seed hectare $^{-1}$). These rates (4.5, 5.6, and 6.7 kg seed hectare $^{-1}$)were chosen as the low and high seeding rate, around the rate routinely used (5.6 kg seed hectare $^{-1}$) by the University of Idaho breeding program. Prior to planting, University of Idaho cultivars were treated with Helix Xtra™(thlamethoxam, difenoconazale, mefenoxam, fludioxonil) at a rate of 14 mL kg^{-1} seed while DKL 30-42-RR was treated with Prosper 400™ (clothianidin, thiram, carboxin, metalaxyl) at a rate of 16.3 mL kg^{-1} and InVigor L.130-LL was treated with Prosper EverGol™ (clothianidin, penflufen, trifloxystrobin, metalaxyl) at a rate of 739 mL/45.36 kg to protect against soil and seed borne fungal disease and flea beetle damage.

Six N application rates were examined, 0, 33, 67, 100, 134 and 168 kg N hectare^{-1}. These N rates were chosen to create a range from adding 0 kg N hectare $^{-1}$ of N to a high level that was expected to cause a yield plateau. N treatments were applied at seeding using a five row flexi coil with a stealth double opener drill with fertilizer placement between paired rows 10 cm apart and 2.5 cm below placement of the seed.

Prior to planting, soil samples were analyzed to determine base nutrient levels. Residual available N was determined in the top two feet of the soil. Base N levels for the study in 2013 were 58 kg N hectare^{-1}, and 79 kg N hectare^{-1} of residual N at Genesee in 2013 and 2014, respectively, with an average residual N of 69 kg N hectare^{-1} over both years. At Craigmont, the residual N level was 84 kg N hectare^{-1} and 55 kg N hectare^{-1} of N in 2013 and 2014, respectively, with an average residual available N of 69 kg N hectare^{-1} over two years.

Phosphorous and sulfur were applied as part of the fertilizer, with the phosphorous and sulfur levels maintained at a N to P_2O_5 ratio of 3:1 and a N to S ratio of 4:1. The fertilizer blend was composed of a 50:50 mixture by weight of urea (46% N) and ammonium phosphate sulfate (31% N, 10% P_20_5, 0% K and 7.5% S) for a final analysis of 31-10-0-7.5. Soils were tested and found not to be deficient in potassium or boron.

3.3.3. *Experimental design*

The experimental design of the complete trial at each site was a strip-split-split-plot design with four replicates (i.e. 2 planting dates x 4 cultivars x 6 N levels x 3 seed rates x 4 replicates = 576 plots site^{-1}). Strips were assigned at random to planting dates. Main-plots were randomly assigned to different N rates; split-plots assigned to different cultivars, sub-sub-plots assigned to seeding rate. Plot size was 1.5 m x 5 m, and planted using a five row flexi coil cone-type double-opener plot drill with press wheels (see above).

3.3.4 *Data collected*

Seedling stand was estimated by counting seedlings from two 1 m rows, located 1 m from the plot edge. Days from planting to 50% bloom was estimated visually. Post-bloom plant height (cm) was recorded after flowering and before maturity.

At crop maturity, all plots were direct harvested using a Wintersteiger Nurserymaster Elite™ (Wintersteiger, Inc.; Salt Lake City, UT) small plot combine. Seed from each plot was dried following harvest for two day at 50^o C before being weighed. Sub-samples of seed were taken at the time of weighing to determine seed oil content and 1000-seed weight. Oil content was determined on single 12-g samples following the procedure outlined by Hammond (1991) using a Newport MKIIIA Nuclear Magnetic Resonance (NMR) Analyzer (Oxford Instruments Inc.; Concord, MA). The NMR was calibrated with a single reference sample of known oil content and the sample analysis carried out as described by Howard and Daun (1991). Seed weight per 1000 seeds was determined by counting a sub-sample from each plot and weighing it.

3.3.4 *Data analysis*

Data was analyzed using a general linear model, Duncan’s multiple range tests, orthogonal contrasts (SAS, 2009) and trend contrasts (Brown and Caligari, 1998). In the analysis of variance, the significance of the differences between years was tested using the replicates within year mean square (Error 1). The effect of site and site x year were tested using the location x replicate within year mean square (Error 2). The effect of planting date (main-plot) planting date x year and planting date x location interactions were tested for significance using the planting date x replication within years means square (Error 3). The effect of N rate, N rate x year, N rate x location, N rate x planting date, N x year x location, N x location x planting date, N x year x location x planting date were tested for significance using the N rate x replication within year mean square (Error 4). The effect of cultivar, cultivar x year cultivar x location, cultivar x planting date, cultivar x N rate, cultivar x year x location, cultivar x year x planting date, cultivar x year x N rate, cultivar x location x planting date, cultivar x year x location x planting date were tested for significance using the cultivar by replicates within year mean square (Error 5). All other effects were tested using the pooled replicate error mean square (Error 6). All computations were carried out using the Statistical Analysis Software (SAS, 2009) program for the entire data set.

3.4 Results and discussion

Significance of mean squares from the analyses of variance for seedling stand, crop establishment, weed counts, days to 50% flower bloom, plant height after flower end, seed pod shatter, crop lodging, oil content, oil yield, meal yield and yield showed varying significance except for thousand seed weight of four cultivars, planted at two sites over two years, with three seeding rates, and six N application rates, and four replicates (Table 3.3, 3.4).

3.4.1 Cultivars

Overall stand counts were highest from InVigor L.130-LL, followed by DKL 30-42-RR, Empire, and lowest stand counts obtained from Cara (Table 3.5). Stand counts from the two hybrid cultivars (DKL30-42-RR and InVigor L.130-LL) were significantly ($P<0.05$) greater compared to the two open-pollinated cultivars Cara and Empire. Indeed, stand counts from the hybrid cultivar InVigor L.130-LL were 41% higher than those from the open pollinated cultivar Cara. Among canola cultivars the major differences in seed size can occur hybrid cultivars are typically larger seeded than open cultivars (Hanson, 2008). However, seed sizes for both types can overlap one another. Within this study by observation the hybrid cultivars seed size was larger and for this reason germination tests and thousand seed weight test were used in this study to determine the adequate seeding density. Due to the larger seed these varieties are planted at higher densities that may aide in increased stand counts and improved establishment. Studies have shown that canola seed yields are not significantly reduced unless plant stand counts at harvest are less than 37 plant per m^{-2} or greater than 200 plant m^{-2} (Brown *et al.*, 2008).

DKL 30-42-RR and InVigor L.130-LL also had 60% increase in weed control compared to imidazilinone tolerant cultivar Cara or Empire

The interaction cultivar x flowering date was scalar, and there were no crossing over between flowerings of the cultivars and did not in turn effect the recommendation. The difference between 50% bloom of the four cultivars was only 2 d. All cultivars produced taller plants when planted late compared to early planting. Overall, InVigor L.130-LL had tallest plants, followed by Cara, Empire and DKL 30-42-RR (Table 3.6). Year interaction was significant, 2013 had 8.1cm taller plants on average compared to 2014 (Table 3.6).

Over ripening, causes canola seed pods to shatter, especially under adverse weather conditions (Oplinger *et al.*, 1989; Salunkhe and Desai, 1986) resulting in yield loss. Cara and Empire had least seed shatter compared to DKL 30-42-RR, while InVigor L.130-LL significantly more seed shatter. Compared to DKL 30-42-RR and InVigor L.130-LL, Cara and Empire showed severe lodging.

There were no significant differences between thousand seed weights between cultivars from harvested seed. Averaged over years and sites, DKL 30-42-RR had highest oil content (433 g kg^{-1}), then InVigor L.130-LL at 423 g kg^{-1}, then Cara at 422 g kg^{-1} and lowest oil content was from Empire (412 g kg^{-1}) (Table 3.7).

Averaged over factors, DKL 30-42-RR produced the highest oil yield at 969 kg hectare $^{-1}$, followed by InVigor L.130-LL at 902 kg hectare $^{-1}$, Empire at 716 kg hectare $^{-1}$, and lowest oil yield was produced from Cara at 670 kg hectare $^{-1}$ (Table 3.8). Similarly, DKL 30-42-RR produced highest seed meal yield at 1,271 kg hectare $^{-1}$, then InVigor L.130-LL at 1,230 kg hectare^{-1}, then Empire 1,016 kg hectare $^{-1}$, and Cara at 911 kg hectare $^{-1}$ (Table 3.9).

Similarly, DKL 30-42-RR produced highest seed yield at 2,239 kg hectare $^{-1}$, then InVigor L.130-LL at 2,133 kg hectare $^{-1}$, then Empire 1,732 kg hectare $^{-1}$, and Cara at 1,581 kg hectare $^{-1}$ (Table 3.10). Overall, cultivars tested produced higher yield when planted earlier except 2014 were both DKL 30-42-RR and L.130-LL produced higher yields in later plantings (Table 3.10).

3.4.2 Seeding dates

In 2013, late planting had higher stand count, on average of 25% higher, in both locations compared to the earlier planted canola (Table 3.12). However, in 2014 plant counts were higher by an average of 17% in the early planted compared to the late planting. Average over two years, establishment scores showed no significant difference between planting dates. Time of planting is very important for establishment for spring canola due to hot dry conditions during the summer months in the PNW the can reduce available moisture for the seeds. To avoid reduction in stand and establishment most spring planted alternative crops must be planted early in the spring. In Canada delayed planting of canola often results in decreased seed yield (Hockings, 1993; Degenhardt and Kondra, 1981).

Early planting showed a significant increase 60% in weed control compared to the later planted canola. Early planted canola allows for quicker ground cover to reduce inter row competition with weeds. Hence early planting offered a competitive advantage over weeds.

Early flowering is desirable in the PNW, as weather conditions are traditionally unfavorably hot later into the summer months which shortens the duration of the bloom and reduces seed yield. Averaged over years and sites, early planted canola started flowering between June 18th and 23rd. The later plantings (delayed for 14 d) did not flower until between June 26th and July 3rd, a delay of 8 to 10 d. Early planted canola had a significantly longer ($P<0.05$) time from planting to maturity compared to later planted canola. Canola is more sensitive to heat stress at flowering than wheat since flowering and seed initiation occur over long period of time and a long duration of flowering is directly related to high seed yields (Koenig, 2011).

Taller plants usually will provide more crop residue and ground cover, helping to reduce soil erosion. However, tall plants may negatively affect harvest ability of the crop by lodging and delayed maturity. Dengenhardt and Kondra (1981) reported that delayed planting of canola did not reduce plant height. Later planted canola were 6% taller than earlier planted canola. Due to the longer period of plant resources allocating to vegetative material.

Lodging was most severe in 2013, planting later also resulted in 2% less lodging than was observed from earlier planted canola. Due to the extended length of seed set leading to higher yields and top heavy canola plants that are more prone to lodge.

In 2013, the earlier planted canola produced 83 kg ha^{-1} higher oil yields compared to the later planted crop. However, in 2014 the opposite occurred with late planted canola producing higher oil yields (Table 3.8). There was no significance among planting date and oil yield. However, delayed planting did significantly ($P<0.001$) reduce oil content by 8 g kg^{-1} (Table 3.7).

In 2013 the earlier planted canola produced 81 kg hectare^{-1} higher meal yields compared to the later planted crop (Table 3.9). However, in 2014 the opposite occurred with late planted canola producing 8% higher oil yields.

The addition of N increased both seed yield at both planting dates. At a N rate of 30 kg hectare $^{-1}$ there was a 1.5% difference in yields from early to late seeding beyond this point early planted canola yielded higher (Table 3.10). In Canada delayed planting of canola often results in decreased seed yield (Hockings, 1993; Degenhardt and Kondra, 1981). Due to shortening of the pre-flowering as well as the period between flowering and senescence by planting later can result in decreased plant biomass. Also making grain fill occur later in the growing season when there is more likely chance to be increased drought temperatures and photoperiodic stress (Degenhardt and Kondra 1981; Hocking and Stapper 2001).

3.4.3 Nitrogen levels

As N availability increased, stand counts decreased (Table 3.11). Overall Genesee produced higher stand counts in both years with 2014 having the greatest emergence (Table 3.11). Increased N contributed to increased growth and higher intercrop competition. As N application increased, days to 50% flower increased, most likely due to additional energy and growth directed into vegetative rather than reproductive growth. However, lowest levels of N led to stressed canola plants that also reduced the days from planting to flowering.

Increased application of N always resulted in increased yield, irrespective of planting date. In general, early planted canola produced higher seed yield.

Plant height after flowering was directly related to N application, with taller plants from higher N rates. At the 120 kg N hectare $^{-1}$ rate plant height peaked, and additional N actually reduced plant height.

Increased N significantly ($P<0.05$) increased seed shatter and significantly ($P<0.05$) increased lodging. Due to increased yields caused by the increased application of N, canola plants grew taller and became heavier with seed and were more prone to lodging.

Increased N application resulted in a reduction in oil content. However, at 120 kg N hectare^{-1} the effect of the N plateaued, and in some cases declines with higher rates. A similar trend was observed for all cultivars. Other researchers have observed reduced seed oil content with higher N rates (Taylor *et al.,* 1991, Grant and Bailey, 1993; Jackson 2000; Kutcher *et al.,* 2005), others found that oil content was not affected by increased N (Chamorrow *et al.,* 2002). The decrease in oil content with increased N is thought to be due the higher N levels delaying seed ripening causing immature seed with a lower oil content to be harvested (Grant and Baily 1993).

Oil yield responded in a similar manner to that shown for oil content. However, maximized oil yield was achieved by the addition of between 90-150 kg N hectares $^{-1}$. However, each cultivar respond differently although there was an overall increase in oil yield with increased N rate until their optimal N input was reached and thereafter a decline.

N increased the meal yield at each location. An increase of 30 kg N hectare $^{-1}$ increased the meal yield on average 95 kg hectare $^{-1}$. Similar meal yield increased among each cultivar varying with different N rates. Over all DKL 30-42-RR yielded highest however, under lower N rates InVigor L.130-LL was a stronger competitor. At 0 kg of N hectare $^{-1}$ InVigor L.130-LL yielded 52 kg hectare $^{-1}$ more and was only on average yielded 19 kg hectare $^{-1}$ less than DKL 30-42-RR at 30 and 60 kg N hectare $^{-1}$.

Seed yield increased proportional to the addition of N to the soil. However, each cultivar showed a differential response to N application, and each reached optimal yield at different N rates.

3.4.4 Seeding rates

Increasing planting rates to 900,000 seeds hectare $^{-1}$ increased seeding stand counts by an average of 37,012 more plant hectare^{-1}. Low seeding rates can result in uneven stands, delayed maturity, and make the crop more susceptible to infestation by weeds, insects and diseases (SAF, 2004). Reduced crop stands can result from poor germination and emergence therefore plant density is not as closely correlated with seeding rates as determined (Brandt, 1994).

There was no significant difference in stand counts between the high and intermediate seeding rates. However, crop established significantly better in the highest seeding rate compared to the lowest seeding rate. As with stand counts, low seeding rates result in poor crop establishment and more likely increased weediness. Planting at too high a seeding rate results in high plant populations with thin stemmed plants, high intra crop competition, and increased crop lodging (Brown *et al.,* 2008). Suboptimal environmental conditions and unequal plant distribution limits the ability of plants to compensate for lower seeding rate higher seeding rates (Angadi *et al.*, 2002). Weed infestation increased significantly ($P<0.05$) by over 3 weeds m^{-2} between the highest and lowest seeding rate.

Decreasing seeding rate resulted in taller plants, likely due to the decreased competition and therefore more resources available per plant. Increasing the seeding rate to 540,0000 seeds $hectare^{-1}$ cause plants to be 1 cm shorter, however, there was no significant change in height from low seeding rate to intermediate or high rates. Canola planted at higher to intermediate seeding rates showed more seed shatter damage compared to the lower seeding rates. Days between planting and flowering increased significantly ($P<0.05$) between the highest and lowest seeding rate. This is likely due to the higher seeding rate causing increased interplant competition which resulted in earlier flowering.

Higher seeding rates produced higher oil and meal yields; however, there was no significant difference between oil or meal yield between the intermediate and high seeding rates.

However, seed yield was not significantly affected by any of the seeding rates tested. Other researchers found that seeding rates do not have a significant effect on yield (Degenhardt and Kondra 1981; Chistensen and Drabble 1984). Variation in the soil environment at planting may explain why recommended seeding rates vary. Through increased branching and the unusual plasticity and compensation of Brassicacaceae crops low seeding rates often have the same potential to yield as higher seeding rates (Kondra 1975; Lewis and Knight 1987; Morrison *et al.*, 1990; Brandt 1994).

3.4.5 Conventional till/ No-till

The Craigmont trials were planted under a no tillage system, while Genesee was a conventional tillage system. So it should always be noted that sites and tillage systems are confounded, and hence recommendations on tillage systems may be biased due to other site differences. While over both years Genesee significantly ($P<0.05$) had better stand counts by 18% compared to Craigmont. The no-till site both years had excess straw matter (2014, 4,838 kg $hectare^{-1}$ barley straw) that provided an extra layer for the canola seedlings to push through.

Lodging is an undesirable characteristic in most crops as it may influence crop loss, and decreases harvest speeds, thus increase harvest cost. Lodging was only observed in 2013. During 2013 both locations were affected by lodging Craigmont had significantly ($P<0.05$) less severe lodging compared to Genesee. Since the Genesee trial was located on a hill, it had no protection from the wind, increasing the lodging compared to Craigmont that was station below a sloping hill. Genesee also had significantly ($P<0.05$) taller plants compared to the Craigmont site.

Genesee produced 3% higher yields than Craigmont. Among all cultivars grown, Genesee produced higher oil contents compared to Craigmont.

Year and location significantly ($P<0.05$) impacted oil yield. Yields were higher in 2014 compared to 2013 by 22%. However, oil yield had a substantial difference from Genesee and Craigmont. Genesee average 1,025 kg hectare $^{-1}$ of oil over 2013 in 2014 and produced 71% more oil yields compared to Craigmont oil yield of 600 kg hectare $^{-1}$. Overall, Genesee proved to produce higher oil yields for each individual cultivar. Genesee in 2014 was the highest yielding year with a 50% increase from the year before in the same location.

Comparable to oil yield, meal yield is a byproduct of the canola seed and follows similar interaction trends. Within the trial 2014 was a significantly better year compared to 2013 with a 17% higher in meal yield. Over both location, Genesee was a better site for meal production with an average production of 1,363 kg ha $^{-1}$ and nearly double the yield output of Craigmont at 848 kg hectare $^{-1}$. Overall Genesee produced the highest meal yields among each cultivar.

Year and location significantly ($P<0.05$) impacted yield. Yields were higher in 2014 compared to 2013 by 19%. However, yield had a substantial difference between Genesee and Craigmont. Genesee average 2,388 kg hectare $^{-1}$ of seed over both years and produced 65% higher yields compared to Craigmont seed yield of 1,449 kg hectare $^{-1}$.

3.5 Conclusions and recommendations

Canola seed yield is a function of the interaction between genetic and environmental factors including soil type, sowing time and method, seed rate, fertilizers and time of irrigation among which, row spacing plays a vital role in getting higher yield (Hussain, 2003). It is ideal to understand the effects of each of these aspects when optimizing your canola yields.

Planting date was found to be inconclusive overall on its effects on yield potential for spring canola since both years tested had conflicting results. However, planting early provided higher stand count and 60% better control of weeds. As for seed quality, the increase in seeding date increased the oil content by 2%. Yet, timing of planting did not affect oil and meal yield.

A moderate seeding rate, which in this experiment was 5.6 kg hectare^{-1}, is adequate to ensure maximum yield potential for each cultivar.

Applying N fertilizer is essential to maximizing the yield potential of spring canola. The seed oil content of all cultivars decreased with the increase in the amount of N applied. However, at the highest rates of N applied 168 kg N hectare^{-1} seed oil content was between 39 and 42% for all cultivars tested. Since there is a premium offered for higher quality seed this needs to be a factor into the decision on N fertility. The yields plateaued at higher fertility levels, the average optimal N rate will be dependent on fertilizer prices and seed value. Undoubtedly the amount of fertilizer that should be applied ranges from 100 kg N hectare^{-1} to 168 kg N hectare^{-1} with an increase of 5% in yield.

The conventionally tilled and the direct seed trials produced similar results on seeding and N rates and therefore the same recommendations apply to both cropping systems. However, every other variable tested at Genesee (traditional tillage site) produced higher seed, oil and meal yield along with oil content for each cultivar tested on average. It should be noted that sites and tillage systems are confounded, and hence recommendations on tillage systems may be biased due to other site differences.

Cultivar specific data also indicated that optimum available N in 2013 for DKL 30-42-RR was 121 kg N hectare^{-1} to obtain maximum seed yield of 2,212 kg hectare^{-1} (Table 3.13, Figure 3.1). Optimum N rates for the other cultivars were: InVigor L.130-LL, 119 kg N hectare^{-1} for yield of 2,114 kg hectare^{-1}; Empire, 99 kg N hectare^{-1} for yield of 1,574 kg hectare^{-1} and for Cara 111 kg N hectare^{-1} for a yield of 1,433 kg hectare^{-1}. No optimum yield was reached for any of the cultivars in 2014, and although there was a reduction in seed yield response at higher N applications there was no yield peeks that year (Table 3.14, Figure 3.2). However, with the application of 168 kg N hectare^{-1} cultivars produced higher yields than in

2013. DKL 30-42-RR was 3,153 kg hectare $^{-1}$, InVigor L.130-LL 2,775 kg hectare $^{-1}$, Empire 2,413 kg hectare $^{-1}$, and Cara at 2,385 kg hectare $^{-1}$. When averaged over two years, a range of 133 to 144 kg N hectare $^{-1}$ (mean 139 kg N hectare $^{-1}$) with a range of 201 to 2012 kg N hectare $^{-1}$ (207 kg N hectare $^{-1}$) producing a yield range of 1,909 to 2,683 kg hectare $^{-1}$ (mean 2,257 kg hectare $^{-1}$) (Table 3.15, Figure 3.3).

Further economic analysis to determine maximized crop returns over input costs are examined in Chapter 6. The early planting date along with the addition of N increased seed yield for each cultivar, except DKL 30-42-RR, on average by 222 kg compared to a delayed planting, whereby DKL 30-42-RR yield was decreased by 15 kg when planted early.

The four canola cultivars tested within this experiment have tolerance to different herbicides, and the demand for weed control, weather or crop rotation may determine which herbicide resistance type is most suited. It is also worth note that DKL30-42-RR and InVigor L.130-LL are genetically modified cultivars (GMO), and have the ability to provide easier weeds strategies.. Cara is an imidazoline resistant variety that is able to be planted into soils with high residual of imidazilinone herbicides (i.e. Pursuit® or Beyond®) where the other cultivars would suffer severe damage. Both Cara and Empire are traditionally bred cultivars (non-GMO) and currently there is a premium on the seed for farmers of $.009 kg^{-1}. Each cultivar has its own specific job and when chosen correctly can aide in the development of an agricultural system.

Canola is here to stay in the PNW, and farmers are now looking for information they can use to produce these crops economically. This study allowed us to fine-tune management practices so that the growers will be able to make appropriate decisions on incorporating these factors into their current production systems.

3.5 References

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Table 3.1 Results extracted from of the 2012 PNW Spring Canola & Rapeseed Variety Trial including mean yield (lbs./acre) and rank at sites with all entries, yield by site (lbs./acre) (http://webpages.uidaho.edu/jbrown/brassica/).

Identifier	Mean	Rank	Bonners Ferry	Moscow	Craig-mont	Daven-port	Colfax	Dayton	Pend-leton	Herm-iston
Control cultivars		-------------	-------------	-------------	-------------	lb acre^{-1}	-------------	-------------	-------------	
Westar	1,615	6	1,871	2,560	1,550	1,327	1,313	1,722	599	1,980
Profit	1,671	4	1,757	2,611	1,523	1,372	1,680	1,804	696	1,921
Chosen cultivars										
InVigor.L130.LL	2,030	1	2,485	2,928	1,976	1,943	1,973	1,976	765	2,191
DKL.30-42.RR	2,015	2	2,555	2,725	2,423	1,719	1,755	1,854	743	2,345
Cara IMI	1,631	5	1,825	2,544	1,713	1,172	1,617	1,928	573	1,672
Empire	1,677	3	1,879	2,440	1,635	1,461	1,807	1,823	787	1,585
Mean	1,773	-	2,062	2,635	1,803	1,499	1,691	1,851	694	1,949
LSD 5%	308	-	313	371	254	342	327	342	131	386

Table 3.2 Results extracted from of the 2013 PNW Spring Canola & Rapeseed Variety Trial including mean yield (lbs./acre) and rank at sites with all entries, yield by site (lbs./acre) (http://webpages.uidaho.edu/jbrown/brassica/).

	Yield by location									
Varieties Tested	Mean yield and rank		Bonners Ferry	Moscow	Genesee	Craigmont	Davenport	Colfax	Dayton	Hermiston
Control cultivars	------------		------------	------------	------------	*lbs per acre*	------------	------------	------------	------------
Westar	1,902	4	2,363	2,143	1,951	1,210	1,578	1,042	2,216	1,445
Profit	1,836	5	2,293	2,093	2,365	952	1,675	1,151	2,169	1,519
Chosen cultivars										
InVigor L130 LL	2,545	2	3,219	2,923	*	1,826	2,238	1,457	2,521	1,858
DKL 30-42 RR	2,546	1	2,577	3,261	*	1,884	2,240	1,531	2,766	1,601
Cara IMI	1,831	6	1,881	2,425	2,716	1,037	2,008	1,098	1,805	1,479
Empire	2,095	3	2,178	2,506	3,226	1,425	2,030	1,148	2,337	1,628
Mean	2,126		2,419	2,559	2,565	1,389	1,962	1,238	2,302	1,588
LSD ($p = 0.05$)	150		479	357	489	317	389	302	349	294

Table 3.3 Significance of means squares from the analysis of variance of seedling stand, crop establishment, weed counts, days to 50% flower bloom, plant height after flower end, seed pod shatter, crop lodging and thousand seed weight of four cultivars, planted at two sites over two years, with three seeding rates, and six N application rates, and four replicates.

Source	d.f.[a]	Stand†	Estab.	Weed	Flower	Height	Shatter	Lodge
Year	1	***	***	.	***	***	.	.
Rep(Year)	6	**	**	***	**	***	***	***
Site	1	***	***	.	.	***	.	***
Year*Site	1	***	.	.	.	***	.	.
Rep*Site(Year)	6	***	***	.	.	***	.	ns
Date	1	ns	***	***	***	***	.	***
Year*Date	1	***	***	.	***	***	.	.
Site*Date	1	***	***	.	.	***	.	***
Year*Site*Date	1	*	.	.	.	***	.	.
Rep*Date(Year)	6	**	**	**	***	***	.	**
N (n)	5	***	ns	*	***	***	***	***
Year*n	5	**	ns	.	***	ns	.	.
Site*n	5	***	***	.	.	***	.	**
Date*n	5	ns	ns	*	***	*	.	*
Year*Site*n	5	*	.	.	.	*	.	.
Year*Date*n	5	ns	ns	.	***	ns	.	.
Site*Date*n	5	*	*	.	.	ns	.	*
Year*Site*Date*n	5	ns	.	.	.	*	.	.
Rep*N(Year)	30	ns	ns	ns	***	ns	***	ns
Cultivar (cv)	3	***	***	***	***	***	***	***
Year*cv	3	***	*	.	***	***	.	.
Site*cv	3	ns	***	.	.	***	.	***
Date*cv	3	ns	*	ns	***	***	.	***
cv*n	15	ns	*	ns	***	*	**	*
Year*Site*cv	3	*	.	.	.	*	.	.
Year*Date*cv	3	ns	ns	.	***	***	.	.
Year*cv*Seed rate	6	ns	ns	.	ns	ns	.	.
Site*Date*cv	3	ns	*	.	.	ns	.	***
Site*cv*n	15	**	**	.	.	ns	.	ns
Date*cv*n	15	ns	**	ns	ns	ns	.	ns
Year*Site*Date*cv	3	ns	.	.	.	***	.	.
Year*Site*cv*n	30	ns	ns	.	ns	ns	.	.
Site*Date*cv*n	15	ns	**	.	.	ns	.	ns

Table 3.3 (continued) Significance of means squares from the analysis of variance of seedling stand, crop establishment, weed counts, days to 50% flower bloom, plant height after flower end, seed pod shatter, crop lodging and thousand seed weight of four cultivars, planted at two sites over two years, with three seeding rates, and six N application rates, and four replicates.

