POTENTIAL OF INCLUDING COVER CROPS INTO DRYLAND WINTER WHEAT CROPPING SYSTEMS IN NOTHERN IDAHO

A Thesis

Presented in Partial Fulfillment of the Requirements for the

Degree of Master of Science

with a

Major in Plant Science

in the

College of Graduate Studies

University of Idaho

by

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May 2016

Authorization to Submit Thesis

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Abstract

Cover crops have potential to provide multiple benefits in a cropping system. There is a renewed interest in these crops due to their role in reducing chemical inputs and improving soil quality. However, there have been mixed results in the effectiveness of cover crops to prevent erosion, improve soil's physical and biological properties, supply nutrients, suppress weeds, improve the availability of soil water, and break pest cycles along with various other benefits. The objective of this study is to examine the effects of growing a variety of spring planted cover crops compared to spring seed crops (i.e. canola, wheat, barley, and pea) and their impact on subsequent winter wheat production and profitability. Factors examined include soil fertility, soil moisture, plant biomass, yield from seed crop, and following wheat crops. Results provide information for growers to determine the economic, environmental, and sustainable feasibility of utilizing cover crops in the dryland regions of Northern Idaho.

Acknowledgements

I would like to express my sincere gratitude to my advisor Jack Brown for his continuous support of my master's degree and related research, for his patience, motivation and flexibility in working through this process with me long distance.

Besides my advisor, I would like to thank the rest of my thesis committee: Dr. Kurtis Schroeder and Dr. Kathleen Painter for their support.

This research would not have been possible without the help of the Canola breeding program including Jim Davis, Megan Wingerson, and Bradley Pakish. As well as my fellow graduate students Katie Reed, Pedee Ewing, and Cole Senefsky for their help and support the last two years. I'd also like to thank undergraduates Bailey Luna, Samantha Wright, James Ihli, and Ashley Job.

I would like to thank my amazing family: my parents Cris and Randy McClintick for always encouraging me to further my education, Jordan and Evan Chess for their support, Camie and Utahnna Andersen, Fred and Jan Jones, Marguerite Wavra, and Janelle and Norbert Niehenke for their hospitality through my field research. Without the love and support of these people I wouldn't have made it this far. Last but not least, my husband Frank Friddle who has been my rock through this process, thank you for always being by my side and encouraging me every day to follow my dreams.

Dedication

This thesis is dedicated to farmers around the world who work in acres, not hours. Thank you for the food on our tables, the clothes on our backs, and giving me the opportunity to do this research.

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Chapter 1:

Introduction

Cover crops have the potential to provide multiple benefits in a cropping system. There is a renewed interest in these crops due to their role in reducing chemical inputs and improving soil quality. Different climates, management practices, and rotations determine which cover crops can provide the most benefits to a cropping system. Increased organic matter would be especially important to farmer's practicing conventional tillage. Deep taproots provided by many cover crops, break up plow pans and utilize nutrients deep in the soil profile. Erosion is a common problem in heavily tilled farming regions; cover crops provide increased organic matter and deep root systems to help hold the soil in place. Where monoculture systems are prevalent cover crops could provide rotational benefits. In the Pacific Northwest where cereal crops are pre-dominantly grown, there is a need for broadleaf rotation crops.

Despite these benefits, a very small percentage of Pacific Northwest acreage is dedicated to cover crops. There have been mixed results in the effectiveness of cover crops to prevent erosion, improve soil's physical and biological properties, supply nutrients, suppress weeds, improve the availability of soil water, and break pest cycles. The operating costs associated with growing cover crops and lack of crop return during that growing season may not be economically possible for many growers. Concerns over soil moisture and nutrient depletion are common.

Research pertaining to cover crops in the Pacific Northwest is very limited. This research will explore cover crops options available to growers in the dry land Pacific Northwest. The specific objectives for this research include:

1. Determine the basic economics of growing a range of cover crops and compare the results to spring canola, wheat, barley, and pea production.
2. Determine the environmental and rotational effects of cover crops compared to spring seeded cash crops by examining soil health parameters and productivity of subsequent winter wheat crops.

Chapter 2:

Literature Review

2.1 Pacific Northwest Climate

Although the Pacific Northwest (PNW) can be compared to other dryland climates in the United States it is unique in many ways. Dryland cropping can be defined as that practiced where average annual precipitation is 60 cm or less, and irrigation is not used (Schillinger *et al.*, 2006). The PNW semiarid Mediterranean-like climate is dominated by winds and weather fronts from the Pacific Ocean (Schillinger and Papendick, 2008). Other low rainfall regions of the United States receive the majority of their rainfall throughout the summer growing season. In the PNW the majority of precipitation is received during the winter months. About two-thirds of the PNW precipitation occurs between October and March with about one-third of that coming as snow. A quarter of the annual precipitation occurs between the months of April and June, with July through September being the driest months (Schillinger and Papendick, 2008). Water is therefore a limiting factor in this region during the growing season. However, deep soil with good water holding capacity allows for the production of both spring and winter crops in the higher rainfall region of northern Idaho. Dryland areas that receive low winter precipitation, like the PNW, do not have active plant growth during the time when most of the precipitation is received (Unger *et al.,* 2006).

2.2 Dryland Agriculture in the Pacific Northwest

The dryland cropping region in the inland PNW includes eastern and central Washington, the Idaho panhandle, eastern and north-central Oregon, the intermountain region of southeastern Idaho, northern Utah, and western Montana, where an approximate 4,380,000 ha of land is devoted to dryland cropping (Schillinger *et al.,* 2006).

Dryland wheat farming has only been practiced in the PNW for about 100 years, while it has been common place worldwide for centuries (Granatstein, 1992).

Dryland agriculture in the PNW is divided into three systems: (1) low precipitation; (2) intermediate precipitation; and (3) high precipitation. The low precipitation (less than 30 cm annual precipitation) dryland cropping region in east-central Washington and north-central Oregon covers 1,556,421 ha, and is one of the largest cropping zones in the western United States (Schillinger *et al.,* 2003). The low precipitation region is limited to a winter wheat-fallow rotation where the fallow in the rotation is necessary to preserve soil moisture content for following winter wheat crops. The PNW intermediate (30-45 cm annual precipitation) region is composed of 971,246 ha of crop production (Schillinger *et al.,* 2003). Crop rotations in the intermediate rainfall region are similar to that in the low precipitation region, and crop-fallow is common. However, sufficient spring precipitation can allow for continuous cropping, including spring wheat (*Triticum ssp.*), barley (*Hordeum vulgare*), Indian mustard (*Brassica juncea*), and camelina (*Camelina sativa).*

The high rainfall region (greater than 45 cm annual precipitation) is the smallest with 819,448 ha of crop production. In the high rainfall region growers have more spring planted rotation crop options with the primary crop of winter wheat (Schillinger *et al.,* 2003). In this higher precipitation region growers usually have the option to include winter and spring wheat, barley, spring grain legume crops such as peas (*Pisum sativum*), lentil (*Lens culinaris*), and garbanzo beans (*Cicer arietinum*), and the spring *Brassica* crops canola (*B. napus*) and Indian mustard.