Source	d.f.^{a}	Stand†	Estab.	Weed	Flower	Height	Shatter	Lodge
Seed rate	2	***	***	**	***	*	***	ns
Year*Seed rate	2	ns	ns	.	ns	ns	.	.
Site*Seed rate	2	ns	ns	.	.	*	.	ns
Date*Seed rate	2	ns	ns	ns	ns	ns	.	*
n*Seed rate	10	ns	ns	ns	ns	ns	ns	ns
cv*Seed rate	6	ns	ns	ns	ns	ns	ns	ns
Year*Site*Seed rate	2	ns	.	.	.	ns	.	.
Year*Date*Seed rate	2	ns	ns	.	ns	ns	.	.
Site*date*Seed rate	2	ns	ns	.	.	ns	.	*
Site*n*Seed rate	10	ns	ns	.	.	ns	.	ns
Date*n*Seed rate	10	ns	ns	ns	ns	ns	.	ns
Site*cv*Seed rate	6	ns	ns	.	.	ns	.	ns
Date*cv*Seed rate	6	ns	*	*	ns	ns	.	ns
cv*n*Seed rate	30	ns	ns	ns	*	ns	ns	ns
Year*Site*Date*Seed rate	2	ns	.	.	.	ns	.	.
Year*Site*n*Seed rate	20	ns	ns	.	ns	ns	.	.
Year*Site*cv*Seed rate	6	ns	.	.	.	ns	.	.
Site*Date*N*Seed rate	10	ns	*	.	.	ns	.	ns
Site*Date*cv*Seed rate	6	ns	*	.	.	ns	.	ns
Date*cv*n*Seed rate	30	ns	*	ns	ns	ns	.	ns
Year*Site*Date*n*Seed rate	20	ns	ns	.	ns	ns	.	.
Year*Site*Date*cv*Seed rate	12	ns	ns	.	ns	ns	.	.
Site*date*cv*n*Seed rate	60	ns	***	.	.	ns	.	*
Year*Site*Date*cv*n*Seed rate	150	ns	ns	.	ns	ns	.	.

d.f.^{a}=degrees of freedom

*=0.01<P<0.05; **=0.05<P<0.001; ***=P<0.001; ns= not significant

† stand = seedling stand, estab = crop establishment, weed = weed counts, flower = days to 50% flower bloom, height = plant height after flower end, shatter = seed pod shatter, lodge = crop lodging, and TSW = thousand seed weight.

Table 3.4 Significance of means squares from the analysis of variance of oil content, oil yield, meal yield and seed yield, of four cultivars, planted at two sites over two years, with three seeding rates, six N application rates, and four replicates.

Source	d.f.[a]	TSW	Oil Content†	Oil Yield	Meal Yield	Seed Yield
Year	1	ns	***	***	***	***
Rep(Year)	6	ns	***	***	***	***
Site	1	ns	***	***	***	***
Year*Site	1	ns	***	***	***	***
Rep*Site(Year)	6	ns	***	***	***	***
Date	1	ns	***	***	***	***
Year*Date	1	ns	*	***	***	***
Site*Date	1	ns	*	*	ns	ns
Year*Site*Date	1	ns	*	***	***	***
Rep*Date(Year)	6	ns	***	***	***	***
N (n)	5	ns	***	***	***	***
Year*n	5	ns	***	***	***	***
Site*n	5	ns	***	***	***	***
Date*n	5	ns	*	**	***	***
Year*Site*n	5	ns	***	***	***	***
Year*Date*n	5	ns	*	***	***	***
Site*Date*n	5	ns	*	***	***	***
Year*Site*Date*n	5	ns	*	***	***	***
Rep*N(Year)	30	ns	*	***	***	***
Cultivar (cv)	3	ns	***	***	***	***
Year*cv	3	ns	ns	***	***	***
Site*cv	3	ns	***	***	***	***
Date*cv	3	ns	**	***	***	***
cv*n	15	ns	**	**	***	***
Year*Site*cv	3	ns	ns	*	**	**
Year*Date*cv	3	ns	*	***	***	***
Year*cv*Seed rate	6	ns	*	ns	ns	ns
Site*Date*cv	3	ns	*	*	ns	ns
Site*cv*n	15	ns	*	ns	ns	ns
Date*cv*n	15	ns	ns	ns	ns	ns
Year*Site*Date*cv	3	ns	ns	ns	*	ns
Year*Site*cv*n	30	ns	ns	*	**	*
Site*Date*cv*n	15	ns	ns	ns	ns	ns

Table 3.4 (continued) Significance of means squares from the analysis of variance of oil content, oil yield, meal yield and seed yield, of four cultivars, planted at two sites over two years, with three seeding rates, six N application rates, and four replicates.

Source	d.f.[a]	TSW	Oil Content†	Oil Yield	Meal Yield	Yield
Seed rate	2	ns	ns	**	**	**
Year*Seed rate	2	ns	ns	*	*	*
Site*Seed rate	2	ns	ns	ns	ns	ns
Date*Seed rate	2	ns	ns	ns	ns	ns
n*Seed rate	10	ns	ns	ns	ns	ns
cv*Seed rate	6	ns	ns	ns	ns	ns
Year*Site*Seed rate	2	ns	ns	ns	ns	ns
Year*Date*Seed rate	2	ns	ns	ns	ns	ns
Site*date*Seed rate	2	ns	ns	ns	ns	ns
Site*n*Seed rate	10	ns	ns	ns	ns	ns
Date*n*Seed rate	10	ns	ns	ns	ns	ns
Site*cv*Seed rate	6	ns	ns	ns	ns	ns
Date*cv*Seed rate	6	ns	ns	ns	ns	ns
cv*n*Seed rate	30	ns	ns	ns	ns	ns
Year*Site*Date*Seed rate	2	ns	ns	ns	ns	ns
Year*Site*n*Seed rate	20	ns	ns	ns	ns	ns
Year*Site*cv*Seed rate	6	ns	ns	ns	ns	ns
Site*Date*N*Seed rate	10	ns	ns	ns	ns	ns
Site*Date*cv*Seed rate	6	ns	ns	ns	ns	ns
Date*cv*n*Seed rate	30	ns	ns	ns	ns	ns
Year*Site*Date*n*Seed rate	20	ns	ns	ns	ns	ns
Year*Site*Date*cv*Seed rate	12	ns	ns	ns	ns	ns
Site*date*cv*n*Seed rate	60	ns	ns	ns	ns	ns
Year*Site*Date*cv*n*Seed rate	150	ns	ns	ns	ns	ns

d.f.[a]=degrees of freedom

*=0.01<P<0.05; **=0.05<P<0.001; ***=P<0.001; ns= not significant

† seed oil content ing kg^{-1} of oil, oil yield inkg hectare^{-1} of oil, meal yield in kg hectare^{-1} of meal, seed yield in kg hectare^{-1} of seed

Table 3.5 Plant stand counts of four cultivars grown in 2013 and 2014. Data presented are averaged over two sites, six N treatments, three seeding rates, and four replicates.

	Cultivar				
Year	30-42-RR†	Cara	Empire	L.130-LL	Mean
	----------------------------------- plants m row^{-1}			--------------------------------	
2013	248,888	168,509	211,632	269,619	224,662 ^{x}
2014	269,979	219,757	266,816	278,239	258,798 ^{y}
Mean	259,434 ^{b}	193,772 ^{d}	238,737 ^{c}	273,884 ^{a}	
s.e. Mean		7.56			

Means within rows or columns assigned to different superscript letters are significant (Duncan P<0.05)
†30-42-RR= DKL 30-42 RoundupReady®, L. 130-LL = InVigor L.130 LibertyLink®

Table 3.6 Plant height of four cultivars planted early and late in 2013 and 2014. Data presented are averaged over two sites, six N treatments, three seeding rates, and four replicates.

	Cultivar					
Date-year	30-42-RR†	Cara	Empire	L.130-LL	Date Mean	Year Mean
	-- cm			---		
Early-2013	122.2	124.7	119.8	140.3	123.5 ^{z}	131.6 ^{w}
Late-2013	129.1	137.1	131.0	148.4	131.5 ^{y}	
Early-2014	115.8	122.5	116.4	126.5	123.5 ^{z}	123.5 ^{x}
Late-2014	120.5	129.3	121.4	135.1	131.5 ^{y}	
Mean	121.9 ^{c}	128.4 ^{b}	122.2 ^{c}	137.6 ^{a}		
s.e. Mean		7.54				

Means within rows or columns assigned to different superscript letters are significant (Duncan P<0.05).
†30-42-RR= DKL 30-42 RoundupReady®, L. 130-LL = InVigor L.130 LibertyLink®

Table 3.7 Seed oil content of four cultivars planted early and late. Data presented are averaged over two site, six N treatments, three seeding rates, and four replicates in 2013 and 2014.

	Cultivar				
Date	30-42-RR†	Cara	Empire	L.130-LL	Mean
	------- g kg $^{-1}$ -------				
Early	437	426	416	429	427 ^{x}
Late	429	419	409	417	419 ^{y}
Mean	433 ^{a}	422 ^{b}	412 ^{c}	423 ^{b}	
s.e. Mean		1.48			

Means within rows or columns assigned to different superscript letters are significant (Duncan $P<0.05$)

†30-42-RR= DKL 30-42 RoundupReady®, L. 130-LL = InVigor L.130 LibertyLink®

Table 3.8 Oil yield of four cultivars planted early and late in 2013 and 2014. Data presented are averaged over two site, six N treatments, three seeding rates and four replicates.

	Cultivar					
Date-year	30-42-RR†	Cara	Empire	L.130-LL	Date Mean	Year Mean
	------- kg ha $^{-1}$ -------					
Early-2013	993	613	707	1,017	856	735 ^{b}
Late-2013	839	502	507	701	773	
Early-2014	950	821	841	903	856	896 ^{a}
Late-2014	1,098	749	812	989	773	
Mean	969 ^{a}	670 ^{d}	716 ^{c}	902 ^{b}		
s.e. Mean		174				

Means within rows or columns assigned to different superscript letters are significant (Duncan $P<0.05$)

†30-42-RR= DKL 30-42 RoundupReady®, L. 130-LL = InVigor L.130 LibertyLink®

Table 3.9 Meal yield of four cultivars planted early and late in 2013 and 2014. Data presented are averaged over two site, six N treatments, three seeding rates and four replicates.

	Cultivar					
Site-year	30-42-RR†	Cara	Empire	L.130-LL	Date Mean	Year Mean
	------ kg ha^{-1} ------					
Early-2013	1,314	847	1,026	1,388	1148	1021 ^{b}
Late-2013	1,145	707	742	1,000	1067	
Early-2014	1,205	1,074	1,148	1,177	1148	1195 ^{a}
Late-2014	1,422	1,020	1,154	1,359	1067	
Mean	1,271 ^{a}	911 ^{d}	1,016 ^{c}	1,230 ^{b}		
s.e. Mean		233				

Means within rows or columns assigned to different superscript letters are significant (Duncan $P<0.05$)
†30-42-RR= DKL 30-42 RoundupReady®, L. 130-LL = InVigor L.130 LibertyLink®

Table 3.10 Yield of four cultivars planted early and late in 2013 and 2014. Data presented are averaged over two site, six N treatments, three seeding rates and four replicates.

	Cultivar					
Site-year	30-42-RR†	Cara	Empire	L.130-LL	Date Mean	Year Mean
	------ kg ha^{-1} ------					
Early-2013	2,307	1,460	1,734	2,406	2,004	1,757 ^{b}
Late-2013	1,985	1,210	1,249	1,701	1,840	
Early-2014	2,155	1,895	1,990	2,080	2,004	2,090 ^{a}
Late-2014	2,510	1,770	1,967	2,349	1,840	
Mean	2,239 ^{a}	1,581 ^{d}	1,732 ^{c}	2,133 ^{b}		
s.e. Mean		403				

Means within rows or columns assigned to different superscript letters are significant (Duncan $P<0.05$)
†30-42-RR= DKL 30-42 RoundupReady®, L. 130-LL = InVigor L.130 LibertyLink®

Table 3.11 Plant stand counts of six nitrogen treatments planted in Craigmont and Genesee in 2013 and 2014. Data presented are averaged over four cultivars, three seeding rates and four replicates.

	N rate (kg hectare^{-1})							
Site-year	0	33	67	100	134	168	Site Mean	Year Mean
	plants m row $^{-1}$							
Craigmont-2013	202,443	184,673	169,810	165,575	151,625	154,697	221,612 ^{b}	224,662 ^{b}
Genesee-2013	315,705	336,962	289,888	264,388	243,976	217,639	224,662 ^{a}	
Craigmont-2014	269,370	283,486	273,049	283,736	270,046	263,475	221,612 ^{b}	258798 ^{a}
Genesee-2014	290,877	256,417	261,067	239,145	226,606	191,648	224,662 ^{a}	
Means	269,599 ^{a}	265,385 ^{a}	246,963 ^{b}	238,211 ^{b}	222,363 ^{c}	206,865 ^{d}		
s.e. Mean			75,025					

Means within rows or columns assigned to different superscript letters are significant (Duncan P<0.05)

Table 3.12 Plant stand counts of early and late planted in Craigmont and Genesee in 2013 and 2014. Data presented are averaged over four cultivars, three seeding rates, six nitrogen treatments and four replicates.

	Planting Date			
Site-year	Early	Late	Site Mean	Year Mean
	-------------------------plants m row^{-1}-------------------------			
Craigmont-2013	134,713	208,228	221,612 ^{b}	224,662 ^{b}
Genesee-2013	263,668	292,039	224,662 ^{a}	
Craigmont-2014	290,655	255,692	221,612 ^{b}	258,798 ^{a}
Genesee-2014	267,460	221,126	224,662 ^{a}	
Mean	239,124 ^{a}	244,028 ^{a}		
s.e. Mean	156,907			

Means within rows or columns assigned to different superscript letters are significant (Duncan $P<0.05$)

Table 3.13 Maximum seed yield potential in 2013, and optimum applied N, and available N to achieve yield potential for each cultivar.

Cultivar	Max Yield -kg hectare^{-1}-	Optimum N -kg N applied hectare^{-1}-	Optimum N -kg N available hectare^{-1}-
L.130-LL	2,114	119	194
30-42- RR	2,212	121	196
Empire	1,574	99	174
Cara	1,433	111	186
Mean	1,833	112	187

Table 3.14 Maximum seed yield potential in 2014, and optimum applied N, and available N to achieve yield potential for each cultivar.

Cultivar	Max Yield -kg hectare^{-1}-	Optimum N -kg N applied hectare^{-1}-	Optimum N -kg N available hectare^{-1}-
L.130-LL	2,775	168	228
30-42-RR	3,153	168	228
Empire	2,413	168	228
Cara	2,385	168	228
Mean	2,683	168	228

Table 3.15 Maximum seed yield potential averaged between 2013 and 2014, and optimum applied N, and available N to achieve yield potential for each cultivar.

Cultivar	Max Yield -kg hectare-	Optimum N -kg N applied hectare-	Optimum N -kg N available hectare^{-1}-
L.130-LL	2,445	143	211
30-42-RR	2,683	144	212
Empire	1,994	133	201
Cara	1,909	139	207
Mean	2,257	139	207

Figure 3.1 Yield (kg ha^{-1}) of four cultivars under different N rates averaged over 2013 and 2014.

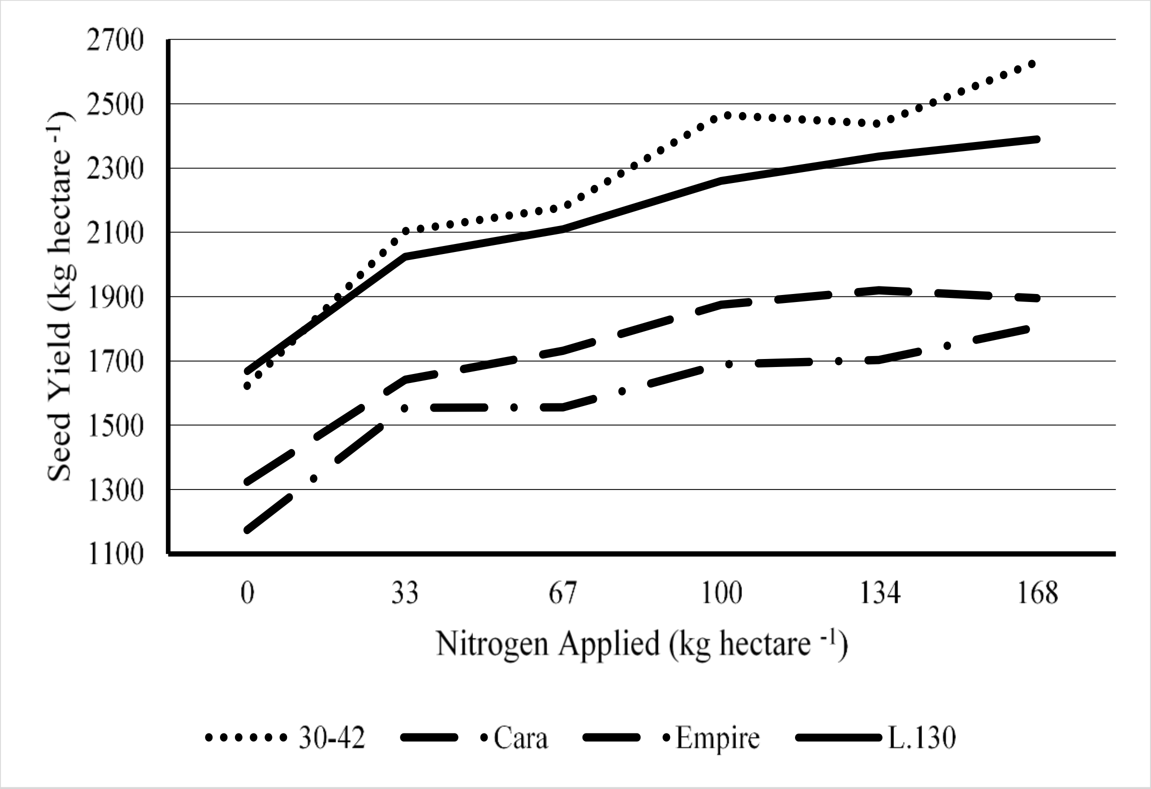


Figure 3.2 Yield (kg ha^{-1}) of four cultivars under different N rates in 2013.

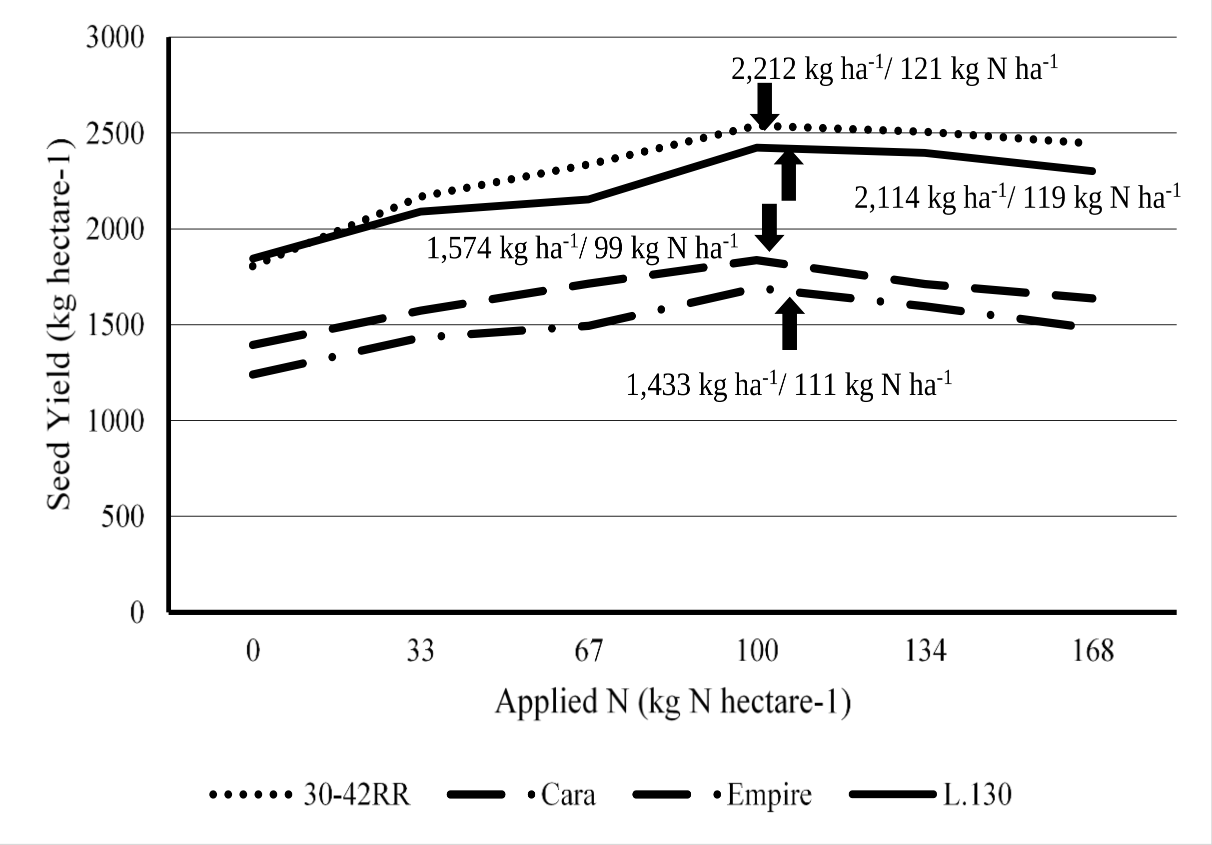
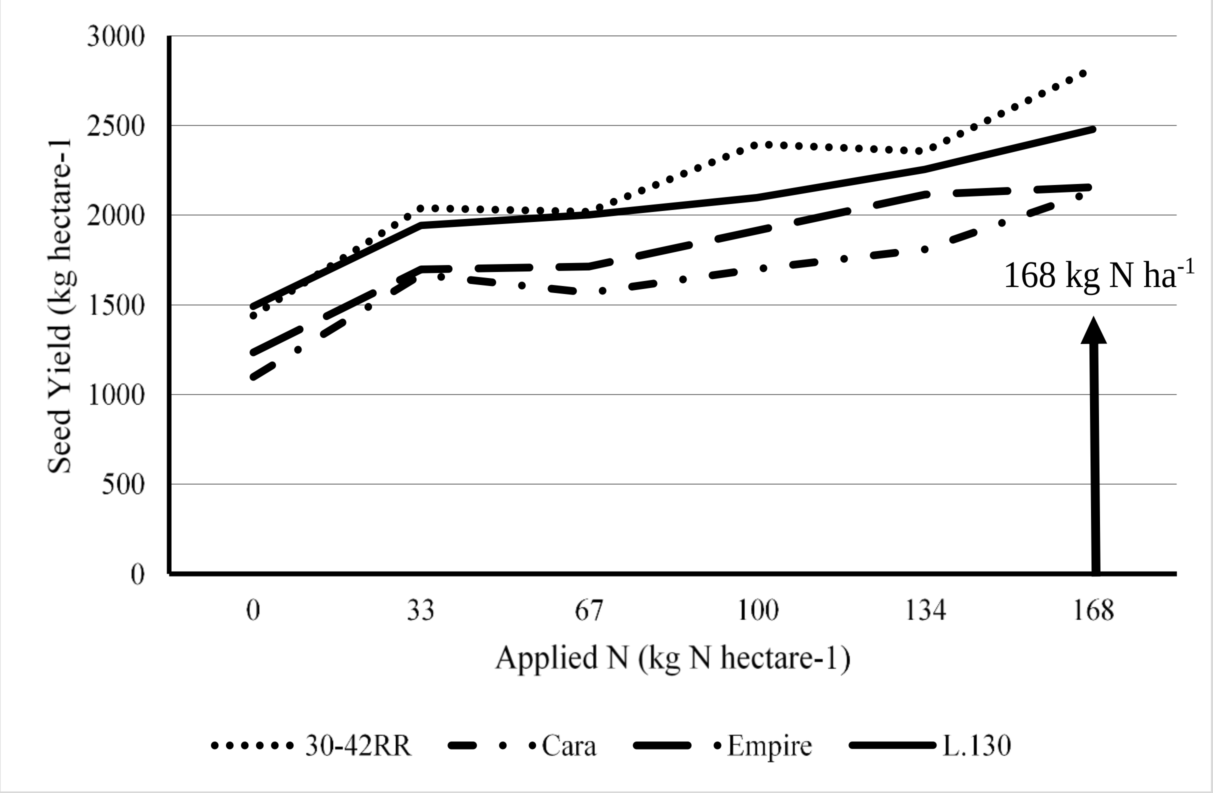


Figure 3.3 Yield (kg ha^{-1}) of four cultivars under different N rates in 2014.



Chapter 4: Optimal agronomic practices for maximized productivity of winter canola (*Brassica napus* L.) in northern Idaho

4.1 Abstract

Modern, industrialized agriculture in the United States (U.S.) tends towards monolithic crops with limited diversity in rotations, which can contribute to a host of issues from increase disease, weed and pest problems, to increased erosion and decreased soil health and fertility. In the Pacific Northwest (PNW), there are few well-adapted and profitable alternative crops to grow in rotation with small grain cereals (wheat and barley) which is predominated in the region. Winter canola provides numerous environmental and financial benefits when included in crop rotations dominated by small grains. However, this is a fairly new crop to the region, and proper management is needed to maximize seed yield. Winter canola is traditionally planted in the fall and harvested for seed in the following year. However establishment of fall-planted canola in dry soils produces variable and unreliable yields which have discouraged many farmers from including canola in crop rotations. Field plot studies were planted in 2013 to examine the response of winter canola under early and delayed planting conditions in Intermediate to higher rainfall regions of the PNW, and to determine optimum seeding and nitrogen rates under both seeding conditions. Factors examined included: two cultivars (Amanda and HyClass® 125W), two planting dates (planting earlier than has been traditional in early July, and delayed seeding until the more traditional planting date of early August), three seeding rates (900,000, 1,250,000 and 1,350,000 seeds per hectare), and six nitrogen application rates treatments (0, 56, 112, 168, 224, and 280 kg hectare $^{-1}$). The experimental design was a four replicate, split-split-plot with planting dates being assigned to main strips, nitrogen rates assigned to split-plots, and cultivars and seeding rates assigned to split-split-plots. In general winter canola cultivars had better establishment when planted early, at intermediate seeding rates and with moderate to high nitrogen availability; although cultivars responded differently to nitrogen availability. Highest optimal winter canola yield was 3,952 kg hectare^{-1} from planting the cultivar Amanda, at 1,250,000 seeds hectare^{-1}, with 241 kg N applied hectare^{-1}. Information from this project will be

valuable to growers to aid in the correct choice of cultivar and management practices to optimize profitability. Better agronomic practices combined with genetically superior cultivars will make provide growers with more consistent canola production and will increase the acreage of winter canola in northern Idaho and other regions in the PNW.

4.2 Introduction

Growers in the PNW have a long history of growing small grain cereal crops, such as wheat and barley which predominate the dryland hectarage. In the PNW there is about 1.3 million hectares of land in a grain-fallow rotation and almost all of this is in a continuous wheat-fallow rotation. In 2013 and 2014 growers in the U.S. planted 22,743,180 and 22,871,970 acres, respectively, of wheat (USDA, NASS 2013). In the PNW in 2014, 526,905 hectares of were planted to wheat in Idaho, 332,100 hectares in Oregon, and in 919,350 hectares in Washington (USDA, NASS, 2013).

Agriculture in the PNW is intensely monolithic predominated by small grain cereals. More than 60% of all agricultural land in the PNW is planted to wheat (*Triticum aestivum*), and more than 85% of all dryland acres are planted to wheat, with very few alternative crops available for rotations. It has been noted that when wheat is grown in monoculture or in rotation with closely related crops like barley, disease, pests and weeds can become increasingly problematic and yields decline over time (Krupinsky *et al*., 2004). In addition the PNW region has some of the most erosion sensitive soil in the world with an estimated 40% of the Palouse regions topsoil already lost to erosion (Pimentel *et al.*, 1995). In high rainfall regions where annual cropping is possible crop rotations crops include pea, garbanzo bean and lentil. However, these legume crops lack sufficient crop residue for effective winter ground cover and soil erosion can be severe. Pea and lentil crops maintain less than 25% ground cover during the winter months and commonly produce only 450 to 900 kg residue hectares^{-1} (Gareau and Guy, 1995). Legume crops are all spring planted and do not fit into the crop-fallow regions where fall-seeded crops are needed to utilize winter rains.

Demand for canola products continues to rise in the U.S., and indeed worldwide. When pressed this oilseed crop produces healthy oils for cooking, lubrication or for biofuel production. In addition, the seed meal byproduct of oil extraction serves as a high quality feedstock protein supplement for livestock production.

Both spring (*B. napus L spp. Oleifera (Metzg) Sinsk. F. annua*) and winter (*B. napus* L. *spp. Oleifera (Metzg) Sinsk. F. biennis*) can be grown in the PNW and both crops have proven to be valuable rotational crops. Winter canola could be an ideal crop to use in a rotation scenario with wheat in a crop-fallow system. Winter canola would add diversification to dry-land farmer's rotations within the PNW (Pakish, 2014). It not only has the same growing season as winter wheat, but growers can use the same equipment for planting and harvesting (Johnson, 2009), limiting the need for large capital investments in machinery.

Rotational benefits of canola includes crop rotation can increase overall crop yields (Classen and Kissel, 1984; Larney and Lindwall, 1994; Bourgeois and Entz, 1996), decrease weed populations (Liebman and Dyck, 1993), reduce insect and disease infestations (Krupinsky *et al.,* 2004), improve soil health and fertility (Weinert *et al.,* 2002; Vos and Van Der Putten, 2004) and reduce soil erosion (Peterson and Rohweder, 1983). An average canola crop will provide as much residue as a normal cereal crop. For example, a canola crop yielding 2,000 kg per hectare of seed will also produce approximately 3,000 to 4,000 kg hectare^{-1} of dry plant residue, (Guy and Gareau, 1997) which reduces soil erosion, water run-off and nutrient leaching and can increase soil organic matter. Wheat and barley crops following canola in rotation showed an increase in seed quality and a decline in disease (Wilson *et al.,* 1994). It also has been shown that winter wheat following winter canola has greater seed yield than when following small cereal grains (Guy and Karow, 1998). Canola can provide the opportunity to clean up grassy weeds since canola is a broadleaf that are difficult to control in a continuous winter wheat production system (Johnson, 2009). The deep taproots of canola break up plow pans and mine nutrients deep in the soil profile making them available through mineralization (Angus *et al*., 1991). The low investment costs and increasing consumer demand for canola oil make it a potentially good alternative crop for growers (Nelson, 1992).

Canola can germinate and grow in cool temperatures and is one of the few oilseed crops that can be cultivated over wide areas of the temperate zone. Winter canola normally produces double the yield of spring canola in the same production area (Ehrensing, 2008).

Failure to obtain good fall stand establishment prior to the onset of winter is a major limiting factor of winter canola production in the PNW. Canola stand establishment and seedling survival is more variable than cereals. This is largely attributed to its epigeal emergence whereby the cotyledons and the shoot growing point emerge above the soil surface, increasing the plants exposure to environmental stress (Koenig, 2011). In contrast cereals exhibit hypogeal emergence resulting in the shoot growing point remaining below ground and therefore more protected from extreme aerial climatic conditions (Koenig, 2011).

Fall rains come too late in the year to establish winter canola in an annual cropping system and winter canola in the PNW need to be planted into fallow ground. Without good soil moisture to germinate winter canola can produce erratic stands or complete crop establishment failure (Ehrensing, 2008), resulting in inconsistent yields. Established winter canola when planted late in the fall has only a short growth period before the onset of winter and winter kill can be severe causing significant yield reduction or crop loss. Temperatures that were high shortly after seedling emergence can also damage and kill young canola plants by burning the stems at the soil surface (Ehrensing, 2008). Seeding during favorable temperature and moisture conditions is therefore more critical for canola than for wheat stand establishment.

Winter canola is traditionally planted into summer fallow in the PNW from early August to the second week of September (Moore and Guy, 1997). Generally winter canola needs to be well established six weeks before the first killing frost (Brown *et al.*, 2008). Therefore winter canola needs at least 45 days of good plant growth before the onset of winter conditions (Brown *et.al*, 2008). So winter canola needs to be planted early enough that the crop achieves full ground cover before November and plants must have developed to a suitable rosette stage for reliable winter survival (Auld *et al.*, 1984). However, the performance of winter canola in the low and intermediate rainfall regions is often unreliable because of dry soil conditions in the fall which combined with high surface soil temperatures results in poor crop establishment.

Soil moisture is often plentiful in the summer months and surface soil temperatures markedly lower in July than August. Planting winter canola earlier than traditionally would greatly improve the dependability of winter canola establishment. If planted earlier, winter canola would remain vegetative into the winter months due to vernalization requirements. Eight years ago, the Canola Breeding group at the University of Idaho began studying the potential of early-planted winter canola, where winter canola is planted into fallow ground in early July when soil moisture is not limiting and soil temperatures are low (*per. com.* Jack Brown). Early planted winter canola in the PNW wheat-fallow region has tremendous potential for increasing the acreage of winter canola harvest in the region by offering growers a more repeatable and reliable alternative crop. Indeed, initial results continue to be encouraging, and several growers in the region are now planting winter canola earlier than has been traditional.

Many Brassicaceae crops are able to compensate for low plant densities by increasing branching excessively. Seeding rates that are low can result in uneven stands these stands require more time to mature and can make the crop more susceptible to the effects of weeds, insects and diseases (SAF, 2004). Reduced stands can result due to poor germination and emergence therefore plant density is not as closely correlated with seeding rates as determined (Brandt, 1994). In both cases, a seeding rate that is too low will result in poor crop establishment and more likely increased weediness. Planting too high a seeding rate will result in high plant populations with thin stemmed plants and high intra-crop competition and crop lodging at maturity. Seed must be placed into moisture, and planting too shallow can result in irregular germination and patchy stand. Conversely, planting too deep can delay seedling emergence resulting in poor vigor (Brown *et al.*, 2008). Research has concluded that there is no significant yield difference due to seeding at 7 and 14 kg hectare $^{-1}$ (Christensen and Drabble 1984; Degenhardt and Kondra, 1981) Others found that higher canola seed yields could be initially be achieved when seeding rates were increased rates (Clarke and Simpson 1978 and Clarke *et al.*, 1978).

The plant nutrient needed in the greatest quantity is nitrogen since it is usually the most limiting factor for growth and seed production of *B. napus* (Ukrainetz *et al.*, 1975). Plants take the nitrogen and convert to protein and chlorophyll. Nitrogen supply has a larger influence on plant cell size and leaf area which is required for photosynthesis and growth. Nitrogen promotes vigorous growth and increase leaf area and has a strong impact on yield. It is nearly always deficient in agricultural soils due to repeated crop production. As canola plants mature plant nitrogen moves to the seed. The nitrogen use efficiency of a cultivar is key since not all of the fertilizer nitrogen applied is actually taken up by canola. Winter canola is primarily fertilized in the fall and proceeding spring.

There have been very few nitrogen fertility studies conducted on winter canola in the U.S. and recommendations for northern Idaho are based on Canadian and North Dakota research primarily with spring cereal (Grant and Bailey, 1990; Mahler and Guy, 1994). The bulk of the previous work has been done on nitrogen and its interactions with other agronomic practices for canola. It is recommended that 110 to 295 kg available N hectare^{-1} be available for winter canola to obtain potential yields in northern Idaho (Mahler and Guy, 2005). At applied nitrogen rates ranging from 0 to 252 kg N hectare^{-1} (Jackson, 2000) the increase in canola yields from additional nitrogen was found to be both linear and quadratic. Significant increase in seed yield as additional nitrogen is applied to the crop is supported by many researchers, with the best gain in yield coming from the addition of the first 40 kg N hectare^{-1} (Kutcher *et al.*, 2005).

Weeds will competition with canola for nutrients and soil moisture since canola is not competitive as seedlings. Conversely, once established the crop is more competitive letting less than 9% of full sunlight down to the soil surface where late-emerging weeds are in near darkness (Martin *et al.*, 2001). Rapid establishment of winter canola is key for adequate weed control. Winter canola can offers non-Group 2 grassy weed herbicide options in cereal rotations. The potential to reduce Group 2 herbicide resistant weeds makes winter canola a useful cleanup tool in cereal rotations (Esser, 2012).

Few rotations studies have been attempted to quantify the effect of winter canola on subsequent performance of winter wheat under a crop-fallow system. A field-scale test was conducted near Ritzville Washington between 2006 and 2009 whereby fallow-winter wheat-fallow winter wheat crop rotation was compered to fallow-winter canola-fallow-winter wheat (Esser, 2012). In the first crop year of this study yield of winter canola was 34% less than winter wheat. However, winter wheat following canola yielded over 39% more than winter wheat following winter wheat, resulting in greater two crop year profitability from the winter canola rotation (Esser, 2012). Market price differential between the two crops can vary dramatically from year to year, and has a larger influence on system profitability. Canola overall needs to have a 26% price advantage per bushel over wheat to produce significantly greater gross returns.

Comparison of the genetic and non-genetic yield gains over 20 years of variety trials in the PNW showed that winter canola genetic improvements were responsible for yield increases of 604 kg hectare $^{-1}$(or 55% of the total increase), while agronomic improvements only attributed 483 kg hectare^{-1}(or 45% of total increase) (Pakish, 2014). However, despite the valuable adaptation and yield potential information that has been obtained by breeders, the cultivar evaluations are conducted under uniform conditions, and there is no attempt to optimize productivity of any specific cultivars in any of the test regions. Therefore test entries in breeding programs are all tested under the same nitrogen management, seeding rate and seeding date at each location.

In this project two winter canola cultivars that had previously performed well in PNW Regional Yield Trials were chosen for agronomic studies that examine the following: (1) two seeding dates; (2) three seeding rates; and (3) six nitrogen levels, to determine optimize management practices to maximize productivity of winter canola planted into summer fallow. Evaluate the performance of two adapted winter canola cultivars under six variable nitrogen, three seeding rates and two seeding dates. The objective of this research is:

- To make the farming community aware of the best crop management practices that will increase productivity, and acreage of canola in Idaho through field tours and grower presentations and printed summaries.

4.3 Materials and methods

4.3.1 Site and trial specifications

Agronomic performance of two *B. napus* cultivars was evaluated in field trials grown at two locations in northern Idaho, Genesee and Moscow. Genesee (46°55’N, 116°92’W, elevation 815m) trials located at the University of Idaho Kambitch Research Farm 15.3 km south of Moscow. Moscow trials were at the University of Idaho Parker Research Farm located 3 km east of Moscow (45°73’N, 116°99’W, elevation 790m). The 20-year average annual precipitation is 60 cm for Genesee and 55 cm for Moscow. The soil type at the Kambitch Farm is Naff Palouse silt loam complex consisting of fine-silty, mixed, mesic Typic

Argixerolls. The soil type at the Parker Farm is a Palouse silt loam complex consisting of fine-silty, mixed, mesic Pachic Haploxerolls.

The Moscow trial and the later seeded Genesee trial were planted into conventional tillage soils following mechanical fallow. Fields were chisel plowed in the prior fall and then lightly cultivated and harrowed in the spring. Prior to planting the trial area was treated with 2.38 L a.i. hectare^{-1} of the Trust™ herbicide was pre-plant incorporated to a depth on 10 cm with two perpendicular cultivar passes to control broadleaf weeds and mayweed chamomile.

The early seeded trial at Genesee was direct seeded into standing wheat stubble after chemical fallow. Prior to planting the no-tillage plots the trial area was treated with 0.96 L hectare^{-1} of the herbicide Roundup RT3™ to control weed seedlings.

4.3.2. Planting dates

Two planting dates were examined. The early planted trial at Genesee (no-tillage only) was planted on July 16th and late trial at Genesee was 28 d later (August 26th) when winter canola is traditionally planted. There was no early planted trial at Moscow and the late planted trial at that site was planted on August 27th.

4.3.3 Cultivars tested

The two winter canola cultivars were chosen from amongst those that had shown adaptability from Regional Variety Trials (Table 4.1, 4.2). One cultivar was the Roundup Ready® hybrid cultivar ‘HyClass® 125W’, developed by Winfield. The second was the open-pollinated herbicide susceptible (non-GMO) cultivar ‘Amanda’ developed and released by the University of Idaho (Brown *et al.*, 2015).

4.3.4 Seeding rate and variable nitrogen application

The three seeding rates examined were 900,000, 1,125,000, and 1,350,000 seeds hectare^{-1} (equivalent to approximately 4.5, 5.6, and 6.7 kg seed hectare^{-1}). These rates were chosen as the low and high end of the seeding rate routinely used in the University of Idaho breeding program and then a moderate rate between the high and low was selected.

Prior to planting seed from both cultivars was treated with Helix Xtra™ (Thlamethoxam, Difenoconazale, Mefenoxam, Fludioxonil) at a rate of 14 mL kg hectare^{-1} to protect against soil and seed borne fungal disease and insect (mainly flea beetle) control.

Six nitrogen application rates were examined, 0, 56, 112, 168, 224, and 280 kg N applied hectare^{-1}. These nitrogen rates were chosen to create a range from adding 0 kg N applied hectare^{-1} to a high level that was expected to cause a yield plateau or yield decline.

4.3.5. Planting

Prior to planting, soil samples were analyzed to determine base nutrient levels. Residual available nitrogen was determined in the top two feet of the soil. Available residual nitrogen, calculated as the sum of the ammonium (NH_4^+) and nitrate (NO_3^-) in the top two feet, was determined. Base nitrogen levels were 24 kg N hectare $^{-1}$ at Genesee, and 40 kg of N hectare $^{-1}$ at Moscow. These rates resulted in an average residual available nitrogen of 32 kg N hectare^{-1} over both sites.

Other commonly deficient macro and micro nutrients levels to minimum levels necessary for canola production in the north Idaho. Sulfur and nitrogen were applied together in a ratio of 50:50 of Urea (46% N) and ammonium phosphate sulfate (16 % N, 20% P, and 15% S).

The experimental design of the complete trial was a split-split-plot design planted at two dates, each with four replicates (i.e. 2 planting dates x 2 cultivars x 6 nitrogen levels x 3 seed rates x 4 replicates = 288 plots site^{-1}). The main-plots were randomly assigned to nitrogen application rates, sub-plots assigned to different cultivars, and sub-sub-plots assigned at random to different seeding rates.

Plots were 1.5 x 5 m and planted using a five row Flexi-Coil shank plot drill with stealth type openers which plants five paired rows 5.5 cm apart, on 25cm centers. Fertilizer was banded 2.5 cm deeper than the seed and between the paired rows on each shank.

One-third of the nitrogen from each treatment was applied at planting and the remaining 2/3 of each nitrogen treatment was top-dress applied the following spring before crop bolting by hand application.

4.3.6. Data collected

Seedling stand counts were done when plants were at the two to six leaf stage. Plants were counted along a 1 m long subplot that consisted for two paired rows located 1 m from the plot edge. Plant stand counts were averaged from the two counts in each plot. Fall establishment was determined by visual assessment prior to the first frost and again in the spring. Winter damage was also visually assessed in the spring. Days from January 1st to 50% flower bloom was recorded within each plot. Post-flower heights were recorded after flowering and before full maturity.

Seed from Moscow and Genesee was harvested at maturity using a Wintersteiger Nurserymaster Elite (Wintersteiger, Inc.; Salt Lake City, UT) small plot combine. Seed from all plots was dried following harvest for two day at 50°C and weighed. Sub-samples of seed were taken at the time of weighing and used to determine oil content and 1000-seed weight. Oil content was determined on single 12 g samples following the procedure outlined by Hammond (1991) using a Newport MKIIIA Nuclear Magnetic Resonance (NMR) Analyzer (Oxford Instruments Inc.; Concord, MA). The NMR was calibrated with a single reference sample of known oil content and the sample analysis carried out as described by Howard and Daun (1991). Seed weight per 1000 seeds was determined by counting a sub-sample from each plot and weighing it.

4.3.7 Data analysis

Data was analyzed using a general linear model, Duncan’s multiple range tests, orthogonal contrasts (SAS, 2009) and trend contrasts (Brown and Caligari, 1998). In the analyses the effects of sites/planting dates was partitioned using orthogonal contrasts to (1) difference between Moscow and the two Genesee plantings, and (2) the difference between early and late planting at Genesee. The difference between sites/plantings was tested using the replicates *within* sites interaction (Error 1). The effect of nitrogen rate, nitrogen rate x site, were tested against the interaction nitrogen rate x rep *within* sites (Error 2). All other variance effects were tested using the pooled replicate error mean square. All computations were carried out using the Statistical Analysis Software (SAS, 2009) program for the entire data set.

4.4 Results and discussion

The significance of source means square from the analyses of variance of seedling stand, crop establishment, weed counts, days to 50% flower bloom, plant height after flower end, seed pod shatter, crop lodging, frost, oil content, oil yield, meal yield and yield are presented in Table 4.4. and Table 4.5. In general, the main effects of differences between sites, cultivars and nitrogen levels were highly significant for most characters recorded, while the majority of interactions were not significant. The exception to this was the three way interaction site x planting date x cultivar which showed significance for thousand seed weights, oil content, seed yield, oil yield, and meal yield (Table 4.5). Although these interactions are difficult to explain with any sound biological meaning and their effects were markedly lower, accounting for a small proportion of the total variation compared to the main effects.

4.4.1 Cultivars

Amanda stand counts (27 plants m-row^{-1}) were significantly ($P<0.001$) higher than HyClass® 125W (23 plants m-row^{-1}). Also Amanda plots showed significantly better established ($P<0.05$) by 6% over HyClass® 125W (Table 4.8). HyClass® 125W reached 50% bloom earlier (70 days after January 1st), while Amanda flowered almost a full 2 days later (72 days after January 1st). There was no significant difference between cultivars for frost damage or final plant heights. Averaged over all other treatments, HyClass® 125W had significantly ($P<0.05$) lower seed yield (3,168 kg hectare^{-1}) compared to Amanda (3,582 kg hectare^{-1}) (Table 4.9). However, there were no cultivars differences in oil content or oil yield. Hybrid cultivars typically produce larger seeded than open-pollinated cultivars (Hanson, 2008), and in this study HyClass® 125W did indeed produced significantly ($0.05>P>0.01$) larger seeds than Amanda.

4.4.2 *Nitrogen levels*

Increased nitrogen application had a significantly delayed days to 50% bloom ($P<0.05$), resulted in significantly taller plants ($P<0.05$), and reduced plant stand counts ($P<0.05$) (Table 4.10), but had no effect of crop establishment.

Increased nitrogen application also increased visible frost damage. When no nitrogen was applied the least amount of frost damage was observed. Increased nitrogen caused plant elongation which raised the growing point of plants above soil surface, exposing the growing points to cold temperature and resulting in greater damage.

Increasing the applied nitrogen rate caused a significant ($P<0.05$) increase in seed yield with the three highest nitrogen rates producing 40% more seed than the lowest rate (Table 4.11). These results are congruent with those form the literature and from the spring trial (See Chapter 3).

Increasing the seeding rate did not significantly affect seed oil content. However, there was a significant ($P<0.05$) interaction between the different nitrogen rates on oil yield. The oil yield tended to increase with increasing nitrogen applied. No added N had a 48% lower oil yield compared to the highest applied nitrogen of 280 kg N hectare^{-1} (Table 4.11).

Average over all 2014 trials meal yield increased linearly with increased nitrogen application. The low nitrogen applications produced significantly ($P<0.05$) lower meal yield than the higher nitrogen applications. Nitrogen applied higher than 168 kg N applied hectare^{-1} showed no significant yield increase (Table 4.11).

Increasing nitrogen rate significantly ($P<0.05$) increased seed weight (Table 4.11). Previous research in canola disagrees as to the effect on seed weight by increasing the nitrogen rate applied (Mudholker and Ahlawat, 1981; Taylor *et al.*, 1991; Hocking and Stapper, 2001; Kutcher *et al*., 2005).

4.4.3 Seeding rates

Highest seeding rates had 44% greater plant stand than the lowest rate, and as expected the number of plants increased linearly with the increasing seeding rate (Table 4.12). Crop establishment at the intermediate and high rates both were better than that from the low seeding rate. Seeding rate did not affects frost tolerance. On average the high seeding rate flowered significantly earlier than the others but only by about ¼ of a day.

Tallest plant stature was from the low seeding rates, and shortest from the intermediate rates (Table 4.12). Decreasing seeding rate reduces inter-plant competition, offering more resources per plant. However, high seeding rates increase inter-plant competition and plants etiolated.

There was no significant difference among the three different seeding rates for thousand seed weight, oil content, oil yield or meal yield. This is similar to other finding where there was no relationship between seed rate and yield (Kondra, 1977; Clarke *et al.*, 1978; Dengenhardt and Kondra, 1981.) High seeding rates produced significantly higher seed yield compared to intermediate rates but there were no other significant relationships (Table 4.13).

4.4.4 Seeding dates

Stand counts between plantings at Genesee were not significantly different, but higher stand counts were observed from the Moscow trial compared to the other site. Frost damage was not severe in 2013-2014 and no damage symptom were observed at Moscow or Genesee planted late. However, severe frost damage was found from the early Genesee planting.

The Moscow trial was fastest to 50% flower bloom (70 days after the 1st of January), followed by Genesee early planted, and then Genesee late planting at 72 d. The 2014 summer was mild, and had no negative affect on flowering for later planted canola.

In 2014 Moscow late planted canola produced significantly (P<0.05) higher seeds weights compared to both Genesee early and late planted canola (Table 4.6).

Oil content was significantly (P<0.05) higher from Genesee late planting compared to Moscow. Thousand seed weights when compared to tested variables only showed a significant interaction within sites (Table 4.7). Chen *et al.*, (2005) found that the increase heat stress during flowering and seed fill caused by delayed planting resulted in lower canola yields. All the reviewed studies did indeed show a decrease in yield with delayed planting, however, the early planting date in this experiment average 6.5% more yield than the late seeding.

4.5 Conclusions and recommendations

All of the agronomic factors examined had significant effects on seed yield and oil content. Different sites (confounded with tillage systems) all produced similar results and therefore the same recommendations will be applied to both cropping system.

Planting early is the best way to maximize establishment of winter canola. However, in this study planting dates had no affect on seed yield. Early planting did resulted in a small increase in seed oil content (0.5% over all cultivars in late planted plots).

Applying nitrogen fertilizer is essential to maximizing the winter canola seed yield. Seed oil content was not affected by fertilizer rates. As the rate of seed yield plateaued at higher fertility levels, the average optimal nitrogen rate will be dependent on fertilizer prices and seed value. It was found that at an application of at least 168 kg N hectare^{-1} to 280 kg N hectare^{-1} within this study showed a 5% increase in seed yield. Cultivar specific data indicated that optimum available nitrogen for Amanda was 241 kg N hectare^{-1} to obtain a maximum seed yield of 3,952 kg hectare^{-1}. Optimum nitrogen rates for HyClass® 125W was 231 kg N hectare^{-1} for a yield of 3,332 kg hectare^{-1} (Table 4.14, Figure 4.1). A greater in-depth economic evaluation of these data are presented in Chapter 5 where economic optimums based on input and commodity prices are calculated.

In conclusion, an intermediate to high seeding rate (between 1,125,000 and 1,350,000 kg seed hectare^{-1}) are optimal for producing good crop establishment and rapid ground cover and to reduce weed pressures. Among the three seeding rates tested yields were significantly similar. Unless there are severe detrimental environmental conditions likely to limit seedling emergence and plant development, seeding rates higher than 900,000 kg seed hectare^{-1} are unnecessary for maximizing yield potential.

In this study Amanda have the best establishment and the highest yield, compared to the Roundup Ready® hybrid cultivar HyClass® 125W. It should be noted that the agronomic advantage of Amanda is greater in the PNW region because as a non-GMO cultivar it carries a premium on the seed of \$0.009 kg^{-1}.

Canola has found its spot within the crop rotation of the PNW. Farmers are now looking for information they can use to produce these crops economically. This study allowed us to fine-tune management winter canola practices so that the growers will be able to make appropriate decisions on incorporating these factors into their current production systems.

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Table 4.1 Results extracted from of the 2012-2013 PNW Winter Canola & Rapeseed Variety Trial including mean yield (lbs./acre) and rank at sites with all entries, yield by site (lbs./acre) (http://webpages.uidaho.edu/jbrown/brassica/).

			Yield by location					
Varieties Tested	Mean Yield	Rank	Odessa WA	Reardan WA	Moscow ID	Grangeville ID	Pendelton OR	Hermiston OR
			-------------------------------------		*lbs per acre*		---------------------------------	
Controls								
Ericka	2,788	3	3,729	3,232	2,667	3,610	1,598	2,832
Athena	3,439	2	4,780	3,031	3,258	4,817	2,214	3,875
Chosen cultivars								
CROPLAN 125W RR	2,773	4	3,149	2,534	2,728	3,896	2,010	2,699
Amanda	3,515	1	5,770	4,459	3,329	4,228	1,698	3,859
Mean	3,129		4,357	3,314	2,996	4,138	1,880	3,316
LSD (*p* = *0.05*)	300		917	816	580	653	606	739

Table 4.2 Results extracted from of the 2013-2014 PNW Winter Canola & Rapeseed Variety Trial including mean yield (lbs./acre) and rank at sites with all entries, yield by site (lbs./acre) (http://webpages.uidaho.edu/jbrown/brassica/).

	Yield by location								
	Overall		Idaho			Washington			Oregon
Cultivar	Mean	Rank	Moscow	Genesee	Grangeville	Odessa	Reardon	St John	Pendleton
Control cultivar									
Athena	3,350	2	2,583	4,876	4,517	3,011	1,492	3,979	2,994
Chosen cultivar									
Amanda	3,546	1	2,915	4,996	3,572	3,979	2,238	3,683	3,441
HyCLASS.125W.RR	2,881	3	2,748	5,104	3,079	2,112	2,016	2,660	2,449
Mean	3,259	-	2,749	4,992	3,723	3,034	1,915	3,441	2,961
LSD ($p = 0.05$)	324		291	345	273	311	197	476	498

Table 4.3 Significance of means squares from the analysis of variance stand counts, number of plants, establishment, frost score, flower start and height at maturity of two cultivars grown at three sites, with three seeding rates, six nitrogen application levels, and four replicates.

Source	d.f.[a]	Stand[†††]	Plants	Est.	Frost	Flower	Height
Site	2	***	***	***	***	***	***
Moscow vs. Genesee[‡]	1	***	***	*	***	***	ns
Early vs Late	1	ns	ns	***	***	**	**
Error (1)[‡‡]	9	*	*	***	***	***	***
Nitrogen rate (Nitro)	5	**	**	ns	***	***	***
Site*Nitrogen	10	*	*	**	***	***	***
Error (2)[‡‡]	45	*	*	ns	ns	ns	ns
Cultivar (cv)	1	***	***	***	ns	***	ns
Site*cv	2	*	*	ns	ns	***	ns
cv*Nitrogen	5	ns	ns	ns	ns	*	ns
Site*cv*Nitrogen	10	ns	ns	ns	ns	ns	ns
Seed rate	2	***	***	***	ns	**	**
Site*Seed rate	4	***	***	ns	ns	ns	*
Nitrogen*Seed rate	10	ns	ns	ns	ns	ns	ns
cv*Seed rate	2	ns	ns	ns	ns	ns	ns
Site*Nitrogen*Seed rate	20	ns	ns	ns	ns	ns	ns
Site*cv*Seed rate	4	ns	ns	ns	ns	ns	ns
Seed rate*cv*Nitrogen	10	**	**	ns	*	ns	ns

† d.f.[a] = degrees of freedom

† *=0.01<P<0.05; **=0.05<P<0.001; ***=P<0.001; ns= not significant

[‡] The effects of site were partitioned, using orthogonal contrasts into (1) differences between the Moscow and Genesee site, and (2) the difference between Genesee early and late plantings.

[‡‡] Error (1) = replicates *within* sites; Error (2) = nitrogen x Replicates *within* sites.

[†††] Stand = seedling stand; Plants = number of plants; Est. = ;crop establishment, Frost = frost damage; Flower = days to 50% flower bloom; Height = plant height after flower end.

Table 4.4 Significance of means squares from the analysis of variance Thousand seed weight, seed oil content, seed yield, oil yield and seed meal yield of two cultivars grown at three sites, with three seeding rates, six nitrogen application levels, and four replicates.

Source	d.f.[†]	Thousand Seed Weight	Oil[†††] content	Seed Yield	Oil Yield	Meal Yield
Site	2	***[††]	ns	**	N.S.	*
Moscow vs. Genesee[‡]	1	-	ns	-	-	-
Early vs Late	1	ns	ns	ns	ns	ns
Error (1)[‡‡]	9	***	ns	***	ns	*
Nitrogen rate (Nitro)	5	ns	ns	***	**	***
Site*Nitrogen	10	ns	ns	ns	ns	ns
Error (2)[‡‡]	45	ns	ns	ns	ns	ns
Cultivar (cv)	1	*	ns	***	*	**
Site*cv	2	*	ns	*	ns	ns
cv*Nitrogen	5	ns	ns	ns	ns	ns
Site*cv*Nitrogen	10	ns	ns	ns	ns	ns
Seeding rate	2	ns	ns	**	ns	ns
Site*Seed rate	4	ns	ns	ns	ns	ns
Nitrogen*Seed rate	10	ns	ns	ns	ns	ns
cv*Seed rate	2	ns	ns	ns	ns	ns
Site*Nitrogen*Seed rate	20	ns	ns	ns	ns	ns
Site*cv*Seed rate	4	ns	ns	ns	ns	ns
Seed rate*cv*Nitrogen	10	ns	ns	*	ns	ns

[†] d.f. = degrees of freedom

[††] *=0.01<P<0.05; **=0.05<P<0.001; ***=P<0.001; ns= not significant

[‡] The effects of site were partitioned, using orthogonal contrasts into (1) differences between the Moscow and Genesee site, and (2) the difference between Genesee early and late plantings.