2.3 Crop Rotations

Winter and spring wheat became the dominant crops throughout the dryland PNW, when it became apparent that it could be grown profitably over a range of climates and soil conditions (Schillinger and Papendick, 2008). In this region both soft white and hard red winter and spring wheat cultivars are grown (Schillinger *et al*., 2006).

Crop rotations in the higher precipitation regions of the PNW are generally more varied than the intermediate or low precipitation regions, and although cereal grain crops (wheat and spring barley) are predominant, legumes (pea, lentils or garbanzo bean) and spring canola are common rotation options. A popular 3-yr rotation is legume-winter wheat-spring wheat, because winter wheat yields following a legume crop are 10% to 20% higher than winter wheat yields following a spring cereal crop (Guy and Gareau, 1998). Four-year rotations in this region include winter wheat-spring wheat-barley-legume or winter wheat-spring wheat-barley-canola. Winter wheat is always the primary crop, as it is usually the most profitable and reliable crop. Alternative crops are barley or spring wheat (approximately 40%), peas, lentils, or garbanzo beans (another 40%), and alternative crops, including canola, grass seed or fallow (20%) (Papendick, 1996). Growers in the region want to increase the intensity of cropping, for example by decreasing the frequency of fallow, and reduce or eliminate tillage (Schillinger *et al*., 2008).

2.4 Cereal Crop Overview

Over two-thirds of all major food crops are grain cereals (Hancock, 2004). Cereal crops are the primary crop grown in the Palouse region of northern Idaho. Since the 1800’s, when grasslands in this region were cultivated for farming the system has been almost exclusively a tillage-based wheat-fallow system, where fallow is common and only one crop is grown every second year (Shillinger *et al.*, 2006). Plant breeding has played a huge role in creating the superior cereal cultivars we produce today. Modern cereal cultivars usually have shorter structure (dwarf or semi-dwarf) which can be grown at higher fertility rates without lodging, significantly higher seed yield with better harvest index, and have better disease resistance (Deshpande, 1991). Wheat cultivars in the United States are classified as hard or soft. Soft wheat will, when ground, return relatively large quantities of finely granulated flour, while hard wheats yield a more course product when processed under similar conditions. Hard wheats produce products such as bread, rolls, and bagels. Soft wheats produce crackers, cookies, cakes, and muffins (Smith, 1995).

2.5 Cereal Crops

2.5.1 Wheat (Triticum ssp.)

Wheat is one of the oldest domesticated crops. The wild predecessor of wheat thrived throughout the Fertile Crescent of the Middle East, where it was first domesticated about 10,000 years ago along with barley and several pulses, these crops were selected for non-shattering, and larger seed forms (Harlan and Zohary, 1966). Feldman (2001) has estimated that over 17,000 different wheat varieties have been developed. Wheat is the mainstay food source in many world regions and is very diverse in end-use products. Hard wheat produces flour that contains a high percentage of gluten and is often used to make breads and cakes. Durum wheat the hardest-kernelled wheat is used to produce pasta products. White and soft wheat are paler in color and have starchy kernels, flour produced from these varieties are preferred for biscuits and pie crusts. Alternative uses for wheat include whiskey, beer, bran, and use of the plant as livestock feed (Karvy and Comtrade, 2010).

2.5.2 Barley (*Hordeum vulgare L.*)

Barley (*Hordeum vulgare*) was first domesticated in the same region and around the same time period as wheat, around 10,000 years ago (Salunkhe and Deshpande, 1991). Hancock (2004) has suggested that pre-farmer gatherers collected wild barley with easily shattered seeds about 9,000 years before early farmers were cultivating non-seed shattering types in what is now Syria. Early peasant farmers and modern-day plant breeders have genetically altered barley into the cultivars we propagate today. These cultivars are grown across temperate climates and mainly used for making beer and livestock feed (Simmonds, 1995).

2.6 Legume Crops

With 20,000 different species, legumes are the third largest family of advanced crops behind cereals (Pratap, 2011). Common legume crops grown in the PNW include garbanzo bean, pea, and lentil. These three legume crops also are important throughout the world for sustainable agricultural production especially in areas where double cropping is common to provide nutrition and food security to increasing human populations (Chaturvedi *et al*., 2011).

Legume crops are often grown in rotation with cereal crops. In general, broadleaf crops usually increase yield of subsequent cereal crops, but identifying the specific cause of this yield increase has been difficult. Including legumes in a crop rotation can be particularly beneficial to following crops. Wright (1990) compared three legume crops, peas, lentils and fava bean (*Vicia faba* L.) for impact on following barley yields in Saskatchewan, Canada, and found that barley responded equally to the each of the preceding crops, yielding 21% more than continuous barley production.

2.6.1 Origin of Legume Crops

Garbanzo beans (*Cicer arietinum*) were likely first domesticated and associated with the development of grain crops that occurred in the Fertile Crescent in the Near East (Hancock, J. 2004). There is evidence of garbanzo bean domestication from small carbonized seeds that were discovered in Turkey and Syria around 9,000 to 10,000 years ago (Zohary and Hopf, 1993; Ladizinsky, 1995). World garbanzo bean production has increased over the past 30 years from 6.6 million Mt to 10 million Mt. South Asia accounts for more than 75% of the world garbanzo bean production area. Garbanzo beans are a highly nutritious grain legume crop and are one of the cheapest sources of protein. Garbanzo beans can be eaten raw, roasted, or boiled. Garbanzo beans can also be processed into flour or de-hulled grain (CGIR, 2012).

Neither the wild progenitor nor the early history of the pea (*Pisum sativum*) crop is known. Excavations of Neolithic settlements (*ca.*7,000 B.C.) in the near east and Europe have revealed carbonized pea seeds which suggested that Ethiopia the Mediterranean and Central Asia was the original center of origin for pea, with a secondary center of diversity in the Near East (Vavilov, 1949).

Genetic stock from which lentils (*Lens culinaris*) were domesticated is represented by three lines collected from Turkey and northern Syria. The pattern of migration of lentils across Asia and Europe closely matches that of important grain species and other legume crops, lentils are thought to have arrived in Spain and Germany 6,000-7,000 years ago (Hancock, 2004).

2.7 Canola

The diverse genus of *Brassica* has given us the oil-seed rape (rapeseed or canola, *B. napus* and *B. rapa*) (Hancock, J. 2004). It is uncertain whether or not *B. napus* exists in a truly wild form, but if it does, it would be in the European-Mediterranean region where the diploid ancestors of the allotetraploid *B. napus,* (*B. oleracea,* and *B. rapa*) can be found growing in the same environments (McNaughton, 1974). Oilseed rape has been grown as an oil-seed crop in Europe since at least the Middle Ages, however it is unclear as to exactly which specific *Brassica* was grown (Appelqvist and Ohlson, 1972).