[‡‡] Error (1) = replicates *within* sites; Error (2) = nitrogen x Replicates *within* sites.

[†††] Oil content = g kg^{-1} of oil, oil yield = kg hectare^{-1} of oil, meal yield = kg hectare^{-1} of meal, yield = kg hectare^{-1} of seed.

Table 4.5 Thousand seed weight, oil content, oil yield, meal yield, seed yield of two cultivars grown at Genesee planted early and late and planted late in Moscow. Data presented are average over three seeding rates, six N application rates, and four replicates in 2013-2014.

Site-Planting Date-Cultivar	Variables					Site Mean Yield
	Thousand Seed Weights	Oil Content[††]	Oil Yield	Meal Yield	Seed Yield	
	-g 1000 -seeds^{-1}	-g kg^{-1}-	----------------	kg ha^{-1}		-----------
Genesee Early-Amanda	4.40	445	1,614	2,021	3,635	3,517
Genesee Early-HyClass® 125	4.49	440	1,493	1,904	3,397	
Genesee Late-Amanda	4.39	443	1,579	1,992	3,571	3,235
Genesee Late-HyClass® 125	4.42	487	1,476	1,422	2,899	
Moscow Late-Amanda	4.73	420	1,481	2,050	3,531	3,375
Moscow Late-HyClass® 125	4.71	413	1,329	1,889	3,219	
Mean	4.52	441	1,495	1,879	3,375	
s.e. Mean	.	.	.	.	.	

[††] Oil content = g kg^{-1} of oil, oil yield = kg hectare^{-1} of oil, meal yield = kg hectare^{-1} of meal, yield = kg hectare^{-1} of seed.

Table 4.6 Seeding stand, number of plants, crop establishment, frost damage, days to 50% flower and plant height after flower from Genesee early and late planted and late planting at Moscow. Data presented are averaged over two cultivars, six N application rates, three seeding rates and four replicates in 2013-2014

Site-Planting Date	Variables					
	Stand†	Plants	Estab.	Frost	Flower	Height
	plants m row^{-1}	Seeds ha^{-1}	1-9†† score	1-9†† score	-Days-	--cm--
Genesee Early	17.38 ^{b}	138,560 ^{b}	7.47 ^{a}	7.49 ^{b}	71.13 ^{b}	137.43 ^{b}
Genesee Late	18.92 ^{b}	150,794 ^{b}	6.14 ^{b}	9.00 ^{a}	72.23 ^{a}	143.16 ^{a}
Moscow Late	38.16 ^{a}	304,190 ^{a}	7.13 ^{a}	9.00 ^{a}	69.58 ^{c}	138.00 ^{b}
Mean	24.82	197,848	6.91	8.50	70.98	139.53
s.e. Mean	10.21	81,414	1.94	.872	2.35	13.84

Means within columns assigned to different superscript letters are significant (Duncan $P<0.05$)

† stand = seedling stand, plants = number of plants, estab. = crop establishment, frost = frost damage, flower = days to 50% flower bloom, height = plant height after flower end.

†† 1-9 score = 1 being worst damage or least established and 9 being no damage or no blank spots.

Table 4.7 Thousand seed weight, oil content, seed yield, oil yield, meal yield of spring canola at Genesee planted early and late and planted late in Moscow. Data presented are average over three seeding rates, four cultivars, six N application rates, and four replicates in 2013-2014.

Site-Planting Date	Variables				
	Thousand Seed Weight	Oil†† Content	Seed Yield	Oil Yield	Meal Yield
	-g 1000 - seeds^{-1}	-g kg^{-1}-	--------------- kg ha^{-1} -------------		
Genesee Early	4.44 ^{b}	443 ^{ab}	3,517	1,557	1,963
Genesee Late	4.40 ^{b}	465 ^{a}	3,235	1,528	1,707
Moscow Late	4.72 ^{a}	416 ^{b}	3,375	1,405	1,969
Mean	4.52	441	3,376	1,497	1,880
s.e. Mean	.708	15.50	1,915	1,015	1,283

† Means within columns assigned to different superscript letters are significant (Duncan $P<0.05$)

†† Oil content = g kg^{-1} of oil, oil yield = kg hectare^{-1} of oil, meal yield = kg hectare^{-1} of meal, yield = kg hectare^{-1} of seed.

Table 4.8 Seeding stand, number of plants, crop establishment, frost damage, days to 50% flower and plant height after flower from two cultivars. Data presented are averaged over two seeding dates, six N application rates, three seeding rates, two sites and four replicates in 2013-2014

Cultivar	Variables					
	Stand†	Plants	Estab.	Frost	Flower	Height
	plants m row $^{-1}$	Seeds ha^{-1}	1-9†† score	1-9†† score	days	cm
Amanda	27.01 ^{a}	215,304 ^{a}	7.07 ^{a}	8.49 ^{a}	71.81 ^{a}	139.17
HyClass® 125W	22.61 ^{b}	180,230 ^{b}	6.67 ^{b}	8.50 ^{a}	70.14 ^{b}	139.89
Mean	24.81	197,767	6.87	8.49	70.98	139.53
s.e. Mean	6.63	52,928	1.01	.449	.967	7.37

Means within columns assigned to different superscript letters are significant (Duncan $P<0.05$)

† stand = seedling stand, plants = number plants, estab = crop establishment, frost = frost damage, flower = days to 50% flower bloom, height = plant height after flower end.

†† 1-9 score = 1 being worst damage or least established and 9 being no damage or no blank spots.

Table 4.9 Thousand seed weight, oil content, seed yield, oil yield, meal yield of two cultivars grown. Data presented are average over three seeding rates, two seeding dates, two sites, six N application rates, and four replicates in 2013-2014.

Cultivar	Variables				
	Thousand Seed Weight	Oil Content††	Seed Yield	Oil Yield	Meal Yield
	-g 1000 seeds^{-1}-	-g kg^{-1}-	-------------- kg ha^{-1}	-----------------	
Amanda	4.49 ^{b}	437	3,582 ^{a}	1,563 ^{a}	2,019 ^{a}
HyClass® 125W	4.53 ^{a}	449	3,168 ^{b}	1,439 ^{a}	1,729 ^{b}
Mean	4.51	443	3,375	1,501	1,874.
s.e. Mean	0.202	19.4	765	880	878

† Means within columns assigned to different superscript letters are significant (Duncan $P<0.05$)

†† Oil content = g kg^{-1} of oil, oil yield = kg hectare^{-1} of oil, meal yield = kg hectare^{-1} of meal, yield = kg hectare^{-1} of seed.

Table 4.10 Seeding stand, number of plants, crop establishment, frost damage, days to 50% flower and plant height after flower from six nitrogen application rates. Data presented are averaged over two seeding dates, three seeding rates, two sites two cultivars and four replicates in 2013-2014.

Nitrogen	Variables					
	Stand[†]	Plants	Estab.	Frost	Flower	Height
kg N ha^{-1}	plants m row^{-1}	seeds ha^{-1}	1-9[††] score	1-9[††] score	days	cm
0	26.54 ^{a}	211,577 ^{a}	7.03 ^{a}	8.64 ^{a}	70.43 ^{c}	130.93 ^{d}
56	25.93 ^{ab}	206,705 ^{ab}	6.90 ^{ba}	8.54 ^{abc}	70.42 ^{c}	136.32 ^{c}
112	25.01 ^{abc}	199,398 ^{abc}	6.68 ^{ba}	8.58 ^{ab}	70.83 ^{b}	140.83 ^{b}
168	25.64 ^{ab}	204,380 ^{ab}	7.03 ^{a}	8.40 ^{dc}	70.85 ^{b}	142.08 ^{ab}
224	23.21 ^{bc}	185,005 ^{bc}	6.72 ^{ba}	8.47 ^{bdc}	71.54 ^{a}	143.13 ^{a}
280	22.58 ^{c}	180,023 ^{c}	6.85 ^{ba}	8.35 ^{dc}	71.81 ^{a}	143.89 ^{a}
Mean	24.82	197,848	6.87	8.49	70.98	139.53
s.e. Mean	8.01	63,856	.870	.428	.974	6.35

Means within columns assigned to different superscript letters are significant (Duncan $P<0.05$)

[†] Stand = seedling stand, plants = number of plants, estab. = crop establishment, frost = frost damage, flower = days to 50% flower bloom, height = plant height after flower end.

[††] 1-9 score = 1 being worst damage or least established and 9 being no damage or no blank spots.

Table 4.11 Thousand seed weight, oil content, seed yield, oil yield, meal yield of six N application rates. Data presented are average over three seeding rates, two seeding dates, two cultivars, two sites and four replicates in 2013-2014.

Nitrogen	Variables								
	Thousand Seed Weight		Oil Content††	Seed Yield		Oil Yield		Meal Yield	
kg N ha^{-1}	-g 1000 -seeds^{-1}		-g kg^{-1}-	--------------------- kg ha^{-1} ---------------------					
0	4.43	c	453	2,684	c	1,215	c	1,469	d
56	4.48	bc	445	3,058	b	1,362	bc	1,695	cd
112	4.50	abc	439	3,200	b	1,405	bc	1,794	bc
168	4.55	ab	430	3,594	a	1,548	ba	2,045	ab
224	4.57	a	423	3,721	a	1,581	ba	2,140	ab
280	4.54	ab	471	3,768	a	1,799	a	1,969	ab
Mean	4.51		443	3,337		1,485		1,852	
s.e. Mean	.188		15.34	582		685		699	

† Means within columns assigned to different superscript letters are significant (Duncan P<0.05)

†† Oil content = g kg^{-1} of oil, oil yield = kg hectare^{-1} of oil, meal yield = kg hectare^{-1} of meal, yield = kg hectare^{-1} of seed.

Table 4.12 Seeding stand, number of plants, crop establishment, frost damage, days to 50% flower and plant height after flower from three seeding rates. Data presented are averaged over two seeding dates, 6 N application rates, two sites, two cultivars and four replicates in 2013-2014.

Seeding Rate	Variables					
	Stand†	Plants	Estab.	Frost	Flower	Height
kg seed ha^{-1}	plants m row^{-1}	seeds ha^{-1}	1-9 score††	1-9 score††	days	cm
900,000	20.14 ^{c}	160,545 ^{c}	6.53 ^{b}	8.47	71.17 ^{b}	140.80 ^{a}
1,125,000	25.23 ^{b}	201,157 ^{b}	6.94 ^{a}	8.53	70.94 ^{b}	138.45 ^{b}
1,350,000	29.05 ^{a}	231,561 ^{a}	7.13 ^{a}	8.49	70.83 ^{a}	139.35 ^{ab}
Mean	24.81	197,754	6.87	8.49	70.98	139.53
s.e. Mean	6.39	52,928	1.01	.449	.967	7.37

Means within columns assigned to different superscript letters are significant (Duncan $P<0.05$)

†Stand = seedling stand, plant = number of plant, estab. = crop establishment, frost = frost damage, flower = days to 50% flower bloom, height = plant height after flower end.

†† 1-9 score = 1 being worst damage or least established and 9 being no damage or no blank spots.

Table 4.13 Thousand seed weight, oil content, seed yield, oil yield, meal yield of three seeding rates. Data presented are average over two cultivars, two seeding dates, six N application rates, and four replicates in 2013-2014.

	Variables				
Seeding Rate	Thousand Seed Weight	Oil Content††	Seed Yield	Oil Yield	Meal Yield
kg seed ha^{-1}	-g 1000 - seeds ha^{-1}	- g kg^{-1}-	------------------- kg ha^{-1} -------------------		
900,000	4.53	460	3,362 ^{ab}	1,566	1,795
1,125,000	4.48	434	3,244 ^{b}	1,408	1,836
1,350,000	4.52	435	3,523 ^{a}	1,530	1,992
Mean	4.51	443	3,376	1,501	1,874
s.e. Mean	0.202	19.4	765	880	878

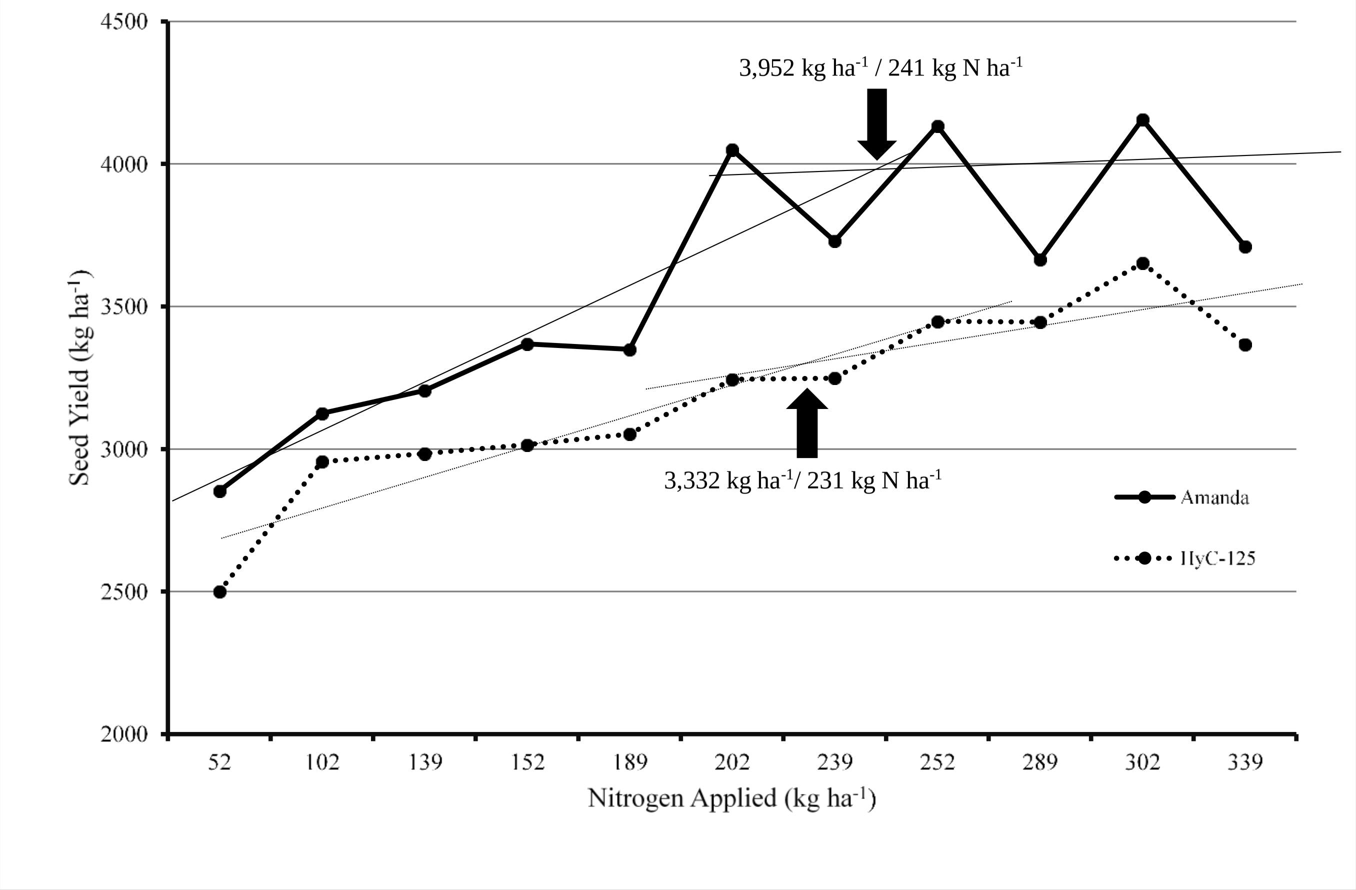
Means within columns assigned to different superscript letters are significant (Duncan $P<0.05$)

†† Oil content = g kg^{-1} of oil, oil yield = kg hectare^{-1} of oil, meal yield = kg hectare^{-1} of meal, yield = kg hectare^{-1} of seed.

Table 4.14 Optimum nitrogen for each cultivar to achieve maximum yield average among 2013-2014.

Cultivar	Max Yield	Optimum Nitrogen
	---kg ha^{-1}---	---kg N ha^{-1}---
Amanda	3,952	241
HyClass® 125W	3,332	231
Mean	3,642	236

Figure 4.1 Seed yield interaction between cultivar and nitrogen rate (kg ha^{-1}) over two sites in 2013 and 2014.



Chapter 5: Economic Feasibility of Canola (*Brassica napus* L.) as an Alternative Crop in the Dryland Regions of the Pacific Northwest

5.1 Abstract

The United States (U.S.) currently imports 456,356 tons of canola seed, 1,543,235 tons of canola oil and 3,185,679 tons of canola meal annually from Canada (Canadian International Merchandise Trade Database, 2012). To simply be self-sustaining in canola oil and seed meal, with todays' yield potential would require 9,191,249 acres of U.S. production. However, U.S. production has been below 1.5 million acres in the regions of North Dakota where Canadian spring cultivars and management practices have been adopted. Canola (*Brassica napus* L.*)* has been shown to be agronomical adapted to many growing conditions in the Pacific Northwest (PNW). While canola seed yield in the PNW is higher than average yields attainable in Canada, canola hectarage continues to increase slowly for reasons that will be explored here.

For canola to be a large hectarage alternative crop in the PNW it must economically competitive with the available alternatives. For this analysis, gross returns were calculated using potential yields and average market prices for winter and spring canola. Variable input costs were estimated for each cultivar of canola examined, and gross returns above variable cost were calculated. Spring canola, at the current price of \$0.20 lb^{-1} for GMO to \$0.22 lb^{-1} for non-GMO varieties, has the potential to return \$274.97 acre^{-1} above variable input cost in traditional tillage systems, and \$91.77 acre^{-1} above variable input cost in no-tillage systems in the PNW. Winter canola at prevailing prices has greater net returns above variable input cost compared to spring canola. Winter canola lowest gross return (HyClass® 125W at \$390.35 was 66% greater than spring canola's highest return (DKL 30-42-RR at \$236.02). However, it should be noted that winter canola is planted into fallow ground and hence gross returns are over two years. Overall, the highest gross revenue on spring canola was achieved under conventional tillage (Genesee) and late planting of DKL 30-42-RR at a seeding rate of 4 lb acre^{-1} and with 150 lb N acre^{-1}, which returned \$413.33 over variable input costs. Highest gross revenue on winter canola was achieved by early planting Amanda with a seeding rate of

5 lb acre^{-1}, and with a N fertilizer rate of 200 lb N acre^{-1} which returned $650.93 over variable input costs.

5.2 Introduction

5.2.1 Canola in the world

Global canola production has grown rapidly over the past forty years, rising from the sixth largest oil crop to the second largest (USDA, NASS 2013). Canola oil is a major edible oil in China, India, Japan, Canada and many European countries. These same countries are also are the major importers. Major exporters include China, India and Canada. Second only to soybean, canola (oilseed rape) is now the most important source of vegetable oil in the world (USDA, NASS 2013).

5.2.2 Canola in the U.S.

Canola is produced extensively in Europe, Canada, Asia. Two species, *Brassica napus* L. and *B. rapa* L. and to a lesser extent the mustards, *B. juncea* L. (brown mustard) and *Sinapis alba* (yellow mustard) supply the world's commerce (Raymer *et al.*, 1990).

Within the U.S. rapeseed crops have been grown on a limited scale, yet canola in the U.S. is considered a new crop, in the sense that its history is relatively short here (Raymer et al. 1990). U.S. domestic production was minimal until GRAS (Generally Recognized as Safe) status was granted by the FDA in 1985, allowing locally produced canola oil to be used in foods manufactured in the U.S. (Raymer *et al.*, 1990).

Since GRAS status approval U.S. canola production has increased dramatically from 155,000 acres in 1992 to 1,348,000 acres in 2014 (Figure 6.1). The growth in U.S. demand for canola oil (and seed meal for livestock feed) has continued to outpace the growth in domestic production. Canola oil demand has more than doubled from 407,385 tons in 1992, to 1,625,541 tons in 2014 (Table 5.A2).

Over the past 10 years, the U.S. canola situation has changed. Between 2013 and 2014 growers in the U.S. planted 1,264,000 and 1,672,000 acres, respectively, producing 2,520,925,000 lb of canola seed in 2014 (USDA, NASS 2013). As in earlier years North Dakota accounted for by far the highest acreage with 1,180,000 acres. Perhaps it is not surprising that this region is adjacent to the major growing region in Canada and has a very similar growing environment, but there is now little possibility of increased acres in the North Dakota region. Instead, greater acreage increases have been found in Oklahoma and in PNW regions. Oklahoma canola acreage has increased from none to 165,000 acres in the past few years. Similarly, the canola acreage in the PNW has increased quite dramatically to 159,000 total acres, with 40,000 acres in Idaho, 12,000 acres in Oregon, 45,000 acres in Washington and 62,000 acres in Montana (NASS, 2013).

Overall in 2014, average canola yield was 1,622 lb acre^{-1}. Average canola yield in North Dakota is high at 1,800 lb acre^{-1} compared to Montana at 1,000 lb acre^{-1}, Idaho with 1,850 lb acre^{-1}, Oregon with 1,500 lb acre^{-1}, and Washington at 1,700 lb acre^{-1} In contrast, canola yield in Oklahoma was markedly lower at only 800 lb acre^{-1} (USDA, NASS 2013).

5.2.3 PNW Agriculture

The dryland farming region of the PNW has a long history of growing small grain cereal crops, such as wheat and barley. Soft white winter and soft white spring wheat are the predominant small grains grown in Idaho. Barley is grown throughout Idaho, where it is typically ranked as the state with the 1st or 2nd highest production in the nation (Idaho Farm Bureau Federation, 2013) with 510,000 acres planted in 2014 (NASS, 2014). With such a high proportion of the PNW in continous cereal production it is not surprising that many growers are are interested in increasing crop diversity by including a legume crop (pea, lentil or garbanzo bean) or Brassicaceae crop (canola or mustard) into their rotations. Widening crop diversity has been shown to have beneficial environmental and economic results compared to rotations with only cereal crops (Peterson and Rohweder, 1983).

In the PNW there is are 3,212,369 acres of land in a grain-fallow rotation and less than 2% of this is planted into canola (Brown *et al.*, 2008). In 2013 and 2014 growers in the U.S. planted 56,156,000 and 56,474,000 acres of wheat, respectively (USDA, NASS 2013). Within the PNW in 2014 wheat was planted on 1,301,000 acres in Idaho, 820,000 acres in Oregon, and 2,270,000 acres in Washington (USDA, NASS 2013).

5.2.4 Canola in the PNW

The biggest growth in canola acres has occurred where wheat is king. In 2014, North Dakota produced 7,490,000 acres of wheat, Oklahoma produced 2,800,000 acres, and Montana grew 5,650,000 acres. Among the PNW states (Idaho, Oregon and Washington), a total of 4,264,000 acres of wheat were grown in 2014 (NASS, 2014). However, the adoption of canola within the PNW has not increased as quickly as in other wheat producing regions. This reduction in canola adoption may be explained by the fact that in this region is one of the highest yielding dryland wheat regions in the world. Within the PNW, wheat typically produces 26.5 more bushels per acre than in North Dakota, Oklahoma or Montana. Farmers are hesitant to replace a high yielding money crop such as wheat that has been grown for decades by their fathers and grandfathers with an unfamiliar rotational crop.

Many have suggested that canola would be an ideal crop to use in a PNW to enhance wheat production. Canola would add diversification to dry-land farmer's rotations. It not only has the same growing season as wheat, but growers can use the same equipment for planting and harvesting as are used for wheat (Johnson, 2009). Adopting a suitable crop rotation can increase overall crop yields (Classen and Kissel, 1984; Larney and Lindwall, 1994; Bourgeois and Entz, 1996), decrease weed populations (Liebman and Dyck, 1993), reduce insect and disease infestations (Krupinsky *et al.*, 2004), improve soil health and fertility (Weinert et al., 2002; Vos and Van Der Putten, 2004) and reduce soil erosion (Peterson and Rohweder, 1983). Increased crop diversity can provide agronomicbenefits. The use of a legume or an herbaceous dicot within a cropping rotation can have a more beneficial result on wheat yields than would a rotation with a more closely related crop such as a barley (*Hordeum spp*.)(Peterson and Rohweder, 1983).

Canola can also provide farmers an opportunity to clean up grassy weeds that are difficult to control in a continuous wheat production system (Johnson, 2009). With the potential to reduce Group 2 herbicide resistant weed population's winter canola can be a viable crop to incorporate into a winter wheat summer fallow rotation to compete economically with winter wheat (Esser, 2012). From 2006 to 2009 a canola: wheat rotation study was conducted near Ritzville Washington. Although it was shown that winter canola yielded 33.7% less than winter wheat, winter wheat following a canola crop yielded 39.3%

more than winter wheat following winter wheat (Esser, 2012). The Canola's deep taproot also provided a source to loosen the soil. Esser (2012) concluded that canola needed a $26.00 price advantage per bushel over winter wheat to produce the same gross revenue per hectare. Obviously market price between the two crops can vary dramatically from year to year which has a large influence on relative profitability between the two crops.

In addition to rotational benefits, more competitive canola prices has created an increased grower interest in spring and winter canola in the region. In addition more local elevators will receive canola than in the past years. (Pakish, 2014).

The initial major constraint on increasing canola acreage with the PNW was the lack of availability of suitably adapted cultivars for this region. Currently, new and adapted cultivars, combined with a better understanding of the correct agronomic needs of the crop in the region and, the availability of local crushing has resulted in higher canola returns to the farmer.

5.2.5 Objectives

The objective of the analyses in this chapter is to determine if canola can be an economically viable crop for farmers in the dryland region of the PNW and, if so, where is it best suited for production and in what kind of cropping systems.

Canola disposition is comprised of domestic consumption, exports and total ending stocks. Total domestic consumption of canola has been growing in the U.S., reflecting its common use in the home and especially in fast-food establishments. Canola oil productionfor the U.S. in2014. Major vegetable oils production for 2014 are 11,824,460 tons for U.S. The U.S. export value equals 300 million pounds of canola oil (ERS, 2014) and is one of the largest buyers of Canadian canola seed, oil, and meal. Total vegetable oil consumption in the U.S. exceeds 13,224,000 tons a year with canola currently ranked as the country's second most popular edible oil.

In the following calculations, the calculations for potential canola hectares in the U.S. assumes that domestic consumption and exports will remain the same over time, although domestic consumption of canola seed in the U.S. has been increasing, and canola seed exports more than doubled from 1991 to 2014. It also assumes that domestic production of canola seed and oil in the U.S. could replace all imports.

Average Canola Seed Imported (2013 to 2014)	1,700,000,000 lb
Average Canola Oil Imported, seed equivalent† (2013 to 2014)	8,130,000,000 lb
Average Canola Meal Imported, seed equivalent‡ (2013 to 2014)	12,010,000,000 lb
Total Canola seed Imported (2013 to 2014)	13,710,000,000 lb
Average domestic production acres from 2013 to 2014	1,348,000 a
Average U.S. Yield (2013 to 2014)	1,748 lb/a
Total potential additional acres to replace imports	7,843,249 a
Total U.S. acres needed to be self-sufficient	9,191,249 a

† Seed equivalent assuming 40% oil and 60% seed meal.
‡ Assumption being if U.S. meal importation is replaced with domestic production this would more than replace the need to import canola oil.

The objective of this research is to obtain representative price information for each cultivar used within the experiment to compare seeding rates, nitrogen rates, planting date along with different tillage systems. Overall, using this data to provide sufficient information to growers to determine the best rotation option for their farming system.

5.3 Material and methods

Operations, input costs, and expected yield of these cropping systems are based on data from cropping system trial plots (Chapter 3 and Chapter 4).

5.3.1 Background and assumptions for returns and input cost for spring and winter canola

Winter canola trials were grown at two Idaho locations, Genesee and Moscow. In this scenario the yields of Genesee late planted was averaged with Moscow's late planting. The spring canola trials were grown in two Idaho locations, Craigmont and Genesee. Our Craigmont site was grown on a cooperator site and was no-till while our Genesee site was planted in a conventional tillage system. These trials were conducted in2013 and 2014. Per acre data are extrapolated from small 5 x 16 feet trial plot results. Adjustments and considerations were made for implementation at a commercial production scale. Input costs are based on the 2013 data (Patterson and Painter, 2013; personal communication from seed companies).

Profitability of each cropping system is examined under the following agronomic management scenarios. Winter canola was based on six nitrogen treatments, three seeding rates, and two winter cultivars.). Spring canola profitability was examined under six nitrogen treatments, three seeding rates, four spring cultivars, and two different cropping systems (confounded within different sites).

5.3.1.1. Spring canola variable input cost

Fertilizer was the greatest expense for canola in both no-till and tillage practices (Table 5.2). At \$0.27 per lb for a 31-10-0-7.5 (31% N, 10% P, 0% K, 7.5% S) blend fertilizer cost was estimated from \$0 acre^{-1} to \$41.23 acre^{-1} (personal communication with farm manager; Patterson and Painter, 2013). These costs were calculated for a range of 0 to0 250 lb N acre^{-1} in increments of 30 lb for each tillage practice.

Certified seed cost was the second greatest variable input cost after fertilizer. Seed costs included technology fees for GMO cultivars and the addition of seed treatment for all cultivars used. Certified seed costs were higher for the two hybrid cultivars than for the open-pollinated cultivars. The highest certified seed cost was for DKL 30-42-RR, which ranged from \$45.32 acre^{-1} for the low seeding rate cost to\$67.98 acre^{-1} for the high seeding rate(Table 5.2). For InVigor L.130-LL, the lowest seeding rate cost \$35.86 acre^{-1} while the high seeding rate cost \$50.31 acre^{-1}. Seed costs for Empire ranged from \$11.00 acre^{-1} for the low seeding rate to \$16.49 acre^{-1} for the high seeding rate. The cost for the Cara low seeding rate was \$10.11 acre^{-1} while the high seeding rate cost \$15.17 acre^{-1}.

The four spring canola cultivars were specifically chosen due to their adaptation to the growing region but they also offered the potential to use different herbicide chemistry. Three of the cultivars were genetically tolerant to herbicides. These included DKL 30-42-RR, with tolerance to glyphosate (Roundup®); InVigor L.130-LL, with tolerance to glufosinate (Liberty®); and Cara, with tolerance to imidazilinone herbicides (Beyond®).

Weed control costs for spring canola will vary greatly depending upon weed species and populations present in the field from previous years and the canola variety planted. In the traditional tillage systems Treflan® (a.i. trifluralin) herbicide was used for an estimated cost of \$3.30 acre^{-1}, while in the no-till system glyphosate pre-plant herbicide cost was used, at a cost of \$10.78 acre^{-1} (personal communication with agricultural chemical dealer; Patterson and Painter, 2013). Expenses for post emergence herbicides were \$2.69 acre^{-1} for DKL 30-42-RR, \$67.12 acre^{-1} for InVigor L.130-LL, \$35.23 acre^{-1} for Empire, and \$45.01 acre^{-1} Cara (personal communication with agricultural chemical dealer; Patterson and Painter, 2013). Application costs were not included along with the use of any adjuvants. Weed control rates were based on practices used in the 2013 and 2014 trials (see Chapter 3).

Insecticides and application costs were constant over all cultivars and locations at \$76.82 acre^{-1} (personal communication with farm manage; Patterson and Painter, 2013).

5.3.1.2. Winter canola variable input cost

Fertilizer was the greatest expense for winter canola in both no till and conventional tillage systems (Table 5.8). At \$0.27 per lb for a 31-10-0-7.5 (31% N, 10% P, 0% K, 7.5%S) blend fertilizer cost was ranged from \$0 acre^{-1} to \$68.72 acre^{-1} according to application rate (personal communication with farm manager; Patterson and Painter, 2013). These cost were calculated for a range of 0 lb N acre^{-1} to 250 lb N acre^{-1} in increments of 50 lb for each tillage practice.

Certified Seed was the second highest variable input cost for winter canola production. Seed costs included technology fees for GMO cultivars and seed treatment for all canola seed used. Certified seed cost for the hybrid cultivar HyClass® 125W at the lower seeding rate was \$22.74 acre^{-1}, with \$31.24 acre^{-1} and \$39.74 acre^{-1} for the intermediate and high rates, respectively. Certified seed cost for the open-pollinated cultivar Amanda was less at \$16.22 acre^{-1} for the low seeding rate, and \$44.27 and \$28.56 acre^{-1}, respectively, for the medium and high seeding rates.

Herbicide costs for winter canola will vary greatly depending upon weed species and populations present in the field from previous years and the canola variety planted. In the traditional tillage systems Treflan® (a.i. trifluralin) pre-plant incorporated herbicide was used for an estimated cost of \$3.30 acre^{-1}, and in the no-till system glyphosate herbicide was used as a pre-planting treatment for an estimated cost of \$10.78 acre^{-1} (personal communication with agricultural chemical dealer; Patterson and Painter, 2013). Although one of the cultivars was a Roundup Ready® variety, no post emergence herbicides were applied due to lack of weeds.

Insecticide and applications costs were estimated at \$76.82 acre^{-1} for both tillage practices and cultivars (personal communication with farm manager; Patterson and Painter, 2013).

Custom swathing cost estimated at \$ 18.33 acre^{-1}, was used to prevent seed shatter loss and assure uniform maturity at harvest (Patterson and Painter, 2011). While many growers will cut the crop with a combine as they harvest it, this pre-harvest practice is used by some growers and, in this case, it insured comparability for the trial plots.

5.3.2. Background assumptions for returns and input costs for rotational crops (winter wheat, spring wheat, barley, lentils, garbanzos, and peas.)

Profitability of winter and spring canola in cropping systems are examined and compared to rotational crops (winter wheat, spring wheat, barley, lentils, garbanzos and peas) within different states within the PNW (Washington, Oregon, Idaho, plus Montana) including North Dakota and Oklahoma. The 2014 State Agriculture Overview (USDA, NASS 2014) for each was used to obtain averages for harvested acres, yield and price per unit.

Price and yield assumption for each rotational crop were obtained from the University of Idaho 2014 enterprise budgets for northern Idaho grain rotations under conventional tillage (Painter, 2014).

5.3.2.1 Winter wheat variable input cost

Fertilizer was the greatest expense for winter wheat in both tillage systems (Table 5.A22). Fertilizer cost was \$81.30 acre^{-1} (Painter, 2014). These cost were calculated from application rates of 90 lb N acre^{-1} at \$0.63 per lb, 30lb P acre^{-1} at \$.72 per lb and 10 lb S acre^{-1} at \$.30 per lb.

Herbicide costs for winter wheat will vary greatly depending upon weed species and populations present in the field from previous years and the wheat variety planted. In the conventional tillage systems Osprey™, Starane Flex™, a surfactant and Brox M™ herbicide was used for an estimated cost of \$32.38 acre^{-1} (Painter, 2014).

Certified seed was the third highest variable input cost. Certified seed for the soft white winter wheat cultivar at a seeding rate of 90lb per acre was \$24.30 acre^{-1}.

Fungicides, including application were estimated at \$23.85 acre^{-1} for both tillage practices and all wheat cultivars (Painter, 2014).

Custom aerial cost were estimated at \$8.95 acre^{-1} were used to reduce compaction and increase control on disease later in the season when ground sprayers are unable to enter the fields (Patterson and Painter, 2013).

5.3.2.2 Spring wheat variable input cost

Fertilizer was the greatest expense for spring wheat (Table 5.A22). Fertilizer cost was \$74.20 acre^{-1} based on an application rates of 80 lb N acre^{-1} at \$0.63 per lb to 15lb P acre^{-1} at \$.72 per lb along with 20 lb K acre^{-1} at \$0.50 per lb and 10 lb S acre^{-1} at \$.30 per lb (Painter, 2014).

Herbicide costs for winter wheat will vary greatly depending upon weed species and populations present in the field from previous years and the wheat variety planted. In the conventional tillage systems Roundup$^{™}$, a surfactant, Axial™, Brox M™, Starane™, InPlace™ and ammonium sulfate (applied twice in two different quantities) were used for an estimated cost of \$24.69 acre^{-1} (Painter, 2014).

Certified seed was the third highest variable input cost. Certified seed for the soft white winter wheat cultivar at a seeding rate of 80 lb per acre was \$21.60 acre^{-1}.

Fungicides and applications costs were estimated at \$13.49 acre^{-1} (Painter, 2014).

Custom aerial cost were estimated at \$8.95 acre^{-1} were used to reduce compaction and increase control on disease later in the season when ground sprayers are unable to enter the fields (Patterson and Painter, 2013).

5.3.2.3 Barley variable input cost

Fertilizer was the greatest expense for barley (Table 5.A22.). Fertilizer cost was \$64.20 acre^{-1} (Painter, 2014). These costs were calculated from application rates of 80 lb N acre^{-1} at \$0.63 per lb, 15lb P acre^{-1} at \$.72 per lb and 10 lb S acre^{-1} at \$.30 per lb.

Herbicide costs for barley will vary greatly depending upon weed species and populations present in the field from previous years and the wheat variety planted. In the conventional tillage system Round-up™, a surfactant, Axial™, Starane Flex™, and ammonium sulfate was used for an estimated cost of \$29.97 acre^{-1} (Painter, 2014).

Certified seed was the third highest variable input cost. Certified seed for the barley at a seeding rate of 85 lb per acre was \$22.10 acre^{-1}.

5.3.2.4 Peas variable input cost

Certified Seed was the highest variable input cost (Table 5.A22.). Certified seed for the peas at a seeding rate of 200 lb per acre was \$76.00 acre^{-1}.

Within this crop fertilizer was not applied. Herbicide costs for peas will vary greatly depending upon weed species and populations present in the field from previous years and the pea variety planted. In the tillage systems Pursuit™, a surfactant, Prowl™, Imidan 70™, Dimethoate™, Far-Go™ and ammonium sulfate was used for an estimated cost of \$37.82 acre^{-1} (Painter, 2014).

Custom aerial cost were estimated at \$8.95 acre^{-1} were used to reduce compaction and increase control on disease later in the season when ground sprayers are unable to enter the fields (Patterson and Painter, 2013).

5.3.2.5 Lentils variable input cost

Within this crop fertilizer was not applied. Herbicide costs for lentils were the highest variable cost (Table 5.A22.). Herbicide costs will vary greatly depending upon weed species and populations present in the field from previous years and the lentil variety planted. In the tillage systems Pursuit™, a surfactant, Prowl™, Dimethoate™, Far-Go™ and ammonium sulfate was used for an estimated cost of \$24.91 acre^{-1} (Painter, 2014).

Certified seed was the second highest variable input cost. Certified seed for the peas at a seeding rate of 45lb per acre was \$18.45 acre^{-1}.

Custom aerial cost were estimated at \$8.95 acre^{-1} were used to reduce compaction and increase control on disease later in the season when ground sprayers are unable to enter the fields (Patterson and Painter, 2013).

5.3.2.6 Garbanzos variable input cost

Within this crop fertilizer was not applied. Certified Seed was the highest variable input cost. Certified seed for the peas at a seeding rate of 130 lb per acre was \$78.00 acre^{-1} (Table 5.A22.).

Herbicide costs for garbanzos were the second highest variable cost. Herbicide costs will vary greatly depending upon weed species and populations present in the field from previous years and the garbanzos variety planted. In the tillage systems Pursuit™, a surfactant, Prowl™, Far-Go™ and ammonium sulfate was used for an estimated cost of \$22.36 acre^{-1} (Painter, 2014).

Custom aerial cost were estimated at \$8.95 acre^{-1} were used to reduce compaction and increase control on disease later in the season when ground sprayers are unable to enter the fields (Patterson and Painter, 2013).

5.4 Results and Discussion

5.4.1 Spring canola

Yield estimates for spring canola were based on the 2013 and 2014 trials for conventional (Genesee site) and not till (Craigmon) practices reported in (Chapter 3). Market price for canola was estimated at \$0.20 lb^{-1} for genetically modified varieties (DKL30-42-RR, InVigor L.130-LL), while a \$0.02 was added to the value of non-GMO varieties (Cara and Empire) market price as a premium (personal communication with growers and researchers; USDA, NASS 2014).

Averaged over all cultivars and treatments, gross margins for spring canola in the PNW were calculated to be \$216.52 acre^{-1} in 2014 and \$152.39 acre^{-1} in 2013. Averaged over years and treatments, returns by cultivar were: \$236.02 acre^{-1} for DKL30-42-RR, \$164.95

acre^{-1} for Empire, \$186.82 acre^{-1} for InVigor L.130-LL, and \$148.43acre^{-1} for Cara (Table 5.6). Under no tillage practices at the Craigmont location, gross margins for spring canola averaged \$91.77 acre^{-1} while under conventional tillage practices at Genesee, net returns over operating costs were more than double at \$274.97 acre^{-1} over the two-year period (Table 5.3).

2014 proved to be a better year for canola yields, and consecutively gross returns were 42% higher compared to the previous year. Overall, seeding dates showed a gross return of \$199.62 acre^{-1} for early planting compared to the later planting at \$168.68 acre^{-1} , therefore a delay in planting can reduce gross returns almost \$31.00 acre^{-1} (Table 5.4).

Seeding rate did not significantly alter gross returns of spring canola (Table 5.6). However, the cultivar DKL 30-42-RR had a large reduction in gross margin from a high seeding rate compared to low seeding rates (\$20 loss acre^{-1}) due to the high cost of seed of this cultivar. A similar but much lower difference (\$3 loss acre^{-1}) was noted for the other hybrid cultivar InVigor L.130-LL. Conversely, open-pollinated cultivars Empire and Cara with lower seed cost had higher gross margins with either the intermediate or high seeding rates (Table 5.6).

Averaged over two years, the difference between no nitrogen rates and a rate of 150 lb per acre increased net return by 55% from adding 0 lb of N acre^{-1} (\$116.41 acre^{-1}) to adding 150 lb of N acre^{-1} (\$211.43 acre^{-1}) (Table 5.4). The effects of increasing both nitrogen application and seeding rates were greatest when cultivars were seeded early and had lesser effects in the later plantings where water stress may have been the limiting factor (Table 5.4). On average, spring cultivars returns were 18.3% greater with early planting compared to later plantings. Returns above variable input costs were greatest for spring canola in the higher nitrogen treatments (90 to 150 lb N acre^{-1}) and low to intermediate seeding rates and greatest when canola was in a conventionally tillage system (Genesee site) and when planted early. Averaged over sites and treatments and assuming a price of \$0.20 lb^{-1} for commodity GMO seed, and \$0.22 lb^{-1} for commodity non-GMO seed, net returns above variable input cost were highest for DKL 30-42-RR (\$236.02 acre^{-1}), followed by Empire at \$186.82 acre^{-1}, then InVigor L.130-LL at \$164.95acre^{-1}, and lowest variable input costs were for Cara at \$148.43 acre^{-1} (Table 5.4).

The optimal agronomic practices to maximize the returns above variable costs under no-tillage and conventional tillage systems were calculated for both years (Table 5.1). The data showed that early planted canola in a no-tillage situation was ideal over all four cultivars tested. The highest return above variable costs at \$250.90 acre^{-1} was DKL 30-42-RR with the application of 150 lb N acre^{-1} at a low seeding rate. The second highest returns of \$144.45 acre^{-1} were achieved by Empire at a high seeding rate with 120 lb N acre^{-1}. Net returns for InVigor L.130-LL were maximized at \$113.25 acre^{-1} with 30 lb N acre^{-1} and intermediate seeding rate. Maximized returns for Cara of \$111.47 acre-1 were achieved under the scenario with 150 lb N acre^{-1} and an intermediate seeding rate. Overall, net returns above variable costs were highest in the conventionally tilled sites. As in, the no-tillage system, early planted canola in the conventional tillage system produced the higher returns. With the exception of, DKL 30-42-RR produced the highest return of \$413.33 acre^{-1} with a late planting date, compared to (\$392.47 acre^{-1} with an early planting) with 150 lb N acre^{-1} at the low seeding rate (Table 5.1). With an intermediate seeding rate and 120 lb N acre^{-1} net returns over variable costs \$382.67 acre^{-1} were achieved with InVigor L.130-LL, \$355.70 acre^{-1}, for Empire and \$336.22 acre^{-1} for Cara. At this seeding rate and nitrogen application, net returns above variable costs DKL 30-42-RR \$335.54 acre^{-1} similar to returns for Cara.

The variable input costs for spring canola (under the most profitable scenario, which was DKL 30-42-RR at low seeding, early planting, and 150 lb N acre^{-1}, showed that canola has the higher input cots at \$169.36 acre^{-1} than peas (\$122.77 acre^{-1}), lentil (\$52.31 acre^{-1}), garbanzos (\$109.31 acre^{-1}), barley (\$116.27 acre^{-1}), spring wheat (\$142.93 acre^{-1}) (Painter, 2014; NASS, 2014) (Table 5.16). However, under the assumptions of this study, the most profitable spring canola crop had high returns above variable cost than these alternative crops, at \$413.33 acre^{-1}. The next most profitable alternative was spring wheat, with \$347.27 acre^{-1}, while barley was third with a net return over variable costs of \$344.33 acre^{-1} (Table 5.16). Net returns over variable costs for garbanzos were \$313.09 acre^{-1}, \$266.69 acre^{-1} for lentils, and \$129.23 acre^{-1} for peas (Table 5.16). When canola is raised using optimal practices to create the highest returns possible and has a relatively high per unit price, canola is able to compete with alternative such as spring wheat and exceed returns over variable costs for other available rotation crops.

The four spring canola cultivars in this study were specifically chosen due to their adaptation to the growing region but also because each had the potential to use different herbicide chemistry. Three of the cultivars were genetically tolerant to herbicides including: DKL 30-42-RR tolerant to glyphosate (Roundup®); InVigor L.130-LL tolerant to glufosinate (Liberty®); and Cara, which is tolerant to imidazilinone herbicides like Beyond®. Herbicide tolerant canola cultivar offer growers greater opportunity to control grassy weeds, which are problematic in predominant cereal production areas. It should also be noted that the imidazilinone tolerant cultivar Cara was developed primarily to allow growers to plant canola in situations where a high residual of imidazilinone herbicides exists, which would make it impossible to profitably produce the other cultivars in this study. As both Cara and Empire are not GMO, a premium of \$0.02 per lb is received on the seed. Each cultivar has its own unique characteristics which when chosen correctly, can provide benefits to the cropping system.

5.4.2 Winter canola

Potential yield of canola was based on the results for the winter crop planted in 2013 (Chapter 4). Market price for canola was \$0.20 lb^{-1} for the genetically modified (GMO) hybrid cultivar (HyClass® 125W), and \$0.22 for the non GMO open-pollinated cultivar (Amanda) which is marketed as premium (personal communication with growers and researchers; USDA NASS 2014).

Averaged over planting dates and treatments, gross returns for cultivars of winter canola in the PNW were \$477.33 acre^{-1} for Amanda, and \$390.35 acre^{-1} for HyClass® 125W (Table 5.10). Two sites planting dates were compared: Moscow, which was a late planted conventional tillage site, and Genesee, which was planted both early and late and was under a no tillage system. For this analysis, yields for both Moscow and Genesee late planted sites were averaged. Net returns for the earlier planted site (\$461.14 acre^{-1}) were \$42.20 acre^{-1} greater than with later planting (\$418.94 acre^{-1}) (Table 5.11). The early planting had the highest return for both cultivars (HyClass® 125W \$429.33 acre^{-1}; Amanda \$492.94 acre^{-1}). The late planting had the lowest return for HyClass® 125W at \$369.08 acre^{-1}, and the lowest return for Amanda at a \$468.80 acre^{-1} (Table 5.11).

Gross returns for the intermediate (\$411.84 acre^{-1}) and high (\$452.63 acre^{-1}) seeding rates were significantly different. However, there were no significant differences between the low and intermediate rates or the low and high seeding rates. Over all seeding rates, the highest returns were achieved with early plantings (Table 5.9).

Averaged over cultivars and treatments, nitrogen application increased net returns over the total costs by 36%, when comparing no N acre^{-1} (\$346.91 acre^{-1}) to applying 250 lb N acre^{-1} (\$471.04 acre^{-1}) (Table 5.10). However, profit was maximized using 200 lb N acre^{-1}, with returns over variable costs of \$477.03 acre^{-1}. While there was a significant nitrogen rate x cultivar interaction in terms of gross margins, higher returns were achieved with increased nitrogen application (Table 5.10). Returns for HyClass® 125W increased by 32% from no N fertilizer (\$318.56 acre^{-1}) to 250 lb applied N acre^{-1} added (\$419.08 acre^{-1}) with a peak return of \$420.15 acre^{-1} at 200 lb applied N acre^{-1}. Net returns for Amanda increased by 39% from no N fertilizer (\$375.26 acre^{-1}) to 250 lb applied N acre^{-1} (\$522.08 acre^{-1}) with a peak return of (\$533.91 acre^{-1}) at 200 lb applied N acre^{-1} (Table 5.10).

Returns above variable input cost were maximized for Amanda with a return of variable costs or \$650.93 acre^{-1} with early planting at an intermediate seeding rate and the nitrogen rate of 200 lb N applied acre^{-1} (Table 5.7). Returns above variable input costs were maximized for HyClass® 125W with a return of \$540.51 acre^{-1} with early planting at a low seeding rate and the nitrogen rate of 250 lb acre^{-1} (Table 5.7).

Comparing operating costs for the most profitable winter canola scenario Amanda with the intermediate seeding rate, early planted, and 200 lb N acre^{-1}), with winter wheat in northern Idaho, canola has slightly higher operating costs at \$184.67 acre^{-1} compared to \$170.78 acre^{-1} for winter wheat (Painter, 2014; USDA NASS, 2014)(Table 5.18). However, winter canola had higher net returns above variable cost of \$650.93 acre^{-1}, compared to \$309.22 acre^{-1} for winter wheat (Table 5.16).

When canola is raised using optimal practices, and in years with above average price it can be more profitable than winter wheat.

Two winter canola cultivars in this study were specifically chosen due to their adaptation to the growing region but also because each had the potential to use different herbicide chemistry. Amanda being non GMO provides a premium on the seed of \$0.02 at market. Each cultivar has its own unique characteristics which when chosen correctly, can provide benefits to the cropping system.

5.5 Conclusions and recommendations

When grown using best management practices for optimizing economic returns, canola may have the potential of producing higher returns above variable costs than wheat and other traditional rotational crops. Canola has the potential, during years of high prices and under favorable growing conditions and using the best management practices for each specific cultivar, to be an economically feasible and a beneficial alternative to small grain cereals in the higher and lower dryland region of the PNW, although the market for canola seed is at present moderately limited in the U.S. Canola production could provide farmers with an alternative source of income and a way to provide sustainability to their cropping systems.

If the PNW had a dramatic increase in canola acreage it would be highly unlikely to saturate the domestic market as it would take over 9 million acres of PNW production simply to make the U.S. self-sufficient in canola oil and seed meal. In addition, canola and rapeseed demand and production has increased ten-fold since 1992 and will likely continue to increase (Table 5.A2).

It is assumed that fixed costs would be similar for each of these crops so that a comparison of returns over variable input cost will indicate that rank in profitability. However, in order to calculate returns above total costs, both fixed and operating, fixed costs would need to be estimated. Changes in relative prices for these commodities could change the profitability ranking.

All of the agronomic factors examined in the spring canola trials had significant effects on the returns above variable costs. Returns at the location using conventionally tilled were significantly better than no-till sites in every situation tested however it should always be noted that sites and tillage systems are complex, hence, recommendations on tillage systems may be biased due to other site differences.

Results of this study showed that planting early, in this case as soon as the pre-plant herbicide could be applied and the seedbed prepared, is the best way to maximize establishment potential of *B. napus;* with the exception of DKL 30-42-RR, which produced the highest net returns when planted late in a conventionally tilled system.

Optimal nitrogen rates will depend on fertilizer prices and seed value, but typical fertilizer rates will range between 90 lb N acre^{-1} to 150 lb N acre^{-1} with an increase of \$95.00 acre^{-1} in returns. Cultivar specific data indicated that optimum spring canola available nitrogen for DKL 30-42-RR was 150 lb N acre^{-1} and, 120 lb N acre^{-1} for Empire, at both the no-till and conventional tillage sites. Optimum available nitrogen for InVigor L.130-LL was 30 lb N acre^{-1} at the no-till location and 120 lb N acre^{-1} at the tillage site. For Cara, optimal available nitrogen at the no-till site was 150 lb N acre^{-1} and 120 lb N acre^{-1} at the conventional tillage site.

The intermediate seeding rate level for this study was equivalent to 5 lb seed acre^{-1}, which was optimal for producing maximized returns at both the no-till and conventional tillage sites. However, among the three seeding rates tested, DKL 30-42-RR had the highest returns when using the lowest seeding rate, which is equivalent to 4 lb seed acre^{-1}. Conversely, Empire had the highest returns in the no-till situation with the high seeding rate of 6 lb seed acre^{-1}.

Under conventional tillage, the spring cultivar DKL 30-42-RR had the highest return of \$413.33 acre^{-1} above variable costs when planted late at a low seeding rate with 150 lb N acre^{-1}. The next most profitable system at the conventional tillage site, with a net return of \$382.67 acre^{-1}, was InVigor L.130-LL planted early at an intermediate seeding rate with 120 lb N acre^{-1}. The third most profitable system was Empire, with a net return of \$355.70 acre^{-1}, also planted early at the intermediate seeding rate with 120 lb N acre^{-1}. Net returns for Cara, planted early at intermediate seeding rate with 120 lb N acre^{-1}, were \$336.22 acre^{-1}.

Under no-tillage systems, the spring cultivar DKL 30-42-RR also had the highest net returns above variable costs of \$250.90 acre^{-1} when planted early at a low seeding rate with 150 lb N acre^{-1}. The second most profitable system was Empire planted early at a high seeding rate with 120 lb N acre^{-1}, with a net return of \$144.45 acre^{-1}. InVigor L.130-LL also planted early at intermediate seeding rate with 30 lb N acre^{-1} with a net return of \$113.25 acre^{-1}. Net returns for Cara, planted early at intermediate seeding rate with 150 lb N acre^{-1}, were only \$11.47 acre^{-1}.

Even though overall DKL 30-42-RR produced the highest returns in both tillage systems, depending on your crop rotation and your goals for your cropping system, your choice of canola variety may change for different situations. For example, a farmer with Pursuit® residue in the soil must plant the spring canola variety Cara (or one similar), which is imidazilinone resistant. If you have a contract for non-GMO varieties you must make a choice between Cara and Empire. If you have a no-tillage system and need a non-GMO cultivar Empire will be your first choice over DKL 30-42-RR.

All of the agronomic factors examined in the winter canola trials had significant effects on returns above variable costs, although planting date had no significant effect on potential returns. Winter canola best practices showed that early planted canola maximized returns for HyClass® 125W while returns under later planting conditions were maximized with Amanda.

The average optimal nitrogen rate will be dependent on fertilizer prices and seed value, but this value will undoubtedly be at least 200 lb N acre^{-1} with an average increase of \$130.12 acre^{-1} in returns. Cultivar specific data indicated that optimum winter canola available nitrogen for Amanda was 200 lb N acre^{-1}, while the optimal return nitrogen for HyClass® 125W was at 250 lb N acre^{-1}.

Among the three seeding rates tested Amanda had the highest returns when using the intermediate seeding rate of 5 lb seed acre^{-1}, while HyClass® 125W had the highest returns with the low seeding rate of 4 lb seed acre^{-1}.

The winter cultivar Amanda had the highest net return above variable costs of \$650.93 acre^{-1} when planted early at an intermediate seeding rate with 200 lb N acre^{-1}. The second most profitable winter cultivar was HyClass® 125W planted early at a low seeding rate with 250 lb N acre^{-1} with a net return over variable costs of \$540.51 acre^{-1}.

Although Amanda overall was best depending on your crop rotation and what you are trying to achieve your choice between cultivars will change. If you have a contract for non-GMO varieties you must choose Amanda. However, if you are trying to clean up weeds with an application of Roundup™ you would choose HyClass® 125W, due to its ability to not be damage by the application of this herbicide.

Overall, on average winter canola produced $139.25 more in net returns over variable costs an acre than the most profitable spring canola cultivar.

5.6 References

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Table 5.1 Optimal spring canola practices to maximize from returns above variable costs under no-till and conventional tillage systems.