2.8 Problems with current cropping system

2.8.1 Monoculture system

Continuous small-grain cereal production, with limited rotational crop options can have negative effects on farm sustainability. In rain-fed agriculture, specifically semiarid regions, a continuing problem for producers is unpredictable precipitation resulting in subsequent yield variability (Baumhardt and Andersen, 2006). Baumhardt and Andersen (2006) found that crops in rotations which include more diversified crops improve crop yields and water-use efficiency. In continuous wheat production systems water and wind erosion can increase due to lack of plant biodiversity and crop residue. Water erosion is a particular problem in the PNW where farming is commonly performed on up to 30% slopes with some slopes as steep as 45% (Bussacca, 1991).

Grassy weed infestations can be severe in continuous cereal production systems and can increase the need for herbicide applications.

2.8.2 Winter & spring wheat

Both winter and spring wheat crops predominant in the PNW and wheat following wheat in rotations are common. The growing period of winter and spring crops generally determines what other crops can be grown in rotation.

2.8.3 Proportion of production

The main dryland seed crop grown in the PNW is winter wheat. In the higher rainfall regions spring wheat, barley, canola, pea, garbanzo bean, and lentil are grown in rotation with winter wheat. In 2015 in the state of Idaho, 485,623 ha^{-1} was planted to wheat, followed by 234,718 ha^{-1} of barley (Table 2.1). In Oregon, wheat was also planted on highest area 337,913 ha^{-1} followed by 19,830 ha^{-1} of barley. In Washington 1,044,088 ha^{-1} of land was planted to wheat in 2015, again followed by barley at 44,515 ha^{-1} (NASS, 2015).

The top five wheat producing countries in the world are India, China, United States, Australia, and Kazakhstan (Table 2.2). In 2004 the top five barley producing countries in the world were Russia, Ukraine, Canada, Australia, and Turkey (Table 2.3) and the top five oilseed producing countries in the world in 2004 were the United States, India, China, Brazil, and Argentina (Table 2.4) (USDA NASS, 2015).

2.8.4 Fallow

Crop fallow is a common practice in the lower rainfall regions of the PNW where winter rains are conserved in fallow ground to ensure sufficient soil moisture to sustain a crop the following year. Fallow is also used to ensure moisture in the seed planting zone in the fall.

Use of synthetic fertilizers has caused fallow acreage to increase in turn simplifying rotations (Meisinger, 1991). Fallow and the tillage associated with fallow decrease soil quality over time by loss of organic matter aggregates (Peterson *et al*., 1993; Unger, 2001). Mechanical fallow management requires several cultivations to reduce weeds resulting in bare ground with little crop or plant residue which increases soil erosion by wind and water (Unger *et al*., 2006).

Although fallow management is designed to preserve soil moisture for crop production, a negative consequence of winter wheat- fallow rotations occurs as a substantial amount of water is wasted by either high evaporation from bare soils, or by water percolation deep in the soil profile and not being accessible to the shallow fibrous roots of wheat plants (Baumhardt and Anderson, 2006; Unger *et al*., 2006). Peterson *et al.*, (1996) estimated that winter wheat in a fallow rotation only utilized about 40% of the annual precipitation.

2.8.5 Soil health

Modern farming practices have trended toward more intensive cropping systems (continuous cereal cropping rotations), less intensive tillage (i.e. conservation tillage, minimum tillage, no-tillage, etc.), and shorter fallow periods. This has been brought about by herbicides for weed control that are effective and economically feasible, advances in planting equipment that allows efficient and precise planting in high residue conditions, and improvement in crop genetics. These changes have been driven by economics, also in part by the realization that farming practices that deplete soil nutrients at a high rate are not sustainable (Schlegel *et al.*, 2013). Low nutrient levels in the soil often lead to the over application of inorganic fertilizers. Nutrients can unintentionally enter surface and ground water through misapplication, movement of treated soils, runoff water from agricultural fields, storm water runoff, and leaching through soil profiles (Mahler *et al.*, 2011). The problems associated with current farming systems can help guide us to determine appropriate solutions for this region.

2.9 Possible Solutions

2.9.1 Management

Conservation tillage is any method of soil cultivation that leaves the previous year's crop, at least 30% of crop residue (such as corn stalks or wheat stubble), on fields before and after planting the next crop to reduce soil erosion and runoff (Minnesota Department of Agriculture, 2016). In the PNW many growers have moved towards conservation or minimum tillage farming to reduce soil erosion, reduce growing costs and make farming more long-term sustainable.

2.9.2 Cover Crops

There has been increasing nation-wide interest in including cover crops into farming systems in the United States. Many claims have been made regarding the benefits (and costs) associated with cover crops in the cereal production systems of the PNW. Many problems associated with a continuous cereal production system are caused by always planting grassy cereal crops. Broadleaf crops in a cereal rotation can increase options for farmers to diversify and manage crop problems (i.e. weeds and diseases). Cover crops have different root systems from fibrous cereal crops, to broadleaves (like canola) which have aggressive taproot systems that can help break up plow pans and may allow better water infiltration.

Cover crops can provide many benefits that may alleviate problems associated with intensive cereal production systems. As previously mentioned there are three different rainfall levels in the PNW, and cover crops may not have equal potential to fit into rotations in each region. For example, in the low rainfall regions it would be highly unlikely that cover crops could replace fallow in the crop rotation. This rotation would likely not be able to manage the loss of moisture that would come with the use of cover crops. However in the intermediate rainfall regions it would be more likely to replace a fallow year, particularly when the cover crop would be terminated before moisture content in the soil was too low to impact establishment of the following crop. In the high rainfall regions, cover crops may be feasible, but would likely need to replace an existing seed crop, and hence the benefit of the cover crop in rotation would need to be weighed against the cost associated with replacing the seed crop.

2.10 Overview of Cover Crops

Cover cropping is the practice of planting a second, unharvested crop in coordination with the cash crop. White, (2014) wrote that “cover crops have been suggested to prevent wind and water erosion, reduce nutrient loss and leaching, and improve general soil health and quality.” Cover crops evolved from the concept of green manure, green manures are non-harvested crops that incorporate green plant material into the soil before crop maturity (Steinhilber, 2013). Most cover crops are classified as winter or summer annuals, which germinate and die in one year or less, while perennials, live for three or more years, each offering a different set of benefits (Ingels, *et al.*, 1997).

2.10.1 History

Legume cover crops are not a new concept and were used by Roman and Greek farmers during the period of the Roman Empire (2,000 years ago) to improve soil quality in vineyards, lupins were grown as green manure crops throughout northern Europe during the same time period (White, 2014). Early European settlers commonly included cover crops in the United States to improve soil fertility, but they were generally abandoned by the late 1950s due to the availability of inorganic fertilizers (Steinhilber, 2013). However, lack of economically viable crop rotations has not been able to address the problem of soil nutrient depletion, nitrogen runoff, and inadequate organic matter. Today's farmers are looking for an alternative to expensive synthetic fertilizers, and cover crops may provide the needed benefits. Cover crop acreage in the United States has increased over the last decade and in 2013 cover crops were planted on 133,124 farms and on 4,168,262 ha^{-1} nationwide (White, 2014)."

2.11 Cover crop species involved

There are many cover crop species options depending on the region and climate, since each region can support an alternative set of cover crops. Many different crop species have been used as cover crops in the past including, but not limited to: clover, vetch, and other legumes (Fabaceae family); grasses (Poaceae family) such as barley and fescues; various *Brassica* crops (Brassicaceae family) and phacelia (Hydrophyllaceae family) (Ingels *et al.,* 1997).

To determine the various potentials and benefits of different cover crop species, mixtures or single species cover crops, field based research is needed.

In the PNW, cover crops options that have been suggested include tropical grasses, and broadleaf crops such as radish, canola, and legumes. In this two-year study we examined six different cover crop options (two of which were species mixtures). Grass species examined were Sudan grass, triticale, pearl millet, foxtail millet, winter wheat and oats. Broadleaf species were Austrian winter peas, winter canola, radish, buckwheat, and turnip. These cover crops were chosen based on their ability to adapt to this region and produce adequate biomass. This study was based on the idea that cover crops could be included in a crop rotation in the high rainfall region of the Palouse.

2.11.1 Brassicaceae cover crops examined

2.11.1.1 Turnip (*Brassica rapa*)

The center of origin of *B. rapa* is thought to be the Mediterranean region, with a secondary center of genetic diversity around Asia Minor (Sinskaia, 1928).

Brassica rapa was likely amongst the first Brassicaceae species domesticated as an oilseed crop (Thompson, 1979) around 4,000 years ago, and developed from wild populations that grew in the region from the Mediterranean to India (McNaughton, 1973). The turnip (root vegetable form) of *B. rapa* was first domesticated about 3,000 years later in northern Europe (Hancock, 2004). Cultivation of oilseed *B. rapa* is thought to have started in Europe in the 13th century (Appelqvist and Ohlson, 1972), where the oil was primarily used as lamp oil.

True turnips (often called forage rape) are important as forage for sheep and cattle, especially in Northern Europe and New Zealand but they are also eaten as a vegetable in many parts of the world. Oil-seed forms, both annual and biennial, are of considerable economic significance (McNaughton, 1972).

2.11.1.2 Rapeseed and Canola (*Brassica napus*)

Brassica napus (oilseed rape, rapeseed or canola) is an allotertraploid species that resulted from a natural cross between *B. oleracea* (n=9, CC genome) and *B. rapa* (n=10, AA-genome) (Olsson, 1960). Rapeseed domestication dates back as early as 2,000 B.C. in India and China (McNaughton, 1972). Rapeseed was a minor crop in Europe since the 13th century and production rose rapidly during the Industrial Revolution where the oil was found to be an ideal lubricant for steam engines. Canola, developed from rapeseed in Canada in the 1960's and 1970's produces seed oil low in erucic acid with reduced glucosinolate content in the seed meal.

2.11.1.3 Radish (*Raphanus sativus L.*)

Radish is an annual or biennial cultivated vegetable. Radish likely originated in the area between the Mediterranean and the Caspian Sea (Crisp, 1995). It is possible that radishes were domesticated in both Asia and Europe. Radish crops were produced in China 2,000 years ago (Li, 1989), and in Japan 1,000 years ago (Crisp, 1995).

2.11.2 Grasses (*Gramineae*)

Grain cereal crops are grown on all continents of the world except Antarctica. Grain cereal crops are the primary food source of most of the world's population. In fact over two-thirds of our major food crops are cereals (Hancock, 2004).

2.11.2.1 Wheat (*Triticum*)

Wheat is one of the oldest domesticated crops by farmers and the history of cultivated wheat and human civilization have been closely interwoven since man's first attempt to farm food

(Feldman, 2001). The wild predecessor of wheat thrived throughout the Fertile Crescent of the Middle East, where it was first domesticated about 10,000 years ago along with barley and several pulses, these crops were selected for non-shattering, and larger seed forms (Harlan and Zohary, 1966; Hancock, 2004). Feldman (2001) has estimated that over 17,000 different wheat varieties have been developed. Wheat is the mainstay food source in many regions of the world and is very diverse in end-use products. Hard wheat produces flour that contains a high percentage of gluten and is often used to make breads and cakes. Durum wheat, the hardest-kernelled wheat, is used to produce pasta products. White and soft wheat are paler in color and have starchy kernels, flour produced from these varieties are preferred for biscuits and pie crusts. Alternative uses for wheat include whiskey, beer, bran, and use of the plant as livestock feed (Karvy and Comtrade, 2010).

2.11.2.2 Barley (*Hordeum vulgare*)

Barley (*Hordeum vulgare*) was first domesticated in the same region and around the same time period as wheat, around 10,000 years ago (Salunkhe and Deshpande, 1991). Hancock (2004) has suggested that pre-farmer gatherers collected wild barley with easily shattered seeds about 9,000 years before early farmers were cultivating non-seed shattering types in what is now Syria. Early peasant farmers and modern-day plant breeders have genetically altered barley into the cultivars we propagate today. These cultivars are grown across temperate climates and mainly used for making beer and livestock feed (Simmonds, 1995).

2.11.2.3 Oats (*Avena spp.*)

The first oat domestication occurred 9,000 year ago in northern Europe. Oat is not thought to have been recognized as an independent crop until 3,000 years ago in Central Europe

(Helbaek, 1959). Oats have had many uses as livestock and human foods. Mostly used for feed grain, but also for pasture, hay or silage (Gibson and Benson, 2002).

2.11.2.4 Triticale (*Triticosecale*)

Triticale is an allopolyploid crop species that was produced simultaneously in research laboratories in Scotland and Sweden by intergeneric hybridization between wheat (*Triticum* spp.) and rye (*Secale* spp.) (*Pers comm.* Jack Brown 2016). Winter and spring triticale types are available, triticale crops are used as either a grain or forage (Larter, 1992).

2.11.2.5 Millet (*Gramineae*)

The origin of millet is uncertain, about 4,000 years ago cultivation of millet probably began in tropical West Africa (D'Andrea *et al.*, 2001). Pearl millet arrived in East Africa by 3,000 B.C. and from there was introduced into India. Two readily available millet species in the United States are foxtail millet (*Setaria italic*) and pearl millet (*Pennisteum typhoides*) these have been suggested for use as cover crops. Foxtail millet is a significant grain crop in areas of south-eastern Europe, North Africa and Asia. It is widely cultivated in India and is the most important millet species in Japan (Smith, 1995). Pearl millet is an important crop in tropical regions of Africa. Flour from millet seed is used to made porridge-like paste, or used for brewing into beer (Kassam, 1976).

2.11.3 Polygonaceae

2.11.3.1 Buckwheat (*Fagopyrum*)

Buckwheat was noted as a crop in Chinese scripts from the 5th and 6th centuries (Hughes and Henson, 1934), and was grown in Europe during the Middle Ages. The grain of the buckwheat plant is generally used as animal or poultry feed, the de-hulled grain is cooked as porridge and the flour is used in pancakes, biscuits, noodles, and cereals (Campbell, 1997).