No-tillage	Plant date	Nitrogen applied	Seeding rate	Returns above variable costs
DKL 30-42-RR	Early	150 lb N $acre^{-1}$	Low	\$250.90 ± 8.21
Empire	Early	120 lb N $acre^{-1}$	High	\$144.45 ± 8.30
InVigor L.130-LL	Early	30 lb N $acre^{-1}$	Intermediate	\$113.25 ± 11.38
Cara	Early	150 lb N $acre^{-1}$	Intermediate	\$111.47 ± 7.06
Conventional Tillage				
DKL 30-42-RR	Late	150 lb N $acre^{-1}$	Low	\$413.33 ± 16.42
InVigor L.130-LL	Early	120 lb N $acre^{-1}$	Intermediate	\$382.67 ± 9.69
Empire	Early	120 lb N $acre^{-1}$	Intermediate	\$355.70 ± 12.67
Cara	Early	120 lb N $acre^{-1}$	Intermediate	\$336.22 ± 11.86

Table 5.2 Summary of variable input cost of canola for different seeding rates, nitrogen applications.

Spring Cultivars	DKL 30-42-RR	InVigor L.130-LL	Empire	Cara IMI
Fertilizer ($ acre):				
0	$0.00	$0.00	$0.00	$0.00
30	$8.25	$8.25	$8.25	$8.25
60	$16.49	$16.49	$16.49	$16.49
90	$24.74	$24.74	$24.74	$24.74
120	$32.99	$32.99	$32.99	$32.99
150	$41.23	$41.23	$41.23	$41.23
Seed cost ($ acre):				
Low	$45.32	$35.86	$11.00	$10.11
Medium	$56.64	$44.81	$13.75	$12.64
High	$67.98	$50.31	$16.49	$15.17
Herbicides Pre-plant ($acre):				
Tillage	$3.30	$3.30	$3.30	$3.30
No-Till	$10.78	$10.78	$10.78	$10.78
Herbicides	$2.69	$67.12	$35.23	$45.01
Insecticides	$76.82	$76.82	$76.82	$76.82

Table 5.3 Returns above variable costs from early and late planting spring canola with different sites. Data presented are averaged over four cultivars and three seeding rates.

	Site			
Date-Year	Craigmont	Genesee	Year Mean	Date Mean
	------------ $ return above variable costs ------------			
Early-2013	164.11	222.51	193.32	199.62
Early-2014	45.63	361.98	206.00	
Late-2013	72.73	150.18	111.46	168.68
Late-2014	83.07	365.19	227.12	
Mean	91.77 ^{b}	274.97 ^{a}		
s.e. Mean	391.83			

† Means within columns assigned to different superscript letters are significant (Duncan P<0.05)

Table 5.4 Returns above variable costs from early and late planting spring canola with different application rates of nitrogen. Data presented are averaged four cultivars and three seeding rates.

	Nitrogen Applied						
Date	0	30	60	90	120	150	Mean
	---------------------------------- $ return above variable costs ----------------------------------						
Early	128.73	183.00	205.11	226.91	225.83	226.60	199.62
Late	104.28	176.88	162.00	189.30	183.06	196.25	168.68
Mean	116.41 ^{c}	179.91 ^{b}	183.96 ^{b}	208.11 ^{a}	204.61 ^{a}	211.43 ^{a}	
s.e. Mean	110.45						

† Means within columns assigned to different superscript letters are significant (Duncan $P<0.05$)

Table 5.5 Returns above variable costs from early and late planting spring canola with different cultivars. Data presented are averaged over six nitrogen treatments and three seeding rates.

	Cultivar				
Date	DKL 30-42-RR	InVigor L.130-LL	Empire	Cara	Mean
	----------------------- $ return above variable costs -----------------------				
Early	234.69	184.63	211.96	166.96	199.62
Late	237.36	145.07	161.76	129.83	168.68
Mean	236.02 ^{a}	164.95 ^{c}	186.82 ^{b}	148.43 ^{d}	
s.e. Mean		75.06			

† Means within columns assigned to different superscript letters are significant (Duncan P<0.05)

Table 5.6 Returns above variable costs from low, intermediate and high planting rates for spring canola with different cultivars. Data presented are averaged over six nitrogen treatments and two seeding dates.

	Seeding Rate			
Date	Low	Intermediate	High	Mean
	--------------- $ return above variable costs ----------------			
DKL 30-42-RR	246.53	235.19	226.45	236.02 ^{a}
InVigor L.130-LL	166.42	165.15	163.30	164.95 ^{c}
Empire	178.74	185.25	196.60	186.82 ^{b}
Cara	141.79	154.57	148.89	148.43 ^{d}
Mean	183.56	185.15	183.83	
s.e. Mean		75.06		

† Means within columns assigned to different superscript letters are significant (Duncan P<0.05)

Table 5.7 Optimal winter canola practices to maximize from returns above variable costs under no-till and conventional tillage systems.

Cultivars	Plant date	Nitrogen applied	Seeding rate	Returns above variable costs
Amanda	Early	200 lb N acre^{-1}	Intermediate	\$650.93 ± 11.80
HyClass® 125W	Early	250 lb N acre^{-1}	Low	\$540.51 ± 8.82

Table 5.8 Summary of variable input cost of canola for different seeding rates, nitrogen applications.

Winter Cultivars	HyClass® 125W	Amanda
Fertilizer ($ acre):		
0	$0.00	$0.00
50	$13.74	$13.74
100	$27.49	$27.49
150	$41.23	$41.23
200	$54.98	$54.98
250	$68.72	$68.72
Seed cost ($ acre):		
Low	$22.74	$16.22
Medium	$31.24	$22.27
High	$39.74	$28.56
Herbicides Pre-plant ($ acre):		
Tillage	$3.30	$3.30
No-Till	$10.78	$10.78
Insecticides ($ acre):	$76.82	$76.82
Custom Swathing ($ acre):	$18.33	$18.33

Table 5.9 Returns above variable costs from early and late planting winter canola with different cultivars and seeding rates. Data presented are averaged over six nitrogen treatments.

	Site			
Date-Seeding Rate	Amanda	HyClass® 125W	Seeding Rate Mean	Date Mean
	--------------- $ return above variable costs ----------------			
Early-Low	532.58	421.85	477.21	461.14
Early-Intermediate	442.41	404.44	423.42	
Early- High	503.75	461.69	482.72	
Late-Low	421.20	398.42	409.81	418.94
Late-Intermediate	468.76	320.37	394.56	
Late-High	485.80	365.79	425.79	
Mean	477.33^{a}	390.35^{b}		
s.e. Mean	139.59			

† Means within columns assigned to different superscript letters are significant (Duncan $P<0.05$)

Table 5.10 Returns above variable costs from low to high nitrogen rates in winter canola with different cultivars. Data presented are averaged over two seeding dates and three seeding rates.

	Nitrogen Rate						
Cultivar	0	50	100	150	200	250	Mean
	------------------------ $ return above variable costs -------------------------						
Amanda	375.26	420.80	449.85	527.10	533.91	522.99	477.33 ^{a}
HyClass® 125W	318.56	378.59	372.95	408.82	420.15	419.08	390.35 ^{b}
Mean	346.91 ^{c}	399.70 ^{b}	411.40 ^{b}	467.97 ^{a}	477.03 ^{a}	471.04 ^{a}	
s.e. Mean			99.33				

† Means within columns assigned to different superscript letters are significant (Duncan $P<0.05$)

Table 5.11 Returns above variable costs from early to late planting dates in winter canola with different cultivars. Data presented are averaged over three seeding rates and six nitrogen treatments.

	Seeding Date		
Cultivar	Early	Late	Mean
	---------- $ return above variable costs ----------		
Amanda	492.94	468.80	477.33 [a]
HyClass® 125W	429.33	369.08	390.35 [b]
Mean	461.14 [a]	418.94 [a]	
s.e. Mean	342.45		

† Means within columns assigned to different superscript letters are significant (Duncan P<0.05)

Table 5.12 The number of acres produced of each crop compared among six states in 2014.

Commodity	Montana	Oklahoma	North Dakota	Washington	Oregon	Idaho
Canola	61,000	155,000	1,190,000	47,000	10,000	34,000
Spring Wheat	2,980,000	-	6,140,000	610,000	78,000	455,000
Winter Wheat	2,240,000	-	555,000	1,640,000	740,000	730,000
Barley	770,000	-	535,000	105,000	30,000	510,000
Peas	504,000	-	255,000	88,000	8,500	44,000
Lentils	-	-	66,000	50,000	-	24,000
Garbanzos	31,200	-	6,200	89,000	1,100	73,000

†Oklahoma total wheat is the same number as their spring wheat.
†Wheat totals includes spring Durum.
†Source: NASS, 2014.

Table 5.13 The average yield of each crop compared among six states in 2014.

Commodity	Montana	Oklahoma	North Dakota	Washington	Oregon	Idaho
Canola	1380lb/a	620lb/a	1,800lb/a	1,200lb/a	1,500lb/a	1,800lb/a
Spring Wheat	35bu/a	-	47.5bu/a	38bu/a	55bu/a	76bu/a
Winter Wheat	41bu/a	-	49bu/a	52bu/a	48bu/a	80bu/a
Barley	58bu/a	-	67bu/a	60bu/a	50bu/a	94bu/a
Peas	1,800lb/a	-	2,130lb/a	1,900lb/a	2,200lb/a	1,800lb/a
Lentils	-	-	1,200lb/a	1,100lb/a	-	1,100lb/a
Garbanzos	1,520lb/a	-	1,230lb/a	1,150lb/a	1,360lb/a	1,320lb/a

†Oklahoma total wheat is the same number as their spring wheat.
†Wheat totals includes spring Durum.
†Source: NASS, 2014.

Table 5.14 Return values of crops compared among six states in 2014.

Commodity	Montana	Oklahoma	North Dakota	Washington	Oregon	Idaho
Canola	$234.60	$93.00	$306.00	$216.00	$285.00	$288.00
Spring Wheat	$211.75	-	$258.87	$277.40	$401.50	$490.20
Winter Wheat	$237.80	-	$222.95	$335.4	$324.00	$480.00
Barley	$313.20	-	$348.40	$195.00	$160.00	$460.60
Peas	$198.00	-	$234.30	$285.00	$242.00	$252.00
Lentils	-	-	$252	$330	-	$319.00
Garbanzos	$425.60	-	$356.70	$368.00	$544.00	$422.40

†Oklahoma total wheat is the same number as their spring wheat.
†Wheat totals includes spring Durum.
†Source: NASS, 2014

Table 5.15 Returns above variable input cost of spring canola, pea, lentil, garbanzos, spring wheat, and barley produced in the dryland region of the PNW per acre.

	Spring Canola	Pea	Lentil	Garbanzos	Spring Wheat	Barley
Variable input cost	$169.36	$122.77	$52.31	$109.31	$142.93	$116.27
Gross returns	$582.69	$252.00	$319.00	$422.40	$490.20	$460.60
Returns above variable cost	$413.33	$129.23	$266.69	$313.09	$347.27	$344.33

† Cost per units were generated using the 2014 Northern Idaho Enterprise Budget.

† Idaho return costs were used in this scenario.

† DKL 30-42-RR at a low seeding rate, with 150 lb N acre^{-1} of fertilizer was used for the spring canola.

Table 5.16 Returns above variable input cost of winter canola and winter wheat produced in the dryland region of the PNW per acre.

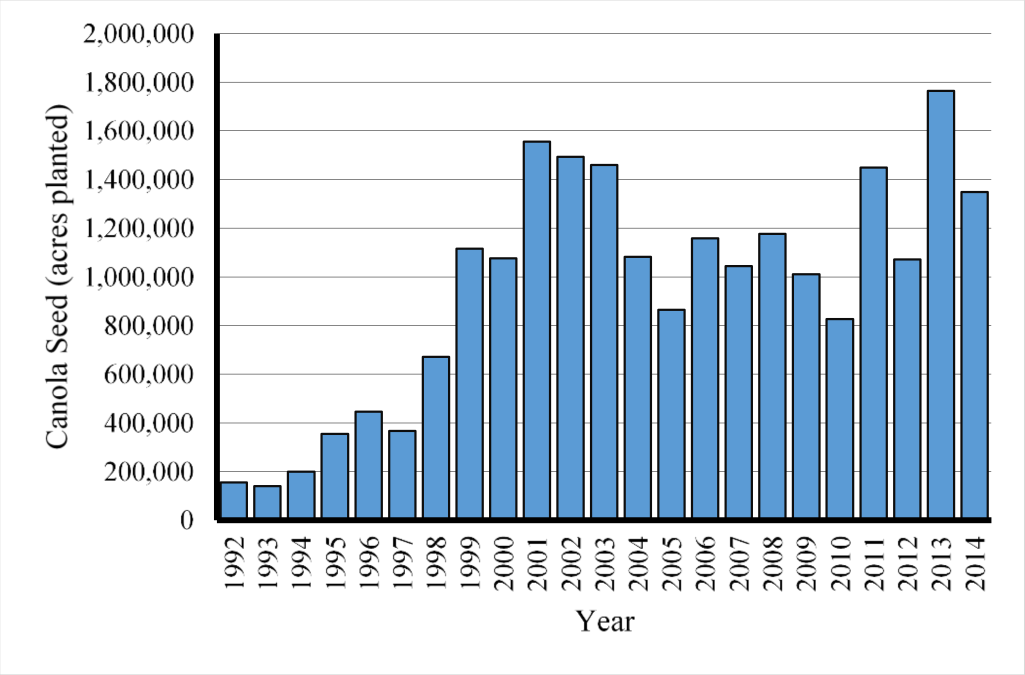
	Winter Canola	Winter Wheat
Variable input cost	$184.67	$170.78
Gross returns	$835.60	$480.00
Returns above variable cost	$650.93	$309.22

† Cost per units were generated using the 2014 Northern Idaho Enterprise Budget.

† Idaho return costs were used in this scenario.

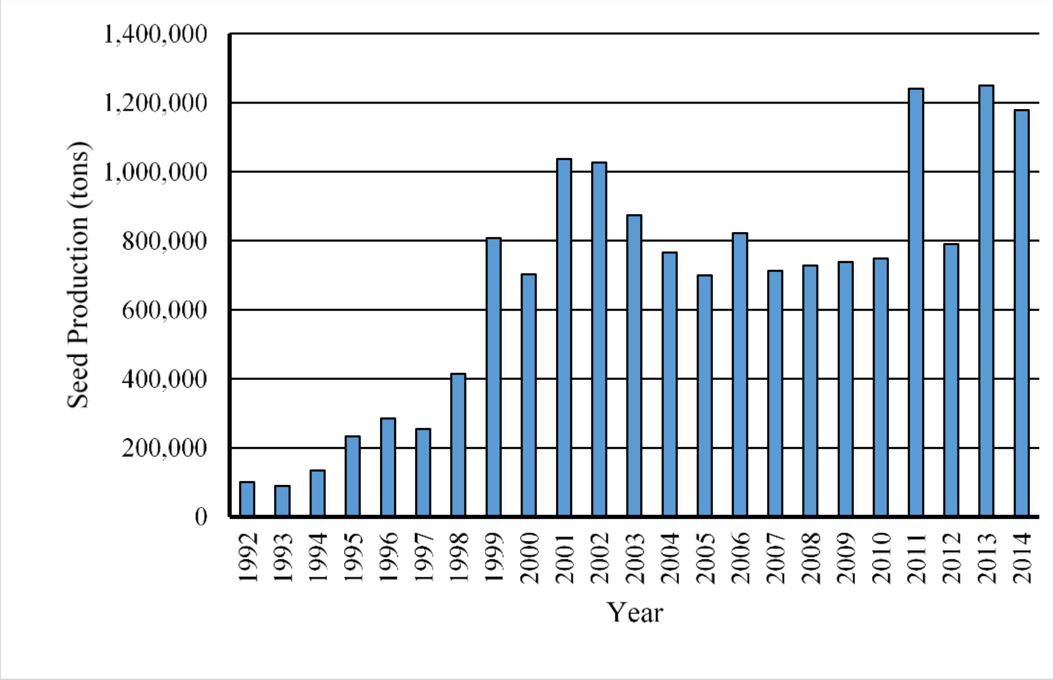
† Amanda at an intermediate seeding rate with 200 lb N acre^{-1} of fertilizer was used for the winter canola.

Figure 5.1 Total acres planted of rapeseed /canola from 1992 to 2014 in the U.S.



†Source: NASS, 2014
† Data acquired for Table 5.A1.

Figure 5.2 Total amount of canola and rapeseed produced in the U.S between 1992 and 2014.



†Source: NASS, 2014
† Data acquired for Table 5.A3.

Chapter 6: Canola Grower Cultural Practices Survey 2013-2014

6.1 Abstract

Small grain cereal crops dominate dryland agriculture throughout the Pacific Northwest (PNW). Adoption of spring and winter canola as a rotation crop has been limited by lack of information about optimal agronomic conditions for maximum crop productivity and seed quality. Despite being a relatively new crop to the region, a number of farmers have several years of experience growing canola, but with different degrees of success and frustration. A two year survey of canola growers was conducted to determine which cultural practices have been beneficial for improved success, and conversely which practices have been detrimental. These different experiences are summarized to identify practices which are most likely to be successful in the future. Survey information collected included: (1) pre-planting and planting practices (field history, tillage system, and fertility management); (2) mid-season practices (weed, insect and disease infestations and their control); and finally pre-harvest and harvest practices (yield, quality, and marketing).

Over the two year survey a total of 41 growers from Idaho, Washington, and Oregon, that produced over 13,222 acres of canola, with an average of yield 1,922 lb acre^{-1} participated. Over half of the farmers (63%) grew winter canola while 37% grew spring types. Although there were fewer fields of winter canola harvested (1,587 acres) compared to spring canola (2,913 acres), the average yield of winter crops, 2,421 lb acre^{-1}, was more than twice the harvested yield of spring crops (1,506 lb acre^{-1}). It is common to produce higher yields from winter canola which has a longer growing season, longer flowering period and seed fill occurring during cooler times, and with less moisture stress that is usual for spring canola.

The most common herbicide used for weed control by growers was Roundup® (70%), mainly because the majority of spring cultivars were Roundup Ready® herbicide tolerant, while over 58% of winter growers chose to grow traditional, non-GMO, cultivars. Most problematic insect pests included: flea beetle; cabbage seedpod weevil; and aphid. Various brands of bifenthrin were used by 57% of farmers to control insects, and 15% added Wetcit® a wetting agent with their insecticide.

Identifying grower's problems in canola production is useful to identify necessary research areas to reduce crop failures. Planting and crop establishment were the most difficult periods for both winter and spring canola, and crop establishment is critical for sustainable production. Weeds were not a significant problem, perhaps due to high competition from winter canola, and use of Roundup Ready® cultivars in spring. Diseases (*Sclerotinia*) in winter canola and insect infestation in spring canola were the most noted pest problems.

All growers had concerns with harvest and marketing canola seed. Growers also expressed concerns with crop loss due to winter kill, seed pod shatter and combine header reel speed at harvest, and weather damage suggesting that they must address these issues in the future.

6.2 Introduction

Few rotational crops have shown adaptability or economic merit for including in rotations with small-gran cereal crops and mono-culture wheat production in the PNW region where a crop-fallow system is common in the low and intermediate rainfall regions. In higher rainfall areas, continual cropping is possible and wheat is typically grown with spring barley, spring peas, garbanzo beans or lentils.

Adopting a suitable crop rotation can increase overall crop yields and improve farm stability (Classen and Kissel, 1984; Larney and Lindwall, 1994; Bourgeois and Entz, 1996). Including canola into a crop rotation can decrease weed populations (Liebman and Dyck, 1993), reduce insect and disease infestations (Krupinsky *et al.,* 2004), improve soil health and fertility (Weinert *et al.,* 2002; Vos and Van Der Putten, 2004) and reduce soil erosion (Peterson and Rohweder, 1983), all which can be beneficial to overall farm output. The use of a legume or an herbaceous dicot within a cropping rotation can have beneficial result on wheat yields than rotation with a more closely related crop such as a barley (*Hordeum spp*.)(Peterson and Rohweder, 1983). Increased crop rotations also increases diversity of farm operations (i.e. planting and harvest times often differ).

In the United States (U.S.), adoption of canola has been limited to counties of North Dakota adjacent to the Canadian border. In 2001 of 1,606,185 acres of canola were produced in the U.S., and 1,373,906 acres or 87% of the production was in North Dakota and most of those within a hundred kilometers of the Canadian border (NASS, 2001). It is said that the U.S. canola production is an extension of Canadian production, since North Dakota is primarily supported by Canadian developed canola cultivars, growing practices, and market (*per. com.* Jack Brown).

Within the U.S. several other production regions have demonstrated good potential for canola production. Yet, canola growth is slow since most other regions of the U.S. are struggling to develop or sustain viable canola industries. The introduction of canola anywhere besides the Northern Plains has largely been unsuccessful due to the host of problems that are all too familiar to those of us who work routinely with new corps (Raymer *et al.*, 1990). These problems include: (1) absence of local crushing facilities and markets; (2) lack of adapted cultivars; (3) limited information on best growing practices; (4) lack of registered crop protection chemicals; combined with (5) reluctance of farmers to adopt new crops.

Various production challenges and the absence of infrastructure, meager research funds, limited crushing capacity and strong world competition, combined with limited incentives for domestic canola production have all played a role in stifling commercialization efforts in one or more regions (Raymer *et al.*, 1990).

Some of these problems were recently addressed in the PNW with the Pacific Coast Canola (PCC) oilseed crush processing facility in Warden, Washington. This processing facility is by far the largest ever in existence in the PNW and has the capacity to crush 3,500,599 kg (7,717,500 lbs.) of canola seed annually and produce an estimated 136,077,711 kg (300,000,000 lbs.) of oil (PCC, 2014). However, since starting operations in fall of 2012, this crush facility has not come close to matching the potential output estimations, even with importing most of its feed stock from outside the local area (*per. com.* Jack Brown). Several successful years of production back to back are often necessary to build up the grower confidence. As confidence grows among farmers the production of the crop will expand to the size necessary to establish profitable and reliable local markets.

At present, most farmers growing canola have adapted practices developed from Canada, or that are common to Canadian production. A few growers in the PNW have been successfully growing canola (or industrial rapeseed) for over 100 years (*per. com.* Jack

Brown), yet there has been little effort to pull together the local expertise information and make it available to new potential canola growers.

The objective of this research is to learn from growers of successful, and not so successful, practices and past experiences of growers, good or bad on how to grow canola. This information has been summarized to help new canola growers anticipate cultural practices and scenario to optimized future canola productivity.

6.3 Materials and Methods

Canola growers were surveyed by contacting each in person, via mail, or having growers interact directly with web based questionnaires, over a two year period (2013 and 2014). The survey questionnaire and letter along with a self-addressed envelope were mailed to canola growers in the PNW. Three separate surveys were sent out or made available to electronically fill out online through the Brassica Breeding and Research website (http://webpages.uidaho.edu/jbrown.brassica/). The first survey was sent immediately after planting each spring or fall seeded crop. This survey requested information regarding previous crop, cultivation, cultivar, seeding rate, seed treatments and fertility management. The second survey was sent mid-growing season, and covering growing the crop and included pesticide application post emergence, and pre-harvest treatments. The final survey was sent at or just after harvest and included yield information of the canola and also possible yield of crops grown before canola the previous year and included a sample envelope for seed which if returned was analyses for oil content and quality. All seed sample analysis were completed in the University of Idaho's Oilseed lab using a Near Infrared Analyzer.

An average of twenty questions relating to canola production and growers cropping systems were asked in each survey. In an attempt to get more and better response from growers, we tested individual growers' seed samples from their crops for oil content, dry matter, and protein content.

Survey information data were summarized by cropping system, tillage management, and by crop region. Averages, ranges and optimum yield situations will be indicated and highlighted. Adverse practices that reduce yield will also be outlined, to indicate situations that growers should avoided. Examples of the grower surveys are presented in Appendix to this chapter.

6.4 Results

6.4.1 Growers contacted

Eighty five growers were contacted to participate in the survey and 41 growers contributed to the survey during the two years. These growers harvested a total of 13,222 acre^{-1} of canola in three states: Idaho, Oregon, and Washington. Farmers were urge to complete each question and survey; however, surveys regularly were not filled out completely. The number of grower responses for each section with Part 1, the planting survey, Part 2, the midseason and Part 3, the harvest survey, and the number of growers who provided acreage information for each section of survey in 2013 to 2014 are presented in Table 6.1.

The two year Canola Grower Survey included production information from 41 growers who farmed throughout the PNW region. Survey results are grouped according to whether they grew winter or spring canola. Over half (63%) of farmers grew winter canola while 37% grew spring types. Most of the farmers (85% winter and 78% spring growers) had grown canola crops prior to the survey. Survey results show that 95% of growers will grow canola again with 50% wanting to grow the same acreage and 22% planning to grow more.

Data reported is based on production of the 41 growers covering a total of 13,222 acre^{-1}. The breakdown by state, canola type, growers, hectares, and average yield are presented in Table 6.2.

6.4.2 *Preceding crop and pre-plant operations*

Most grower’s proceeded canola crops with wheat (69%), 18% preceded canola with fallow and 13% with CRP or barley. All growers had wheat as the major crop in their rotation along with 43% having legumes, and 30% fallow. Almost all growers (92%) planned to plant wheat after canola and 8% have planned to follow canola with fallow.

The majority of growers planted their canola on silt loam soils (42%) while 32% planted in sandy loam and 26% planted in clay loam. The primarily pH range was 5-6 (41%) while 6-7 and 7-8 pH ranges both at 26%. Only 17% of growers irrigated canola while 83%

were rain fed. The majority of spring canola growers plant canola in the intermediate to high rainfall region (16 to 22 inch rainfall), while most winter canola was planted in lower rainfall areas with 7 to 16 inches.

The majority of spring canola cultivars were herbicide resistant. Most spring canola growers (84%) planted a Roundup Ready® cultivar; while 12% grew a LibertyLink® cultivar, and 4% grew a Clearfield® cultivar. Amongst winter canola growers, 58% choose a non-herbicide resistant cultivar, while 36% of winter canola growers planted a Roundup Ready® cultivar, and 6% planted a Clearfield® cultivar. It should be noted that at present only a few herbicide tolerant winter canola cultivars are available compared to spring cultivars.

All spring canola farmers used Roundup® as a pre-plant herbicide (Table 6.4). This was not the case for winter canola farmers, where 56% used only pre-plant Roundup®, 7% used only pre-plant Treflan®, 19% used another pre-plant herbicide,11% used Roundup® plus Treflan®, and 7% used Roundup® plus another herbicide mixture as a pre-plant treatment. The most common pre-plant herbicide use for weed control was Roundup® (77%).

The majority (70%) of spring canola was planted in April, with 15% planted in March and 15% in May, with the bulk of these fields in the 13 to 22 inch rainfall zones. Winter canola was typically planted in areas of lower rainfall, 7 to 16 inches, with 85% planted in August and early September and 15% planted in late June and July.

Overall seeding rates range from less than 3 lb acre^{-1} to greater than 6 lb acre^{-1}. There was a wide range of seed yields for each seeding rate (Table 6.7). However, for seed yields there was difference of 392 lb acre^{-1} between the medium and low seeding rate and 657 lb acre^{-1} difference between high and low seeding rates. The typical seeding rate used was 4 to 5 lb acre^{-1} for spring (79%) and winter (56%) canola.

Growers of both spring and winter canola planted their seed at depths to reach soil moisture ranging from ¼ to 1 inch deep. The majority of spring growers (48%) used a 12-inch row spacing with 20% using a 10-inch spacing. Other spacing included 7 inches, 7.5 inches, 9 inches, and 15 inches. The most common row spacing for winter canola was 15 inches (29%) with 20% growers using 7.5 inches, and 14% using a 10 inches. The rest of the winter canola growers (37%) were evenly distributed among 7-inch, 9- to 10-inch, and 16- to 30-inch spacing.

6.4.3 Weed management and other cultural practices

Both broadleaf (50%) and grassy (50%) weeds infested canola fields. The most common weeds included downy brome (cheatgrass) (*Bromus tectorum*), prickly lettuce (*Lactuca serriola*), wild oats (*Avena fatua*), jointed goatgrass (*Aegilops cylindrica*) and lambsquarter (*Chenopodium album*). The most common herbicide used for pre-emergent weed control was Roundup® (70%).

Common insects pests encountered included: flea beetle (*Alticini*), cabbage seedpod weevil (*Ceutorhynchus obstrictus*), and aphid (*Aphidoidea*). Various brands of bifenthrin™ were used by 57% of farmers to control insects, and 15% included Wetcit™ wetting agent with their insecticide. The only canola disease observed was Sclerotinia white mold, which was controlled by some growers with Quadris™ fungicide. All growers noted that infestation rates of diseases and most insects were moderate and in general their management strategies proved effective.

6.4.4 Nutrient management

The most common winter cultivar was ‘Amanda’. The most common spring cultivar was ‘HyClass® 930’. Farmers applied more anhydrous ammonia (27%) and urea (30%) as a pre-plant fertilizer than any other type of fertilizer. 90% of winter canola growers used a post-emergence fertilizer application while only 10% of spring canola being top-dressed. The most commonly applied fertilizers contained nitrogen, sulfur and phosphorous. Prior to planting winter canola fields had 46% more residual soil nutrients than that of spring canola fields.