2.11.4 Legumes

2.11.4.1 Austrian Winter Peas (*Pisum sativum L. ssp. sativum var. arvense*)

According to (Zohary and Hopf, 2011) Austrian winter pea belongs to the early Neolithic grain crop grouping of the Near East. After years of domestication Austrian winter peas, like other legumes, began to retain the pods and seeds on the plants while increasing seed size from 3.5 to 6 mm (Zohary and Hopf, 1966).

2.12 Cover crops

2.12.1 Broadleaf cover crops

Most broadleaf cover crops are legumes which actively fix nitrogen however there are many other important broadleaf cover crop species. Legumes are a good nitrogen source for the preceding cash crop. Legumes can increase nitrogen supplied in the soil and reduce the amount of nitrogen needed for succeeding crop (Pratap, 2011). Brassicaceae crops are nitrogen scavengers which can mine deep soil nutrients and loosen topsoil with their extensive taproots.

2.12.2 Grass cover crops

Most of the commonly used non-legume cover crops are grasses. These include annual cereals (rye, wheat, barley, and oat), or perennial forage grasses such as ryegrass, and warm season grasses like sorghum-Sudan grass. Grass cover crops are most useful for scavenging nutrients, especially nitrogen, left over from a previous crop, reducing or preventing erosion, producing large amounts of residue, adding organic matter to the soil, and suppressing weeds (Clark, 2012). Tropical grasses including Sudan grass provide erosion prevention and long lasting residue.

2.13 Advantages of Cover Crops

2.13.1 Increased organic matter

Low organic matter leads to soil degradation which in turn reduces water and nutrient availability leading to unstable yields and lack of efficiency in fertilizer applications, water, and energy use (Latos, 2009). Soil organic matter is needed for maintaining soil quality, stabilizing soil structure, increasing water holding capacity and nutrient availability (Latos, 2009).

2.13.2 Break up plow pan

Soil compaction reduces root development and hinders nutrient uptake by restricting the depth roots can reach, causing stunted plants, and increased pest and disease problems (Wolfe, 2012). Tap-rooted cover crop species such as radish, turnip, and canola can penetrate compacted soils better than fibrous-rooted species and therefore be better adapted for use as biological tillage (Chen, 2009). In a study comparing forage radish, rapeseed, and rye, soil penetration by forage radish roots were least affected by compaction while roots of the rye cover crop were most inhibited by compaction (Chen, 2009). Sudan grass has been shown to relieve soil compaction in multiyear studies. Sudan grass most effectively alleviated soil compaction while growing the fastest. Sainju *et al.,* (2007) wrote that “besides C and N inputs from aboveground cover crop biomass, belowground biomass (root) forms an extremely important source of C and N to enrich soil organic matter and improve soil quality.”

2.13.3 Provides ground cover

Several grass crops are highly adapted to the PNW environment and provide large above ground biomass, root biomass and good ground cover (Izaurralde *et al*., 1990). Growing high-biomass cover crops such as barley and rye can increase populations of predator mites and other beneficial insects found in the PNW (William, 1992).

2.13.4 Increases availability of nutrients

Legume cover crops fix nitrogen from the atmosphere and supply nitrogen to the succeeding crop, this can reduce the need for additional nitrogen fertilization (Sainju *et al*., 2007). If residue is left on the soil surface barley can improve phosphorus and potassium cycling. Hairy vetch (legume) in a three-year study in Maryland proved to be more profitable than no-till corn after a winter wheat cover crop. Medium red clover (legume) cover crops had an estimated fertilizer replacement value of 29 to 47 kg nitrogen ha^{-1} to the subsequent crop in Wisconsin (Clark, 2012). Legume mixtures such as Austrian winter pea, hairy vetch, and alfalfa can provide 80 to 100% of a subsequent potato crop’s nitrogen requirement. *Brassica* crops that contain high levels of nitrogen are less likely to tie up nitrogen in straw breakdown due to rapid decomposition (Stark, 1995). Broadbent (1984) showed that about 50% of cover crop above ground biomass was mineralized during the following growing season. Buckwheat takes up phosphorus and other minor nutrients otherwise unavailable to crops, these are then slowly released for seceding crops.

2.13.5 Decreases erosion

Growing cover crops can greatly reduce soil erosion by holding soils together and adding greater crop residue. It has been shown (Latos, 2009) that conservation tillage can reduce water runoff by 53% and reduce erosion by 80%.

2.13.6 Allelopathy/reduced need for pesticides

Many species of plants release chemicals to inhibit the germination or growth of other plants competing for resources. This trait is very beneficial and can be used in combination with other benefits provided by cover crops. Brassicaceae seed meal studies have shown decreased weed densities resulting from use of various seed meals. A specific study testing this theory used seed meals produced from *S. alba* 'Ida Gold' (Brown *et al.*, 1997), *B. juncea* 'Pacific Gold' (Brown *et al.*, 2004), and *B. napus* 'Dwarf Essex' to test weed density in tomato. Results showed lowest weed density was observed in *S. alba* amended at a 2 Mt ha^{-1}rate. Weed counts were 31% and 42% lower in the *B. napus* and *S. alba* seed meal amendments applied at 1 Mt ha^{-1} as compared to no amendment control (Maxwell, 2008). Many studies have been conducted to show this relationship between brassicas and multiple weed species. In southern Idaho brassicas have shown to be effective at suppressing root-knot nematode and are more dependable than Sudan grass hybrids (Clark, 2012).

Cereal rye (*Secale cereal*) can be used as a bio herbicide preferably in no-till field conditions to ensure high levels of residue. Cereal rye is a non-host rotation crop for root-knot nematode and other soil borne diseases. Studies have shown that cereal rye uses allelochemicals to inhibit weed seedling growth to grasses and broadleaf weeds such as red root pigweed. Wheat has a smaller allelopathic effect with less biomass than rye**,** however has been shown to control nematodes and broadleaf weeds (Clark, 2012).

Oats have the ability to germinate quickly, outcompete weeds, and produce residue. This residue can hinder germination and growth of many weeds (Clark, 2012). Roots and residue have allelopathic compounds that can prevent weed pressure for weeks. Oats are also less prone to insect problems than wheat or barley.

Crimson clover (*Trifolium incarnatum*) suppresses weeds with thick mulch and supports beneficial insects. Buckwheat (*Fagopyrum esculentum*) is an effective weed suppressant when planted thick mostly suppressing weeds through competition. Sudan-Sorghum (*Sorghum bicolor*) is a warm season grass that reduces verticillium wilt as a green manure, at the same time yield of the following potato crop was also increased in a study by 24 to 38% (Stark, 2008).

2.13.7 Mixtures

Mixtures of two or more cover crops are often more effective than planting a single cover crops species and mixtures have become a popular alternative to single species cover crops. Mixtures of legume and non-legumes might be ideal for supplying both carbon and nitrogen to improve quality, productivity, and reduce nitrogen leaching (Latos, 2009).

When there is uncertainty in choosing a cover crop, mixtures can reduce risk because each crop in the mixture can respond differently to soil types, pests, and weather conditions (Clark, 2012). Mixtures promote plant biodiversity and nitrogen mineralization rates were higher following long-term increases in organic matter (Latos, 2009).

An Ohio State University study included a mixture of rye, hairy vetch, crimson clover, and barley which kept tomatoes weed free for 6 weeks and yielded as well as weed free tomatoes. After termination there was no regrowth of the crimson clover and barley, and very little of the hairy vetch and rye (Creamer *et al.*,1996).

2.14 Disadvantages of Cover Crops

2.14.1 Volunteer cover crops

Good management is key in successfully incorporating cover crops into a rotation. Buckwheat, millet, and triticale set seed quickly; eliminating cover crop volunteers in following wheat crops would need to be managed carefully.

2.14.2 Additional cost

Cover crops often include species not commonly grown in the cropping region, which increases the price of the seed and limits availability. Mixtures are said to be more beneficial since they can provide a wider variety of advantages in one growing season; however, they may cost more and be more difficult to plant. Seed mixtures usually have a lower seeding rate when compared to a single crop planting, however the total seed costs may still exceed the cost of a single crop planting (Clark, 2012).

2.14.3 Depletes soil moisture and nutrients

In the PNW soil moisture content of the soil plays a huge role in overall yield of crop grown. Cover crops that negatively reduce soil moisture levels are unlikely to be cost effective. In addition grass residue from cover crops can be harder to break down therefore nutrients in residue are likely not available for the following crop.

2.14.4 Host for diseases

Introducing new species into a region can provide the host needed to harbor diseases. For example crown and brown rust are associated with annual ryegrass, this can become an infestation in wheat and barley fields (Clark, 2012). Mixtures of legumes and non-legumes can limit choices for use of pesticides (Clark, 2012).

2.15 Need for Research

Cover crops and cover crop rotations are very new to dryland farming in the Pacific Northwest and virtually no research has examined cover crops and how they may fit into rotations in this region. One preliminary study is ongoing on the Camas Prairie, where three treatments are examined, including: (1) fallow (no cover crop) (2) a cover crop mixture (including winter peas, winter oats, common vetch, red clover, and winter lentil) and (3) a cover crop including winter triticale, spring barley, purple top turnip, nitrogen radish, and winter canola (Hart, 2014).This study was planted as a fall-seeded cover crop trial.

Cover crops have often been studied in areas such as the Midwest where the seasons are longer providing the opportunity to study various species of plants with a decreased risk of failure. These studies mostly focus on crops such as rye and hairy vetch and are often grown during the winter months (Presley, 2015). In this study we researched cover crops as an alternative for fallow. A spring planted cover crop trial allowed us to plant a wide array of cover crops that are more likely to survive in this region. Spring planted cover crops also have the opportunity to produce higher levels of biomass. More research will help growers in this area weigh the benefits of cover crops.

A trial was conducted to test the adaptability of spring planted cover crops in the Pacific Northwest. The specific objectives for this research include:

1. Determine the effects of cover crops on soil properties such as soil moisture content, infiltration rate, and nutrient availability.
2. Evaluate establishment, stand, weed presence, and biomass produced by spring cover crops.

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Tables

Table 2.1 Annual crop production for common seed crops in the Pacific Northwest states, Idaho, Oregon, and Washington by acre in 2015 (NASS, 2015).

	Barley	Wheat	Peas	Garbanzo bean	Lentils	Canola
	------------------------------hectares----------------------------					
Idaho	234,718	485,623	20,639	28,327	13,355	11,331
Oregon	19,829	337,913	2,832	404	-	1,740
Washington	44,515	922,683	42,491	30,351	24,281	14,973
Total	299,062	1,746,219	65,962	59,082	37,636	28,044

Table 2.2 Top five wheat producing countries in the world in 2004 (NASS, 2004).

Country	India	China	United States	Australia	Kazakhstan
	---hectares-------------------------------------				
	24,860,000	22,000,000	21,470,000	13,020,000	11,300,000

Table 2.3 Top five barley producing countries in the world in 2004 (NASS, 2004).

Country	Russia	Ukraine	Canada	Australia	Turkey
	---hectares-------------------------------------				
	10,500,000	4,600,000	4,450,000	4,400,000	3,450,000

Table 2.4 Top five oilseed producing countries in the world in 2004 (NASS, 2004).

Country	United States	India	China	Brazil	Argentina
	---hectares-------------------------------------				
	36,040,000	31,790,000	27,870,000	22,780,000	16,250,000

Chapter 3:

Biomass Accumulation of Cover Crops in the Pacific Northwest

3.1 Abstract

Dryland agriculture in the Pacific Northwest is dominated by small grain cereal crops, primarily spring and winter wheat, which occupy over 80% of the planted hectares (USDA-NASS, 2015). Traditional tillage systems combined with few non-cereal crop options can create problems with soil erosion, weed infestations, pest pressure, and a decrease in soil health. Very few non-cereal crop rotations have shown adaptability to the growing environments that prevail in the PNW with the ability to offer growers a comparable economic return compared to wheat rotations. Several researchers have questioned the sustainability of the wheat production systems in the PNW. This has made local growers consider including cover crops in rotation with winter wheat. Including cover crops may provide benefits to subsequent winter wheat performance. The use of cover crops has become an increasingly popular topic of discussion in the last five years. Farmers are looking for an opportunity to decrease nitrogen costs while still supplying their crops with the nutrients they need to produce high quality crops. Cover crops provide farmers with many options depending upon their field situation. In this study we tested cover crops that could provide multiple benefits to fit needs under different situations.

When cover crops are planted in the spring they can provide a large quantity of plant biomass before termination. The environment is also more favorable for planting and establishment, providing the grower with a longer time between planting and termination. Two trials were planted for this study, one in Moscow and the second in Genesee, Idaho, to determine the feasibility of cover crops in the Pacific Northwest. Characteristics analyzed included biomass, soil nutrient content, and crop water use. Visual analysis of cover crops showed that stands were average for each crop except for Austrian winter pea during the first growing season. Seed depth may not have been appropriate and caused a low stand count. Winter wheat cover crops produced significantly higher above ground biomass (2,699 kg/ha^{-1}) compared to other crops examined. The lowest plant biomass was found in the Austrian winter pea plots at 1,800 kg/ha^{-1}. Soil test results showed little variability in residual soil nutrients between cover crops. The lowest total soil residual nitrogen was after winter wheat and mixture #1. Soil test results by depth showed significantly higher levels of nitrate, ammonium, and total nitrogen in the top 30 cm of the soil profile. Soil moisture content post-harvest was higher in the Austrian winter pea plots and mixture #1. Water use efficiency was higher for mixture #1, mixture #2, and radish. The cover crops that provided the most benefits in this study were winter canola and radish.