Within the range of nitrogen reported by surveyors, there was no relationship between seed yield and nitrogen application. All reported seed yields were grouped from high to low, high being yields over 2,000 lb acre^{-1} of seed, low being less than 2,000 lb acre^{-1} of seed (Table 6.9). The average high yield (2,580 lb acre^{-1}) reported had an nitrogen application average of 177 lb available N acre^{-1}. With an average of 166 lb of applied N per acre^{-1}. The lowest yield (1,335 lb acre^{-1}) resulted with an average of 112 lb of available N acre^{-1} with an average of 91 lb of N acre^{-1} applied. Presented in Table 6.10 is the average yield response of nitrogen when compared to spring and winter canola. Overall winter canola planted in the PNW not only yield higher but also have on average 53 lb of N acre^{-1} more applied.

A small seed yield response was observed resulting from difference due to sulfur application (Table 6.11). The highest yield (2,579 lb acre^{-1}) when grouped by sulfur application rate was achieved with average available 35 lb of S acre^{-1} at an average application of 24 lb of S acre^{-1}. The lowest yield of 1,334 lb acre^{-1} occurred when there was only applied 11 lb of S acre $^{-1}$ with average available being 21 lb of S acre^{-1}. However, similar results compared to the nitrogen applied that 16 lb acre S^{-1} more sulfur is applied to winter canola crops over spring canola (Table 6.12).

6.4.5 *Pre-harvest, harvest and post-harvest*

All spring canola growers direct harvested their canola (Table 6.13). However, half of the winter canola farmers swathed prior to harvest, and an additional 25% used a pod sealant before combining. Winter pre-harvest practices were implemented due to the larger yields, higher amount of biomass, and to speed the harvest operation.

Average yield over all three surveys was 1,922 lb acre $^{-1}$. Twelve of the 20 growers in Idaho produced an average yield of 1,816 lb acre $^{-1}$, and accounted for 40% of the total acres surveyed. One farmer in Oregon grew 8% of the total acres. Eighteen grower surveyed were from in Washington, accounting for 52% of the total acres surveyed. Average yield in Washington was higher than Idaho at 2,186 lb acre^{-1}.

Over 2 years, winter canola growers planted an average of 1,587 acre^{-1} each grower, and produced on average seed yield of 2,421 lb acre^{-1}. Spring canola growers produced a larger total acreage (2,913 acre), with average seed yield of 1,506 lb acre^{-1} (Table 6.2). Although there were fewer acres of winter canola harvested compared to spring canola, the average yield of winter crops produced was more than twice the harvested yield of spring crops. Higher yields are commonly produced by winter canola, which has a longer growing season with flowering and seed fill occurring during cooler times with less moisture stress that is usual for spring canola.

Table 6.6 summarizes the seed subsample provided by growers for protein and oil analysis. Overall spring canola tended to have a higher protein percentage then winters, however, oil content was the same for springs and winters. When the seed samples were analyzed by location Washington samples had lower protein and oil percentage in both cases by 2% compared to Idaho.

Spring canola farmers predominantly used a direct seed tillage system (67%), while 33% used minimum tillage, and no spring canola growers used conventional tillage (Table 6.3). In comparison, winter canola growers used conventional tillage practices (36%), 39% no tillage and 25% minimum tillage systems.

Seventeen growers collectively (33% of the total hectares surveyed) were from the low rainfall regions and received less than 12 inch of average annual precipitation (Table 6.11). One of the seventeen growers, using a no-till tillage system had the lowest seed yield of only 800 lb acre^{-1}. Two of the growers who received less than 13 inches annual rainfall used irrigation and used minimum tillage methods to produce an average seed yield of 3,257 lb acre^{-1} in three fields. Five of these seventeen growers, used conventional methods and had an average seed yield of 3,100 lb acre^{-1} amongst three fields.

Overall, 14 growers, comprising 28% of the total acres, farmed in the intermediate rainfall regions with between 13 and 16 inches of average annual rainfall. One of these growers used conventional tillage practices and had an average seed yield of 2,015 lb acre^{-1}. Four of these 14 growers used minimum tillage methods and had an average seed yield of 2,600 lb acre^{-1} in two fields. Six of these 14 growers used no-till methods, however, they had an average seed yield of only 1,429 lb acre^{-1} in five fields.

Twenty six growers, (39% of the total acres), farmed in high rainfall areas receiving greater than 17 inches of precipitation annually. Two of these growers were using a conventional tillage system seeding practices and four had average seed yield of 2,343 lb acre^{-1} in one field. Eight used minimum tillage methods and had an average seed yield of 1,322 lb acre^{-1}. Sixteen grower who received greater than 17 inches of annual precipitation, used no-till to raise canola. There average seed yield was 1,786 lb acre^{-1} out of five fields.

6.4.6 Problems

Identifying grower's problems in canola production is useful to identify necessary research areas to reduce crop failures.

Planting and crop establishment were the most difficult periods for both winter and spring canola, and crop establishment is critical for sustainable production (Table 6.15). Nineteen growers ranked planting and establishment as one of their top three problems. Weed control was the second biggest problem occurred by growers. Five of the nineteen growers who ranked planting and establishment as problematic, also rated harvest as a problem.

Weeds were not a significant problem, perhaps due to competitive nature of winter canola and the use of Roundup Ready® spring canola cultivars. Diseases in winter canola and insects in spring canola were the most significant pest problems. All growers had concerns with harvest and marketing. Growers also expressed concerns with winter kill, shatter, header speed, and weather damage.

Harvesting was the third most common problem as seven growers had a hard time getting the crop to feed into the combine and setting the combine to property clean the seed. Other problems encountered included fertility, marketing, hail, winter kill, marketing, disease, insects and weeds.

6.4.7 Establishment next year

The most common changes suggested for producing canola next year are related to improving crop stand establishment. Practices mentioned included preparing a smoother seed bed, rolling before or after planting, or using a drill with press wheels. Other suggested changes in canola establishment for next year included later fertilization and applying more sulfur. Changes in seeding practices will be to plant a little earlier. For most parts seeding rates will remain the same. Better stand establishment will reduce the effects of weed pressure and winter kill on the canola crop.

6.4.8 Potential acreage next year

Next year 71% of growers said they will include either the same amount, or more hectares of canola in their rotation, 18% growers will include less canola in their rotation and 11% growers are still undecided, with most of the indecision depending upon the price Table 6.15 summarizes the potential acreage from those growers who plan to include canola next year in their rotations.

6.4.9 Experience

82% of growers had raised canola in the past. 18% of the growers will be growing canola for the first time.

6.5 Conclusions

During years of increased production of canola in the PNW, growers were able to produce the crop with limited inputs in regions that receive lower precipitation than required for traditional alternative crops.

Growers who expressed problems with planting and establishment also had problems with weed control. Overall, growers who were pleased with planting and stand establishment did not have a problem with weeds, therefore by improving planting and stand establishment weeds should be less of a problem.

Within large-scale production, canola showed very good adaptability to conservation farming techniques. Although, canola had the highest average seed yield when growers used minimal till practices. Canola also yielded well for growers using conventional and non-tillage practices.

The survey data when compared to chapters 3 and 4 results showed similar agronomic techniques to optimize canola yields. Such as the addition of nitrogen to increase the yield of a crop when a higher application of nitrogen is applied a higher seed yield was created in both situations. The survey showed the nitrogen application of 106-328 lb N acre^{-1} produced the highest yield (2,571 lb acre^{-1}) while the highest yields were produced in spring canola in chapter 3 with an application of 114 -168 lb N acre^{-1} (1,884 lb N acre^{-1} average among the 3 nitrogen rates) and within chapter 4 winter canola application of 188-313 lb N acre^{-1} (1,825 lb N acre^{-1} average among the 3 nitrogen rates). The trials in chapter 3 were planted in higher rainfall regions and in both the survey and chapter the conventional tillage systems still produced higher yields over no-till sites. It was also discovered that the majority of growers who participated in the survey planted their canola at 4-6 lb acre^{-1}. Our studies found that spring canola planted in 5 lb per acre^{-1} and winter canola planted 6 lb per acre^{-1} were ideal. Overall Amanda not only was the recommended winter cultivar it was also the most commonly grown winter canola. HyClass® 930 which was the most commonly grown spring cultivar amongst growers this cultivar was not tested within the studies however Roundup Ready® cultivar DKL30-42-RR was recommend in the trial.   It was also noted that winter canola produced higher yields over spring canola which was also found true within this survey.

Overall, growers were encouraged with the performance of canola in their rotation and this is shown by three growers who plan on planting greater acres in 2015. Two of the nine growers who are planning to plant the same amount of acres next year have raised canola in the past and already established this crop into their rotation. Three of the three growers who plan to plant fewer acres next year have raised canola in the past and they are planting less to fit it into their crop rotation.

6.6 References

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Table 6.1. The number of responses for each section with Part 1 being the planting survey Part 2 being the midseason and final Part being the harvest survey and the number of growers who provided acres information for each section of survey in 2013 to 2014.

	Part 1	Part 2	Part 3
Number Responded	41	24	20
Number of Growers	35	23	19
Number of Acres	13,222	7,166	4,505

Table 6.2. Number of responding farmers, average acreage and yield from the 2013 and 2014 grower survey.

Canola Type	Number of Growers	Number of Acres	Seed Yield		
			Mean	Min	Max
			--------------------*lb acre*$^{-1}$ --------------------		
Spring	12	2,913	1,506	750	2,125
Winter	15	1,587	2,421	400	3,700
Total	27	4,500	3,927	1,150	5,825

Table 6.3. Number of growers field and their tillage practices on their winter and spring canola from the growers surveyed in 2013 and 2014.

Tillage Practice	Spring Canola	Winter Canola
	---------------Number of Fields---------------	
Conventional Till	0	12
Minimal Till	8	8
No-Till	16	13
Total	24	33

Table 6.4. Number of grower's fields that used pre-plant herbicide on their winter and spring canola in the 2013 and 2014 grower survey.

Pre-Plant Herbicides	Spring Canola	Winter Canola
	----------Number of Fields----------	
Treflan	0	2
Roundup	23	15
Other	0	5
Treflan+Roundup	0	3
Roundup+Other	0	2
Total	23	27

Table 6.5. Summary of the number of growers, acres and the average seed yield (lb acre $^{-1}$) of canola in Idaho, Oregon, and Washington who took part in the canola grower survey in 2013 and 2014.

States	Number of Growers	Acres Planted	Average Seed Yield (lb acre^{-1})	Range of Seed Yield (lb acre^{-1})
Idaho	20	5,283 (17)	1,816 (12)	750 – 3,600
Oregon	1	1,096 (1)	-	-
Washington	21	6,843 (18)	2,186 (12)	400 – 3,700
Summary	42	13,222	1,922	400 – 3,700

† Parentheses depict the number of growers who provided that particular data.

Table 6.6 Summary of the number of samples, protein percentage and oil content of spring and winter canola in Idaho, Oregon, and Washington who took part in the canola grower survey in 2013 and 2014.

	Number of Samples	Protein	Oil content
<u>Canola Type</u>		-- % --	-- g/kg --
Spring	3	27	400
Winter	8	23	400
Summary	11	25	400
<u>Location</u>			
Washington	5	23	390
Idaho	9	25	410
Summary	14	24	400

Table 6.7. Summary of canola seed yield response to planting density with the low seeding rate, medium seeding rate and the high seeding rate being from growers surveyed in 2013 and 2014.

Seeding Rates	Number of Growers	# of Fields	Acres Planted	Average Seed Yield	Range of Seed Yield
				--------------- lb acre^{-1}	--------------
Low†	10	10	2,946	2,435(3)	1,690 – 3,600
Medium†	27	37	8,138	2,041 (18)	797 – 3,688
High†	5	7	995	2,700 (2)	2,400- 3,000
Summary	42	54	12,079	2,392	797 – 3.688

† Parentheses depict the number of growers who provided that particular data.

† Low = less than 3 lb acre $^{-1}$, Medium= between 4 to 6 lb acre $^{-1}$, High = greater than 6 lb acre $^{-1}$

Table 6.8. Summary of average seed yield (lb acre $^{-1}$) of canola grown under conventional, minimal and no-till methods within low, medium and high levels of precipitation from growers surveyed in 2013 and 2014.

	Number of Growers	# of Fields	Acres Planted	Average Seed Yield	Range of Seed Yield
Low Rainfall†				--------------- lb acre^{-1} ---------------	
Conventional	5	11	2,298	3,100(3)	2,500 – 3,700
Minimal	2	3	373	3,257 (3)	3,302 - 3,213
No-Till	3	4	1,450	800 (1)	800
Summary	17	18	4,124	7,157 (7)	800 – 3,700
Medium Rainfall†					
Conventional	1	1	76	2,015 (1)	2,015
Minimal	4	4	640	2,600 (2)	1,600-3,600
No-Till	6	11	2,750	1,429 (5)	80 - 3,00
Summary	14	16	3,466	6,490 (8)	80 – 3,600
High Rainfall†					
Conventional	2	2	173	2,343 (1)	2,343
Minimal	8	7	1,314	1,322 (4)	750 - 1,690
No-Till	16	15	3,482	1,786 (5)	1,681 - 2,125
Summary	26	24	4,969	5,451 (10)	750 - 2,343

† Parentheses depict the number of growers who provided that particular data.

† Low = (<12 inches), Medium = (13 – 16 inches), High = (>17inches)

Table 6.9. Summary of canola seed yield response to nitrogen levels with low and high yields from growers surveyed in 2013 and 2014.

Yields	Number of Growers	Average "N" Residue	Average "N" Pre-Plant	Average "N" Post-Plant	Average Total "N" Available	Average Applied "N"	Average Yield
		----lb. acre^{-1}----					
High	9	67	91	75	177	166	2,580
Low	9	33	74	17	112	91	1,335
Summary	18	50	83	46	145	128	1,958

†High = greater than 2,000 lb. acre^{-1}, Low = less than 2,000 lb. acre^{-1}

Table 6.10. Summary of canola seed yield response to nitrogen levels from spring and winter canola growers surveyed in 2013 and 2014.

Type	Number of Growers	Average "N" Residue	Average "N" Pre-Plant	Average "N" Post-Plant	Average Total "N" Available	Average Applied "N"	Average Yield
		----------------------------------lb. $acre^{-1}$					--------------------------------
Spring	9	45	82	16	143	98	1,505
Winter	9	76	85	66	227	151	2,692
Summary	18	60	167	41	185	124	2,098

Table 6.11. Summary of canola seed yield response to sulfur levels with low and high yields of growers surveyed in 2013 and 2014.

Yields	Number of Growers	Average "S" Residue	Average "S" Pre-Plant	Average "S" Post-Plant	Average Total "S" Available	Average Applied "S"	Average Yield
		----------------------------------lb. acre^{-1}----------------------------------					
High	9	10	18	16	35	24	2,579
Low	9	9	15	8	21	11	1,334
Summary	18	10	16	12	28	18	1,957

†High = greater than 2,000 lb. acre^{-1}, Low = less than 2,000 lb. acre^{-1}

Table 6.12. Canola seed yield response to sulfur levels from spring and winter canola growers surveyed in 2013 and 2014.

Type	Number of Growers	Average “S” Residue	Average “S” Pre-Plant	Average “S” Post-Plant	Average Total “S” Available	Average Applied “S”	Average Yield
		---------------------------------lb. $acre^{-1}$---------------------------------					
Spring Canola	9	8	15	1	24	16	1,505
Winter Canola	9	20	17	15	52	32	2,692
Summary	18	14	16	8	38	24	2,098

Table 6.13. Pre-harvest practices by farmers for spring and winter canola from the 2013 and 2014 grower survey.

Pre-Harvest Practices	Spring Canola	Winter Canola
	---------- Number of Growers ----------	
Swath	-	++++
Push	-	-
Neither	++++++++++	+++++
Desiccant	-	-
Pod Sealant	-	+
Summary	10	10

† (+) a single grower (-) no growers.

Table 6.14. Problems encountered by farmers throughout growing canola in 2013 and 2014.

Problems Encountered	Winter Canola	Spring Canola	Total Number of Growers
Planting	++++++	+++	9
Establishment	++++++	++++	10
Insects	.	+++	3
Weeds	+++	++	5
Disease	+++	++	5
Fertility	+	+	2
Harvest	++++	++	6
Marketing	+++	++	5
Other: winter kill, shatter, header speed, weather	+++++++	+	8

† (+) a single grower (-) no growers.

Table 6.15. Summary of potential acres by surveyed growers who plan on incorporating canola in their crop rotation in 2015.

Number of Growers	Potential Acres
4	More
9	Same
3	Less
2	Undecided

Chapter 7: Conclusion and Recommendations

7.1 Spring canola

Early planting of canola has been proposed as a method to increase the reliability of this valuable alternative crop. Planting date was found to be inconclusive overall on its effects on yield potential for *B.napus* since both years tested had conflicting results. However, planting early provided higher stand count and 60% more control of weeds. GMO cultivars DKL 30-42-RR and InVigor L.130-LL had a 60% increase in weed control compared to non-GMO cultivars Cara and Empire. Early planting also ensures adequate soil moisture in spring canola later in the season compared to late planting.

A moderate seeding rate (equivalent to 5.6 kg hectare^{-1}) is adequate to ensure maximum yield potential for each spring canola cultivar.

Applying nitrogen fertilizer is essential to maximizing the yield potential of spring canola. However, the rate of yield increase, declined at higher fertility levels. The average optimal nitrogen rate to maximize profitability will be dependent on fertilizer prices and seed value, but will be in the range of 102 kg N hectare^{-1} to 150 kg N hectare^{-1}. Cultivar each showed differential responses to N application. For DKL 30-42-RR optimal N was 121 kg N hectare^{-1} to obtain a maximum seed yield of 2,212 kg hectare^{-1}. Optimum nitrogen rates for the other cultivars are: InVigor L.130-LL, 119 kg N hectare^{-1} for yield of 2,114 kg hectare^{-1}; Empire, 99 kg N hectare^{-1} for yield of 1,574 kg hectare^{-1} and for Cara 111 kg N hectare^{-1} for a yield of 1,433 kg hectare^{-1}. None of the cultivars peaked in yield within the N ranges we examined, and each showed highest yield at the maximum application rate of 168 kg N hectare^{-1}. When average among the two years a range of 133 to 144 kg N hectare^{-1} (mean 139 kg N hectare^{-1}) with a range of 2001 to 2012 kg N hectare^{-1} (207 kg N hectare^{-1}) producing a yield range of 1,909-2,683 kg hectare^{-1} (mean 2,257 kg hectare^{-1}).

The early planting date along with the addition of nitrogen increased seed yield for each cultivar beside DKL 30-42-RR on average by 222 kg. The cultivar DKL 30-42-RR decreased by 15 kg when planted early.

The four canola cultivars tested within this experiment are from separate market classes and the demand for weed control, weather or crop rotation may determine which is planted. Not only is DKL 30-42-RR the highest yielding cultivar. DKL30-42-RR and InVigor L1.30 -LL are GMO variety with the ability to control weeds easily yet comes with technology fess. Cara is an imidazoline resistant variety that is able to withstand carry over from previous use of Pursuit® in legumes or Beyond® on IMI wheat. Both Cara and Empire being non-GMO cultivars provide grower with a premium on the seed of $.009 kg. Each cultivar has its own specific job and when chosen correctly can aide in the development of an agricultural system.

7.2 Winter canola

Planting early, in our study the end of July, is the best way to maximize establishment potential of the winter canola and establishment in winter canola is essential for good winter survival

An intermediate and high seeding rate, which in this experiment was 5.6 and 6.7 kg hectare^{-1}, are optimal for producing higher establishment which would lead to quicker ground cover and reduce weed pressures. However, among the three seeding rates tested similar yields were found. Unless there are severe detrimental environmental conditions likely to limit seedling emergence and plant development, seeding rates higher than 4.48 kg hectare^{-1} are unnecessary for maximizing yield potential.

Similar to the spring canola trial as the yield increased it also decreased at higher fertility levels, the average optimal nitrogen rate will be dependent on fertilizer prices and seed value will undoubtedly be at least 168 kg N hectare^{-1} to 280 kg N hectare^{-1} with an increase of 5% in yield. Cultivar specific data indicated that optimum available nitrogen for Amanda was 241.2 kg N hectare^{-1} to obtain a maximum seed yield of 3,952.2 kg hectare^{-1}. Optimum nitrogen rates for HyClass® 125W was 231.1 kg N hectare^{-1} for a yield of 3,332.1 kg hectare^{-1} (Table 4.12, Figure 4.3).

The two canola cultivars tested within this experiment are from separate market classes and the demand for seed may determine which is planted. HyClass® 125W is a RoundupReady® cultivar that allows for better weed control. Not only does Amanda have the best establishment and is the highest yielding cultivar. Amanda is also a non-GMO variety with a premium on the seed of $.009 kg. Overall, the seed oil content was found to be similar among both cultivars.

7.3 Survey

The data provided by the survey provided the University of Idaho Brassica Breeding program a source of agronomic information that will allow them to create projects and develop field days to aid growers in areas in canola production that is in need of help.

The main problem growers had was with planting and establishment and also had problems with weed control. Overall, growers who were pleased with planting and stand establishment did not have a problem with weeds, therefore by improving planting and stand establishment weeds should be less of a problem. Growers also had problems with winter kill with their winter canola.

Within large-scale production, canola showed very good adaptability to conservation farming techniques. Although, canola had the highest average seed yield when growers used minimal till practices. Canola also yielded well for growers using conventional and non-tillage practices.

The survey data when compared to chapters 3 and 4 results showed similar agronomic techniques to optimize canola yields. Such as the addition of nitrogen to increase the yield of a crop when a higher application of nitrogen is applied a higher seed yield was created in both situations. The survey showed the average nitrogen application of 166 lb N acre^{-1} produced the highest yield (2,580 lb acre^{-1}). While the highest yield (1,505 lb acre^{-1}) of spring canola were produced with an average of 98 lb acre^{-1} applied while the highest yield (2,692 lb acre^{-1}) for winter canola were produced with an average applied N of 151 lb acre^{-1}. The highest yields were produced in spring canola in chapter 3 with an application of 114 -168 lb N acre^{-1} (1,884 lb N acre^{-1} average among the 3 nitrogen rates) and within chapter 4 winter canola application of 188-313 lb N acre^{-1} (1,825 lb N acre^{-1} average among the 3 nitrogen rates). The trials in chapter 3 were planted in higher rainfall regions and in both the survey and chapter the conventional tillage systems still produced higher yields over no-till sites. It was also discovered that the majority of growers who participated in the survey planted their canola at 4-6 lb acre^{-1}. Our studies found that spring canola planted in 5 lb per acre^{-1} and winter canola planted 6 lb per acre^{-1} were ideal. Overall Amanda not only was the recommended winter cultivar it was also the most commonly grown winter canola. HyClass® 930 which was the most commonly grown spring cultivar amongst growers this cultivar was not tested within the studies however Roundup Ready® cultivar DKL30-42-RR was recommend in the trial. It was also noted that winter canola produced higher yields over spring canola which was also found true within this survey.

Farmers within the PNW have proved to be able to grow canola successfully and are experimenting on ways to optimize their canola production. Currently within this survey we have witness growers adapting practices to fit their location and farm. With several successful years of production back to back will build up the grower's confidence and the production of the crop to the size necessary to establish profitable and reliable markets.

7.4 Economics and marketing

At prevailing prices spring is as profitable as lentil, garbanzos, and peas as an alternative crop to small grain cereals in the dryland region of the PNW. Winter canola was found to be more than or just as profitable as winter wheat. The incorporation of canola into a small grain cereal monoculture will diversify risk, as the farmer is not relying solely on small grain cereal prices or other rotation crop prices.

The market for canola has rapidly increased the seed production in the United States since 1992. Two potential ways to increase demand of canola is to compete with Canada for export markets and through altering the development of canola and rapeseed quality canola.

Early planting of canola has been proposed as a method to increase the reliability and economic return of this valuable alternative crop. Early planting ensures adequate soil moisture, improving establishment.

7.4.1 Spring canola

The conventional tilled were significantly better than no-till sites in every situation tested. Planting early, in this case as soon as the pre-plant herbicide could be applied and the seedbed prepared, is the best way to maximize establishment potential of the *B. napus*. Planting date had no significant effect on potential returns. However, spring canola optimal practices showed that early planted canola maximized returns in both no-till and tillage systems. Except for DKL 30-42-RR who produced the highest return when planted late in a conventional tilled system.

Yields increased at higher fertility levels, the average optimal nitrogen rate will be dependent on fertilizer prices and seed value will undoubtedly be at least 100.8 kg. N hectare^{-1} to 168 kg. N hectare^{-1} with an increase of \$38.42 hectare^{-1} in returns. Cultivar specific data indicated that optimum spring canola available nitrogen for DKL 30-42-RR was 168 kg. N hectare^{-1}, Empire was 134.4 kg. N hectare^{-1}, at both no-till and tillage sites. InVigor L.130-LL optimum nitrogen was 33.6 kg. N hectare^{-1} at the no-till location and 134.4 kg. N hectare^{-1} at the tillage site. While Cara at the no-till optimal nitrogen was 168 kg. N hectare^{-1} and 134.4 kg. N hectare^{-1} at the tillage site.

There was no significant difference between the seeding rates. Intermediate seeding rate which in this experiment was 5.6 kg. N hectare^{-1}, overall was are optimal for producing maximized returns under both practices. However, among the three seeding rates tested DKL 30-42-RR had the highest returns when using the low seeding rate of 4 lb seed acre-1 at both practices. While Empire had the highest returns in the no-till situation with the high seeding rate of 6.72 kg. N hectare^{-1}.

Within the conventional tillage sites the spring cultivar DKL 30-42-RR had the highest return of \$165.33 above variable costs when planted late at a low seeding rate with 168 kg. N hectare^{-1}. Followed by InVigor L.130-LL planted early at an intermediate seeding rate with 134.4 kg. N hectare^{-1} with a return of \$154.98 hectare^{-1}. Next Empire also planted early at intermediate seeding rate with 134.4 kg. N hectare^{-1} with a return of \$144.05 hectare^{-1}. Lastly Cara planted early at intermediate seeding rate with 134.4 kg. N hectare^{-1} with a return of \$136.16 hectare^{-1}.

Within the no-till sites the spring cultivar DKL 30-42-RR had the highest return of \$101.61 hectare^{-1} above variable costs when planted early at a low seeding rate with 168 kg. N hectare^{-1}. Followed by Empire planted early at a high seeding rate with 134.4 kg. N hectare^{-1} with a return of \$58.50 hectare^{-1}. Next InVigor L.130-LL also planted early at intermediate seeding rate with 33.6 kg. N hectare^{-1} with a return of \$113.25 hectare^{-1}. Lastly Cara planted early at intermediate seeding rate with 168 kg. N hectare^{-1} with a return of \$4.64 hectare^{-1}.

Even though overall DKL 30-42-RR produced the highest returns in both practices. Depending on your crop rotation and what you are trying to achieve with your cropping system each variety of canola used will change for different situations. For example a farmer with

Pursuit® residue in the soil must plant the spring canola variety Cara which is imidazilinone resistant. If you have a contract for non-GMO varieties you must make a choice between Cara and Empire. If you have a no-till system and need a non-GMO cultivar Empire will be your first choice over DKL 30-42-RR

7.4.2 Winter canola

All of the characters evaluated in the winter canola trials had significant effects on the returns above variable costs. Planting date had no significant effect on potential returns. However, winter canola optimal practices showed that early planted canola maximized returns for HyClass® 125W while early planting maximized Amanda's returns.

Applying nitrogen fertilizer is essential to maximizing the yield potential of *B. napus*. As yield increased it also decreased at higher fertility levels, the average optimal nitrogen rate will be dependent on fertilizer prices and seed value will undoubtedly be at least 200 lb N acre^{-1} with an increase of \$130.12 acre^{-1} in returns. Cultivar specific data indicated that optimum winter canola available nitrogen for Amanda was 200 lb N acre^{-1}. While HyClass® 125W at the optimal return nitrogen was at 250 lb N acre^{-1}.

There was a significant difference between the high and intermediate seeding rates. However, there was no difference between the low, intermediate and low, high. Among the three seeding rates tested Amanda had the highest returns when using the intermediate seeding rate of 5 lb seed acre^{-1}. While HyClass® 125W had the highest returns with the low seeding rate of 4 lb seed acre^{-1}.

Winter cultivar Amanda had the highest return of \$650.93 above variable costs when planted early at an intermediate seeding rate with 200 lb N acre^{-1}. Followed by HyClass® 125W planted early at a low seeding rate with 250 lb N acre^{-1} with a return of \$540.51.