3.2 Introduction

Cover crops have the potential to play an important role in crop rotations as they provide multiple benefits to soil health and productivity for the following crops in the system. Throughout the history of agriculture farmers have found that alternating crops in a rotation can provide many important benefits including: (1) reduced soil erosion; (2) better soil physical and biological properties; (3) supplying nutrients (4) suppressing weed populations; (5) improved soil moisture; and (6) breaking pest and disease cycles (USDA NASS, 2014). In recent years there has been increased interest in using cover crops in a regular crop rotation. Rotations in this region generally follow four year rotations of winter wheat-spring wheat-barley-legume or three year rotations of winter wheat-spring wheat-legume (Granatstein, 1992).

The majority of cover crop research has been conducted in regions outside of the PNW such as the Midwest and in corn and soybean rotations. Although this research has proved to be educational to people across the United States, there is a shortage of information in regions such as the dryland Pacific Northwest. Due to the climate and tillage methods commonly practiced in this region there are often problems with erosion and nitrogen runoff during seasons of high rainfall. Nutrients can enter surface and ground waters through misapplication, movement of treated soils, runoff from agricultural fields, storm water runoff, and leaching through soils (Mahler *et al.*, 2011). This can be a huge loss for the grower in respect to yield and increased fertilizer costs.

To identify the usefulness of cover crops different factors need to be considered. There are many benefits that can come from using cover crops; looking at these benefits can help determine if they outweigh the disadvantages. The limitations and economic feasibility of using cover crops can determine whether they have the potential to become part of a traditional crop rotation. It is also important to look at the technology and adoption that would be necessary to implement cover crops into a crop rotation.

3.2.1 History of Cover Crop Use

Legume cover crops are not a new concept and were used by Roman and Greek farmers during the period of the Roman Empire (2,000 years ago) to improve soil quality in vineyards, lupins were also grown as green manure crops throughout northern Europe during the same time period (White, 2014). In the United States during the late 1770’s crop rotations became very important since many acres were nutrient depleted due to continuous growth of tobacco. This cycle had to be broken to restore the land and reduce starvation. Due to resistance by growers this practice wasn't widely adopted until the 1860's (Steinhilber, 2014). As time progresses crop rotations have not been able to fully address the problem of nutrient depletion, nitrogen runoff, and adequate organic matter. By the 1860's, cover crops were common practice in United States agriculture, and remained so until the 1950's when cover cropping was abandoned because conventional agriculture turned to inorganic fertilizers (Steinhilber, 2014). Since the 1950's use of cover crops has been further reduced due to the introduction and widespread use of agrochemicals. As fertilizer costs fluctuate based on fuel prices, growers have searched for alternatives. Research pertaining to cover crops is on the rise, to promote sustainability, soil health, and environmental stewardship.

3.2.2. United States Cover Crop Production

Cover cropping is the practice of planting a crop in rotation with the traditional cash crop. White, (2014) wrote that "cover crops have been suggested to prevent wind and water erosion, reduce nutrient loss and leaching, and improve general soil health and quality. The USDA NASS (2014) defines soil quality as the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans. Cover crop acreage in the United States has increased over the last decade and in 2013 cover crops were planted on 133,124 farms and on 4,168,262 ha^{-1} nationwide (USDA, 2013). The majority of this increase has taken place in regions other than the Pacific Northwest. Cover crops in the PNW are now an important topic in soil conservation with the main goal of sustainably maintaining good soil health through years of crop rotation.

3.2.3 Research in the Pacific Northwest

Limited or no cover crop research has been carried out with traditional rotations in the Pacific Northwest region. One preliminary study is currently ongoing in the Camas Prairie (Hart *et al.,* 2014). In Hart's study, three treatments are examined, including: (1) no cover crop as a control, (2) a cover crop mix (including winter peas, winter oats, common vetch, red clover, and winter lentil), and (3) a cover crop including winter triticale, spring barley, purple top turnip, nitro radish, and winter canola. After the cover crops were terminated, spring canola was direct seeded. As of the fall of 2015 no significant differences were found in the spring canola yields following any of the cover crop treatments. Winter wheat was seeded following the canola to evaluate yields and results have yet to be shared. Although this study proves to be useful in learning which winter cover crops can be grown in the Pacific Northwest, there are many other methods that should be tested to determine which season to grow cover crops, the effects on subsequent rotations, and effects on soil moisture.

In theory integrating cover crops into a crop rotation can provide the grower with many benefits. Benefits include increased organic matter, breaking up plow and tillage soil pans, soil moisture, increased availability if nutrients, and decreased erosion (Farm progress, 2012).

3.3 Benefits of Cover Crops

3.3.1 Break up plow pan and tillage soil pans

Soil compaction reduces root development and hinders nutrient uptake, causing stunted plants, and increased pest and disease problems (Wolfe, 2012). In the Pacific Northwest conventional tillage is still common over large acreage and excessive tillage can result in plow and tillage pan layers, which can adversely affect water infiltration and subsequent crop root development. Many suggested cover crops include plant species which have fast growing and aggressive tap root systems, that penetrate deep into the soil profile and can break up these plow and tillage pans. Tap-rooted cover crop species can penetrate compacted soils better than fibrous-rooted species and therefore be better adapted for use as biological tillage (Chen, 2009). In a study comparing forage radish, rapeseed, and rye soil penetration by forage radish roots were least affected by compaction while penetration by rye roots was most inhibited by compaction (Chen, 2009). Sudan grass also has shown to relieve soil compaction in multiyear studies most effectively while growing the fastest. (Clark, 2012).

3.3.2 Increases availability of nutrients

Cover crops can provide additional soil nutrients throughout the growing season and can be beneficial in nutrient cycling. Curran (2006) found that *Rhizobium* bacteria, in a symbiotic relationship with legumes have the ability to convert atmospheric nitrogen (N_2) which is not accessible to plants, into ammonium (NH_4) nitrogen. When the residues of these cover crops high in nitrogen break down mineralization occurs and releases nitrogen and other nutrients, so they can be used by subsequent crops. Medium red clover (legume) has an estimated fertilizer replacement value of 29 to 47 kg nitrogen ha^{-1} in Wisconsin (Clark, 2012). Aside from carbon and nitrogen inputs from aboveground cover crop biomass, belowground biomass (root) forms an extremely important source of carbon and nitrogen to enrich soil organic matter and improve soil quality (Sainju *et al*., 2007). Deep rooted cover crop plants also have the potential to utilize deep soil nutrients which are below the level usually accessible to shallow rooted crops like small grain cereals and might otherwise end up in ground water. These nutrients can be brought back to the soil surface and mineralized to be accessible to following crops. In addition, re-cycling nitrate deep in the soil profile will prevent these nutrients from being leached into the ground water and hence improve water quality.

3.3.3 Decreases erosion

Cover crops provide ground cover during periods when seed crops are not planted and this can greatly reduce water and wind soil erosion. Large biomass residues from cover crops reduce the impact of raindrops that otherwise would detach soil particles and make them prone to erosion. Not only does the above ground growth provide soil protection, but the root system helps stabilize the soil by infiltrating the profile and holding it in place (Curran, 2006).