Even though overall Amanda depending on your crop rotation and what you are trying to achieve with your cropping system which of the two cultivars to choose will change. If you have a contract for non-GMO varieties you must choose Amanda. However, if you are trying to clean up weeds with an application of Roundup® you would choose HyClass® 125W.

Overall, winter canola on average produced $139.25 more in returns an acre than the highest returned cultivar in spring canola.

7.3 Summary

When spring or winter canola yield are maximized by adopting the best growing practices then canola crop returns after variable costs was as high or higher than other possible crops in the PNW, including spring and winter wheat.

In conclusion to provide the optimal seed yield and return value for your spring canola:

- Plant early (late April/early May).
- Within a conventional system.
- At high fertility rates of 90 to 150 lb N acre^{-1}
- With an intermediate (4 to 5 lb acre^{-1}) to low seeding rate.

For an optimal seed yield and return for winter canola you want to:

- Plant early (Mid July).
- High seeding rates (6 lb acre^{-1})
- High fertility rates of 200-250 lb N acre^{-1}.

While in high weed infested field a GMO canola variety proved essential for weed control. While markets with premiums of non-GMO cultivars would lead you to choose Empire and Cara for a spring cultivar and Amanda for winter. Within this study DKL 30-42-RR was the optimal spring cultivar while Amanda was the lead winter variety. However, it should be noted even though each cultivar did not give high yields and returns each have carry a specific purpose within the canola industry. It is recommended to assess your cropping system and analysis the goal of the canola as a rotation crop and choose the best suited cultivar for your individual system and location.

The true potential of spring and winter canola in the PNW will only be determined when we more fully understand the best growing practices. Making these information available to growers, particularly these growing canola for the first time, will greatly increase the acceptability of the crop and hectarage in the region.

Appendix A: Chapter 5: Economic Feasibility of Canola (*Brassica napus* L.) as an Alternative Crop in the Dryland Regions of the Pacific Northwest

Table. 5.A1 Total amount of canola and rapeseed produced, imported seed, and exported seed in the US between 1992 and 2014.

Year	Production	Seed Imported	Seed Exported	Beginning Stocks	Ending Stocks
-- Tons--					
1992	100,723	1,000	48,486	15,995	6,498
1993	89,996	13,496	51,985	6,498	4,999
1994	134,289	386,391	38,989	4,999	47,487
1995	232,870	314,911	113,468	47,487	16,995
1996	284,918	278,921	68,981	16,995	43,988
1997	254,080	284,920	86,476	43,988	39,989
1998	414,903	390,890	138,461	39,989	20,994
1999	807,046	341,903	271,423	20,994	84,476
2000	702,441	266,925	149,458	84,476	54,485
2001	1,036,910	239,432	242,931	54,485	41,988
2002	1,026,105	137,961	239,932	41,988	74,479
2003	873,578	216,939	316,411	74,479	77,478
2004	765,853	268,424	335,405	77,478	43,988
2005	699,599	514,855	153,957	43,988	64,982
2006	822,092	571,339	172,951	64,982	95,473
2007	712,863	713,298	270,923	95,473	147,458
2008	727,751	962,728	466,368	147,458	172,451
2009	738,339	909,243	209,941	172,451	223,937
2010	748,650	625,823	193,945	223,937	134,462
2011	1,240,739	531,350	323,908	134,462	100,472
2012	790,390	685,306	163,454	100,472	31,991
2013	1,249,288	434,377	190,946	31,991	88,475
2014	1,177,839	849,760	138,961	88,475	172,451
Average	679,620	432,182	190,772	71,023	77,826

Source: NASS, 2013

Table 5.A2 Quantity of imports of canola oil and canola meal into US from 1992 to 2014.

Year	Canola Oil Ton	Canola Meal Ton
1992	407,385	621
1993	430,378	603
1994	451,872	780
1995	468,868	815
1996	543,846	1,013
1997	537,348	954
1998	543,846	1,372
1999	530,350	1,194
2000	572,338	1,260
2001	596,332	1,178
2002	553,844	921
2003	490,361	1,013
2004	611,327	1,638
2005	566,340	1,471
2006	798,774	1,611
2007	783,779	1,651
2008	1,120,184	1,998
2009	1,157,173	1,866
2010	1,175,168	1,278
2011	1,565,058	2,251
2012	1,644,036	3,077
2013	1,379,610	3,442
2014	1,625,541	3,602
Average	806,685	1,548

Source: USDA, 2014

Table 5.A3 Total amount of canola seed harvested, produced, imported seed, and exported seed in Canada from 1986 to 2014.

Year	Area Harvested (a)	Production (tons)	Seed Imported (tons)	Seed Exported (tons)
1986	64,997	4,091,726	n/a	n/a
1987	6,460	4,098,338	n/a	n/a
1988	9,180	4,648,236	n/a	n/a
1989	7,210	3,536,318	n/a	n/a
1990	6,249	3,598,030	n/a	n/a
1991	7,760	4,654,848	n/a	n/a
1992	7,525	4,266,944	n/a	n/a
1993	10,190	6,087,448	n/a	n/a
1994	14,220	7,969,664	n/a	n/a
1995	13,025	7,090,268	n/a	n/a
1996	8,527	5,578,324	n/a	n/a
1997	12,032	7,045,086	n/a	n/a
1998	13,414	8,422,586	n/a	n/a
1999	13,749	9,695,396	n/a	n/a
2000	12,007	7,939,910	n/a	n/a
2001	9,353	5,528,734	n/a	n/a
2002	8,964	4,981,040	n/a	n/a
2003	11,587	7,461,642	263,378	2,638,188
2004	12,026	8,455,646	266,684	4,136,908
2005	12,788	10,450,266	117,914	3,758,922
2006	12,943	9,918,000	153,178	5,959,616
2007	15,649	10,591,322	223,706	6,034,552
2008	16,052	13,933,688	196,156	6,238,422
2009	16,101	14,213,596	132,240	8,713,514
2010	16,945	14,092,376	139,954	7,892,524
2011	18,753	16,098,016	245,746	7,828,608
2012	21,743	15,282,536	105,792	9,586,298
2013	19,785	19,791,920	139,954	8,001,622
2014	19,953	17,141,610	137,750	8,816,000
Average	14,455	8,850,466	176,871	6,633,765

Source: Statistics Canada & COPA Monthly

Table 5.A4 Amount and cost per unit of variable input cost for canola grown in the PNW.

DKL 30-42-RR Input Cost	Unit per Acre	Unit	Cost per Unit	Cost per Acre
Fertilizer ($ acre):				
16-20-0-15	0	lb.	$0.00	$0.00
	30	lb.	$0.27	$8.25
	60	lb.	$0.27	$16.49
	90	lb.	$0.27	$24.74
	120	lb.	$0.27	$32.99
	150	lb.	$0.27	$41.23
Seed Cost ($ acre):	4.16	lb.	$10.90	$45.32
	5.20	lb.	$10.90	$56.64
	6.24	lb.	$10.90	$67.98
Herbicide Pre-Plant ($ acre):				
Trifluralin (Tillage)	32	oz	$0.10	$3.30
Roundup RT3 (No-Till)	64	oz	$0.17	$10.78
Herbicide:				
Roundup RT3	16	oz	$0.17	$2.69
Insecticide ($ acre):				
Warrior II	1.96	oz	$34.63	$67.87
Aerial Application	1	acre	$8.95	$8.95
Total				$76.82

† Cost per units were generated through personal contact with seed companies and agricultural chemical dealers along with using the 2013 Crop Input Cost Summary.

Table 5.A5 Amount and cost per unit of variable input cost for canola grown in the PNW.

InVigor L.130-LL Input Cost	Unit per Acre	Unit	Cost per Unit	Cost per Acre
Fertilizer ($ acre):				
16-20-0-15	0	lb.	$0.00	$0.00
	30	lb.	$0.27	$8.25
	60	lb.	$0.27	$16.49
	90	lb.	$0.27	$24.74
	120	lb.	$0.27	$32.99
	150	lb.	$0.27	$41.23
Seed Cost ($ acre):	3.32	lb.	$10.80	$35.86
	4.15	lb.	$10.80	$44.81
	4.66	lb.	$10.80	$50.31
Herbicide Pre-Plant ($ acre):				
Trifluralin (Tillage)	32	oz	$0.10	$3.30
Roundup RT3 (No-Till)	64	oz	$0.17	$10.78
Herbicide ($ acre):				
Rely (Liberty 280sl)	52	oz	$0.75	$38.99
UAN 2.5%v/v	48	oz	$0.59	$28.13
Total				$67.12
Insecticide ($ acre):				
Warrior II	1.96	oz	$34.63	$67.87
Aerial Application	1	acre	$8.95	$8.95
Total				$76.82

† Cost per units were generated through personal contact with seed companies and agricultural chemical dealers along with using the 2013 Crop Input Cost Summary

† Volumes were based off a 15 gal tank

Table 5.A6 Amount and cost per unit of variable input cost for canola grown in the PNW.

Empire Input Cost	Unit per Acre	Unit	Cost per Unit	Cost per Acre
Fertilizer ($ acre):				
16-20-0-15	0	lb.	$0.00	$0.00
	30	lb.	$0.27	$8.25
	60	lb.	$0.27	$16.49
	90	lb.	$0.27	$24.74
	120	lb.	$0.27	$32.99
	150	lb.	$0.27	$41.23
Seed Cost ($ acre):	3.14	lb.	$3.50	$11.00
	3.93	lb.	$3.50	$13.75
	4.71	lb.	$3.50	$16.49
Herbicide Pre-Plant ($ acre):				
Trifluralin (Tillage)	32	oz	$0.10	$3.30
Roundup RT3 (No-Till)	64	oz	$0.17	$10.78
Herbicide ($ acre):				
Stinger	5	oz	$5.80	$29.02
Assure II	8	oz	$0.69	$5.55
M90 .25% v/v	4.8	oz	$0.14	$0.66
Total				$35.23
Insecticide ($ acre):				
Warrior II	1.96	oz	$34.63	$67.87
Aerial Application	1	acre	$8.95	$8.95
Total				$76.82

† Cost per units were generated through personal contact with seed companies and agricultural chemical dealers along with using the 2013 Crop Input Cost Summary

† Volumes were based off a 15 gal tank

Table 5.A7 Amount and cost per unit of variable input cost for canola grown in the PNW

Cara Input Cost	Unit per Acre	Unit	Cost per Unit	Cost per Acre
Fertilizer ($ acre):				
16-20-0-15	0	lb.	$0.00	$0.00
	30	lb.	$0.27	$8.25
	60	lb.	$0.27	$16.49
	90	lb.	$0.27	$24.74
	120	lb.	$0.27	$32.99
	150	lb.	$0.27	$41.23
Seed Cost ($ acre):	2.89	lb.	$3.50	$10.11
	3.61	lb.	$3.50	$12.64
	4.33	lb.	$3.50	$15.17
Herbicide Pre-Plant ($ acre):				
Trifluralin (Tillage)	32	oz	$0.10	$3.30
Roundup RT3 (No-Till)	64	oz	$0.17	$10.78
Herbicide ($ acre):				
Beyond	4	oz	$4.05	$16.22
UAN 2.5%v/v	48	oz	$0.59	$28.13
M90 .25% v/v	4.8	oz	$0.14	$0.66
Total				$45.01
Insecticide ($ acre):				
Warrior II	1.96	oz	$34.63	$67.87
Aerial Application	1	acre	$8.95	$8.95
Total				$76.82

† Cost per units were generated through personal contact with seed companies and agricultural chemical dealers along with using the 2013 Crop Input Cost Summary.

† Volumes were based off a 15 gal tank

Table 5.A8 Amount and cost per unit of variable input cost for canola grown in the PNW.

HyClass® 125W Input Cost	Unit per Acre	Unit	Cost per Unit	Cost per Acre
Fertilizer ($ acre):				
16-20-0-15	0	lb.	$0.00	$0.00
	50	lb.	$0.27	$13.74
	100	lb.	$0.27	$27.49
	150	lb.	$0.27	$41.23
	200	lb.	$0.27	$54.98
	250	lb.	$0.27	$68.72
Seed Cost ($ acre):	3.51	lb.	$6.48	$22.74
	4.82	lb.	$6.48	$31.24
	6.13	lb.	$6.48	$39.74
Herbicide Pre-Plant ($ acre):				
Trifluralin (Tillage)	32	oz	$0.10	$3.30
Roundup RT3 (No-Till)	64	oz	$0.17	$10.78
Insecticide ($ acre):				
Warrior II	1.96	oz	$34.63	$67.87
Aerial Application	1	acre	$8.95	$8.95
Total				$76.82
Custom Swathing ($ acre):	1	acre	$18.33	$18.33

† Cost per units were generated through personal contact with seed companies and agricultural chemical dealers along with using the 2013 Crop Input Cost Summary

Table 5.A9 Amount and cost per unit of variable input cost for canola grown in the PNW.

Amanda Input Cost	Unit per Acre	Unit	Cost per Unit	Cost per Acre
Fertilizer ($ acre):				
16-20-0-15	0	lb.	$0.00	$0.00
	50	lb.	$0.27	$13.74
	100	lb.	$0.27	$27.49
	150	lb.	$0.27	$41.23
	200	lb.	$0.27	$54.98
	250	lb.	$0.27	$68.72
Seed Cost ($ acre):	4.11	lb.	$3.95	$16.22
	5.64	lb.	$3.95	$22.27
	7.23	lb.	$3.95	$28.56
Herbicide Pre-Plant ($ acre):				
Trifluralin (Tillage)	32	oz	$0.10	$3.30
Roundup RT3 (No-Till)	64	oz	$0.17	$10.78
Insecticide ($ acre):				
Warrior II	1.96	oz	$34.63	$67.87
Aerial Application	1	acre	$8.95	$8.95
Total				$76.82
Custom Swathing ($ acre):	1	acre	$18.33	$18.33

† Cost per units were generated through personal contact with seed companies and agricultural chemical dealers along with using the 2013 Crop Input Cost Summary

Table 5.A10 Amount and cost per unit of variable input cost for winter wheat grown in the PNW.

Soft White Winter Wheat	Unit per Acre	Unit	Cost per Unit	Cost per Acre
Fertilizer ($ acre):				
Nitrogen	90	lb.	$0.63	$56.70
Phosphorous	30	lb.	$0.72	$21.60
Sulfur	10	lb.	$0.30	$3.00
Total				$81.30
Seed Cost ($ acre):	90	lb.	$0.27	$24.30
Pesticides ($ acre):				
Ospery	4.75	oz	$3.72	$17.67
Starane Flex	22	oz	$0.62	$13.64
Surfactant	3.2	oz	$0.20	$0.64
Brox M	1.6	oz	$0.27	$0.43
Total				$32.38
Fungicides ($ acre):				
Quilt	14	oz	$1.48	$20.72
Syltac Sticker	0.5	pt	$6.25	$3.13
Total				$23.85
Custom Aerial ($ acre):	1	acre	$8.95	$8.95

† Cost per units were generated using the 2014 Northern Idaho Enterprise Budget.

Table 5.A11 Amount and cost per unit of variable input cost for spring wheat grown in the PNW.

Soft White Spring Wheat	Unit per Acre	Unit	Cost per Unit	Cost per Acre
Fertilizer ($ acre):				
Nitrogen	80	lb.	$0.63	$50.40
Phosphorous	15	lb.	$0.72	$10.80
Potassium	20	lb.	$0.50	$10.00
Sulfur	10	lb.	$0.30	$3.00
Total				$74.20
Seed Cost ($ acre):	80	lb.	$0.27	$21.60
Pesticides ($ acre):				
Roundup	24	oz	$0.23	$5.52
Surfactant	6.4	oz	$0.20	$1.28
Ammonium Sulfate	1.7	lb	$0.21	$0.35
Axial	8.2	oz	$1.12	$9.18
Brox M	12	oz	$0.27	$3.24
Starane	8	oz	$0.62	$4.96
InPlace	5	oz	$0.02	$0.10
Ammonium Sulfate	3.2	oz	$0.02	$0.06
Total				$24.69
Fungicides ($ acre):				
Quilt	7	oz	$1.48	$10.36
Syltac Sticker	0.5	pt	$6.25	$3.13
Total				$13.49
Custom Aerial ($ acre):	1	acre	$8.95	$8.95

† Cost per units were generated using the 2014 Northern Idaho Enterprise Budget.

Table 5.A12 Amount and cost per unit of variable input cost for barley grown in the PNW.

Barley	Unit per Acre	Unit	Cost per Unit	Cost per Acre
Fertilizer ($ acre):				
Nitrogen	80	lb.	$0.63	$50.40
Phosphorous	15	lb.	$0.72	$10.80
Sulfur	10	lb.	$0.30	$3.00
Total				$64.20
Seed Cost ($ acre):	85	lb.	$0.26	$22.10
Pesticides:				
Roundup	24	oz	$0.23	$5.52
Surfactant	6.4	oz	$0.20	$1.28
Ammonium Sulfate	1.7	lb.	$0.21	$0.35
Axial	8.2	oz	$1.12	$9.18
Starane Flex	22	oz	$0.62	$13.64
Total				$29.97

† Cost per units were generated using the 2014 Northern Idaho Enterprise Budget.

Table 5.A13 Amount and cost per unit of variable input cost for peas grown in the PNW.

Peas	Unit per Acre	Unit	Cost per Unit	Cost per Acre
Fertilizer ($ acre):	-	-	-	-
Seed Cost ($ acre):	200	lb.	$0.38	$76.00
Pesticides ($ acre):				
Pursuit	3	oz	$3.48	$10.44
Prowl	24	oz	$0.25	$6.00
Ammonium Sulfate	50	oz	$0.02	$1.00
Surfactant	1.5	oz	$0.20	$0.30
Imidan 70	1	lb	$12.91	$12.91
Dimethoate	0.3	pt	$4.88	$1.61
Far-Go	1	qt	$5.56	$5.56
Total				$37.82
Custom Aerial ($ acre):	1	acre	$8.95	$8.95

† Cost per units were generated using the 2014 Northern Idaho Enterprise Budget.

Table 5.A14 Amount and cost per unit of variable input cost for spring lentils grown in the PNW.

Spring Lentils	Unit per Acre	Unit	Cost per Unit	Cost per Acre
Fertilizer ($ acre):	-	-	-	-
Seed Cost ($ acre):	45	lb.	$0.41	$18.45
Pesticides ($ acre):				
Pursuit	3	oz	$3.48	$10.44
Prowl	24	oz	$0.25	$6.00
Ammonium Sulfate	50	oz	$0.02	$1.00
Surfactant	1.5	oz	$0.20	$0.30
Dimethoate	0.3	pt	$4.88	$1.61
Far-Go	1	qt	$5.56	$5.56
Total				$24.91
Custom Aerial ($ acre):	1	acre	$8.95	$8.95

† Cost per units were generated using the 2014 Northern Idaho Enterprise Budget.

Table 5.A15 Amount and cost per unit of variable input cost for garbanzos grown in the PNW.

Garbanzos	Unit per Acre	Unit	Cost per Unit	Cost per Acre
Fertilizer ($ acre):	-	-	-	-
Seed Cost ($ acre):	130	lb.	$0.60	$78.00
Pesticides:				
Pursuit	3	oz	$3.48	$10.44
Prowl	24	oz	$0.25	$6.00
Ammonium Sulfate	50	oz	$0.001	$0.06
Surfactant	1.5	oz	$0.20	$0.30
Far-Go	1	qt	$5.56	$5.56
Total				$22.36
Custom Aerial ($ acre):	1	acre	$8.95	$8.95

† Cost per units were generated using the 2014 Northern Idaho Enterprise Budget.

Table 5.A16 Value of Production in Montana in 2014.

Commodity	Acres	Yield	Price per Unit	Return
Canola	61,000	1380 lb/a	$0.17	$234.60
Spring Wheat	2,980,000	35 bu/a	$6.05	$211.75
Winter Wheat	2,240,000	41 bu/a	$5.80	$237.80
Barley	770,000	58 bu/a	$5.40	$313.20
Peas	504,000	1,800 lb/a	$0.11	$198.00
Lentils	-	-	-	-
Garbanzos	31,200	1,520lb/a	$0.28	$425.60

† Wheat totals includes spring Durum.

† Source: NASS, 2014

Table 5.A17 Value of Production in Oklahoma in 2014.

Commodity	Acres	Yield	Price per Unit	Return
Canola	155,000	620lb/a	$0.15	$93.00
Spring Wheat	-	-	-	-
Winter Wheat	2,800,000	17bu/a	$6.45	$109.65
Barley	-	-	-	-
Peas	-	-	-	-
Lentils	-	-	-	-
Garbanzos	-	-	-	-

† Winter wheat only grown in Oklahoma.

†Source: NASS, 2014

Table 5.A18 Value of Production in North Dakota in 2014.

Commodity	Acres	Yield	Price per Unit	Return
Canola	1,190,000	1,800lb/a	$0.17	$306.00
Spring Wheat	6,140,000	47.5bu/a	$5.45	$258.87
Winter Wheat	555,000	49bu/a	$4.55	$222.95
Barley	535,000	67bu/a	$5.20	$348.40
Peas	255,000	2,130lb/a	$0.11	$234.30
Lentils	66,000	1,200lb/a	$0.21	$252.00
Garbanzos	6,200	1,230lb/a	$0.29	$356.70

† Wheat totals includes spring Durum.

†Source: NASS, 2014

Table 5.A19 Value of Production in Washington in 2014.

Commodity	Acres	Yield	Price per Unit	Return
Canola	47,000	1,200lb/a	$0.18	$216.00
Spring Wheat	610,000	38bu/a	$7.30	$277.40
Winter Wheat	1,640,000	52bu/a	$6.45	$335.4
Barley	105,000	60bu/a	$3.25	$195.00
Peas	88,000	1,900lb/a	$0.15	$285.00
Lentils	50,000	1,100lb/a	$0.30	$330.00
Garbanzos	89,000	1,150lb/a	$0.32	$368.00

† Wheat totals includes spring Durum.

†Source: NASS, 2014

Table 5.A20 Value of Production in Oregon in 2014.

Commodity	Acres	Yield	Price per Unit	Return
Canola	10,000	1,500lb/a	$0.19	$285.00
Spring Wheat	78,000	55bu/a	$7.30	$401.50
Winter Wheat	740,000	48bu/a	$6.75	$324.00
Barley	30,000	50bu/a	$3.20	$160.00
Peas	8,500	2,200lb/a	$0.11	$242.00
Lentils	-	-	-	-
Garbanzos	1,100	1,360lb/a	$0.40	$544.00

† Wheat totals includes spring Durum.

†Source: NASS, 2014

Table 5.A21 Value of Production in Idaho in 2014.

Commodity	Acres	Yield	Price per Unit	Return
Canola	34,000	1,800lb/a	$0.16	$288.00
Spring Wheat	455,000	76bu/a	$6.45	$490.20
Winter Wheat	730,000	80bu/a	$6.00	$480.00
Barley	510,000	94bu/a	$4.90	$460.60
Peas	44,000	1,800lb/a	$0.14	$252.00
Lentils	24,000	1,100lb/a	$0.29	$319.00
Garbanzos	73,000	1,320lb/a	$0.32	$422.40

† Wheat totals includes spring Durum.

†Source: NASS, 2014

Table 5.A22 Summary of variable input cost of spring canola, pea, lentil, garbanzos, spring wheat and barley produced in the dryland region of the PNW per acre.

	Spring Canola	Pea	Lentil	Garbanzos	Spring Wheat	Barley
Fertilizer ($ acre^{-1}):	$41.23	-	-	-	$74.20	$64.20
Seed Cost ($ acre^{-1}):	$45.32	$76	$18.45	$78	$21.60	$22.10
Herbicides ($ acre^{-1}):	$5.99	$37.82	$24.91	$22.36	$24.69	$29.97
Insecticides ($ acre^{-1}):	$67.87	-	-	-	-	-
Fungicides ($ acre^{-1}):	-	-	-	-	$13.49	-
Custom Aerial ($ acre^{-1}):	$8.95	$8.95	$8.95	$8.95	$8.95	-
Variable input cost	$169.36	$122.77	$52.31	$109.31	$142.93	$116.27

† Cost per units were generated using the 2014 Northern Idaho Enterprise Budget.

† DKL 30-42-RR at a low seeding rate, with 150lb of fertilizer was used for the spring canola.

Table 5.A23 Summary of variable input cost of winter canola and winter wheat produced in the dryland region of the PNW per acre.

	Winter Canola	Winter Wheat
Fertilizer (\$ acre^{-1}):	\$54.98	\$81.30
Seed Cost (\$ acre^{-1}):	\$31.24	\$24.30
Herbicides (\$ acre^{-1}):	\$3.30	\$32.38
Insecticides (\$ acre^{-1}):	\$67.87	-
Fungicides (\$ acre^{-1}):	-	\$23.85
Custom Aerial (\$ acre^{-1}):	\$8.95	\$8.95
Custom Swathing (\$ acre^{-1}):	\$18.33	-
Variable input cost	\$184.67	\$170.78

† Cost per units were generated using the 2014 Northern Idaho Enterprise Budget.

† Amanda at an intermediate seeding rate with 200 lb. N acre^{-1} of fertilizer.

Appendix B: Chapter 6: Canola Grower Cultural Practices Survey 2013-2014

SURVEY PART 1: *Planting Survey:*

Crop History

(1) Have you raised canola in the past? Winter: Yes ☐ No ☐ Spring: Yes ☐ No ☐

(2) What is your normal crop rotation? ________________, ____________________, ____________________, ____________________, ________________________.

(3) What crop preceded this year's Canola? ____

(4) What herbicide(s) were used on this previous crop? ______________________________

(5) Soil type? sandy loam ☐ silt loam ☐ clay loam ☐

(6) pH range? _____________

(7) Do you irrigate your canola? Yes ☐ No ☐

(8) What is your average annual rainfall (inches)? (7-10) (10-13) (13-16) (16-19) (19-22) (<22)

Current Crop Information

(9) What type of fertilizer did you use?

☐ Anhydrous Ammonia ☐ Ammonium Nitrate

☐ Ammonium Sulfate ☐ Urea

Other: _________________________

Rate of Nutrient Inputs

Nutrients	Soil Residual	Pre-Plant (lb/a)	Post Plant (lb/a)
N			
P			
K			
S			
B			

Planting Information

Type Winter; Spring	CV Name	Type RR=Roundup Ready; LL=Liberty Link; CF=Clearfield; T=Traditional	Tillage Conventional; Min. Till; No Till	Pre-Plant herbicide Treflan; Roundup; Other?	# of Acres Planted	Location of Field(s) GPS	Planting Date	Seeding Rate	Planting Depth	Row Spacing

SURVEY PART 2: *Midseason Survey*:

Weed Control

Weeds	Infestation Rate High; Med; Low	Name of Chemical(s) Used	Application Date(s)	Was your weed management effective?
Grasses				Yes ☐ No ☐
Broadleaves				Yes ☐ No ☐

Insect Control

Insects FB=flea beetle CSW=cabbage seedpod weevil A=aphid DBM= diamond back moth or Other:____________	Infestation Rate High; Med; Low	Name of Chemical(s) Used	Application Date(s)	Was your insect management effective?
				Yes ☐ No ☐
				Yes ☐ No ☐
				Yes ☐ No ☐
				Yes ☐ No ☐
				Yes ☐ No ☐

Disease

Diseases S=Sclerontinia or Other:_________	Infestation Rate High; Mid; Low	Chemical(s) Used if any	Application Date(s)	Was your disease management effective?
				Yes ☐ No ☐
				Yes ☐ No ☐
				Yes ☐ No ☐

Midseason Fertilizing

Type of Fertilizer	Fertilized date/Stage of growth

SURVEY PART 3: *Harvest Survey:*

Pre Harvest

(1) Harvest Date: ____________________________

(2) Pre Harvest Practice: Swath ☐ Push ☐ Neither ☐

(3) Did you apply a desiccant pre-harvest? Yes ☐ No ☐

(4) Did you apply a pod sealant pre-harvest? Yes ☐ No ☐

Fields Harvested

Type Winter; Spring	CV Name	Type RR=Roundup Ready; LL=Liberty Link; CF=Clearfield; T=Traditional	# of acres planted	# of acres harvested	Yield lbs/acre	What crop will follow your Canola?

Problems encountered

What gave you the most problems growing canola?	Rank top 3 problems
Planting	
Establishment	
Fertility	
Weed control	
Insects	
Disease	
Harvesting	
Marketing	
Other:________________	

(5) Will you consider raising canola next year? Yes ☐ No ☐

(6) If yes will you plant: same acres ☐ more acres ☐ less acres ☐ undecided ☐

Canola Sample

Sending a sample for quality analysis? Yes ☐ No ☐

Return Address if different from already provided:

____

City: _____________________ State: _________________ Zip: ________________