3.4 Problems Associated with Cover Crop Production

Although cover crops can provide a wide variety of benefits when included as part of crop rotations it is important to consider problems that may be associated with cover crops. Additional grower input cost is perhaps the greatest issue with regards to cover crop production. However, some other negative impacts of cover crop systems include: (1) difficulties associated with planting such as seed mixtures of variable seed size; (2) termination problems, defoliation and incorporation of cover crop biomass, (3) controlling cover crop diseases in plant mixtures; (5) and reduction in yield for the following crop (Dabney, 2001).

A survey of farmers across the United States showed that the top five concerns associated with growing cover crops were: (1) the time and additional labor for planting and increased management; (2) establishing cover crops, particularly in crop mixtures; (3) high cover crop seed cost; (4) selecting specific cover crops suitable for their current farming operation; and (5) the cost of planting and managing (Myers, 2014).

Cover crops need to be managed properly to alleviate any negative outcomes. Extra expenditures include the cost of the cover crop seed as well as labor, time for planting, and specialized or alternative equipment needed to handle the greater amounts of residue present in no-till-systems (Curran, 2006). Buckwheat and millet set seed quickly in the Pacific Northwest limiting the time between planting and termination, which can limit biomass accumulated during that time. Triticale can become a huge problem in the PNW; eliminating it from a field and preventing carryover into a wheat crop would need to be managed carefully.

In this study, field trials were established to test the adaptability of spring planted cover crops in the Pacific Northwest. Six different cover crops (winter wheat, Austrian winter pea, winter canola, radish, cover crop mixture #1 [mixture of triticale, buckwheat, radish, Austrian winter pea, and Sudan grass], and cover crop mixture #2 [radish, turnip, oats, pearl millet, and foxtail millet] were grown in field trials along with four seed crops (spring wheat, barley, canola, and pea) at two locations. Crops were monitored throughout the growing season. Above ground biomass and root biomass (tap root crops only) was recorded on cover crops and seed yield recorded on the seed crops. The following year the complete trial area was planted to winter wheat and harvested separately based on the previous year’s crop.

The specific objectives for this research include:

1. Compare establishment, crop stand, weed presence, above ground and root biomass of different cover crops.

2. Determine the effects of cover crops and seed crops on soil moisture content, water infiltration rate, and nutrient availability.
3. Compare yield potential and crop return of different seed crops (Chapter 4).
4. Determine the effect of cover and seed crops on productivity and profitability of following wheat crops (Chapter 5).

3.5 Materials and Methods

3.5.1 Site characteristics

These studies were conducted under dryland farming conditions in northern Idaho in 2014 and 2015. Two sites were used to evaluate biomass potential of different cover crop options in the PNW region. The first location was the University of Idaho Parker Research Farm in Moscow, Idaho (46°43'N 116°57'W). This location has a Palouse-Latah complex soil type, this soil type has slopes varying from 0 to 25 %. Rainfall was 736 mm in 2014 and 917 mm between the months of January and August in 2015. The second location was the Kambitsch Research Farm near Genesee, Idaho (46°55'N, 116°92'W) which has a Palouse silt loam soil with slopes of 3-7%. The rainfall at Kambitsch was 507 mm in 2014 and 289 mm between the months of January and August in 2015. Monthly rainfall and average temperatures during the field experiments are presented in Table 3.1.

3.5.2 Treatments and Experimental Design

Cover crops included in this study were as follows: (1) winter canola (*Brassica napus*), (2) winter wheat (*Triticum aestivum*),(3) Austrian winter peas (*Pisum sativum L. ssp. sativum var. arvense*), (4) radish (*Raphanus sativus*), (5) Cover crop mixture # 1 [triticale (*Triticosecale*), buckwheat (*Fagopyrum*), radish (*Raphanus sativus*), (6) Austrian winter pea (*Pisum sativum L. ssp. sativum var. arvense*) and Sudan grass (*Sorghum × drummondii*), and (7) mixture # 2 [radish (*Raphanus sativus*), turnip (*Brassica rapa*), oats (*Avena spp.*), pearl millet (*Pennisteum typhoides*), and foxtail millet (*Setaria italic*)], and (8) a not crop/fallow treatment which was not seeded and kept weed-free.

Seeding rates were determined for the cover crops based on germination rate and seed weight. Target seeding rate was 303,514 seeds ha^{-1} for mixtures to ensure good establishment of each variety used in the mixture. Mixture #1 was planted to have a 2:3 ratio of grasses to broadleaves. Mixture #2 was planted to have a 3:2 ratio of grasses to broadleaves. Single variety cover crops were planted to standard rates of this region for example winter canola 'Amanda' was planted at 5.14 kg ha^{-1}, winter wheat 'Brundage 96' was planted at 95 kg ha^{-1}, radish at 10 kg ha^{-1}, and Austrian winter pea at 115 kg/ha^{-1}.

All fields were previously planted to spring barley. Each location was chisel plowed, harrowed, and fertilized with a 50:50 blend of urea (46-0-0) and ammonium sulfate phosphate (16-20-0-15) to give an overall rate of 31-10-0-7.5 applied at 336 kg ha^{-1}, approximately 100 kg of N ha^{-1}. Cover crops were planted using a small plot, single cone six row planter. Rows were spaced 13 cm apart. The sizes of the plots were 3.58 m x 8 m which required three passes of the small plot planter. Planting depth was adjusted as necessary for each crop according to standard planting depths in this region, ranging from 1.25 cm to 5 cm.

Planting dates varied by location and year depending on weather conditions. In the 2014 growing season cover crops were planted at both locations on May 15th after each field was rolled to compact soils. In the 2015 growing season the Genesee location was planted on

May 22nd, the Moscow location was planted on May 20th. *Brassica* species: canola, turnip, and radish were treated with Helix Xtra™ (Syngenta, 2011) at a rate of 15 mL kg^{-1}, to reduce insect pressure and soil fungi effects.

Plants at both locations were sprayed to control flea beetles (*Psylliodes cruciferae*), diamondback moth (*Plutella xylostell*), and aphids (*Aphidoidea*) starting May 29th in 2014 and May 24th in 2015 and reapplied throughout the season as necessary with Warrior II insecticide (Syngenta, 2014). Warrior II was applied at a rate of 116 milliliters per hectare, 0.14 % v/v R-56 surfactant, 206 liters' ha^{-1} solution. Weeds were controlled in fallow plots with Roundup® (Monsanto, 2003), 2-4D (Winfield Solutions, 2003) and crop oil. Roundup was mixed in 7.6 liter batches, with 40 ml of roundup, 60 ml of 2,4-D, and 20 ml of M-90 with the remainder filled with water.

During the first growing season weed pressure was not significant, however during the 2015 growing season weed pressure was high prior to planting and throughout the season. In 2015 a roundup mixture was applied at 1,752 mL ha^{-1} April 19th and April 20th, at both sites, followed by harrowing. In the spring canola 'DKL 30-42' weeds were controlled with a Roundup® mixture of 1,022 mL ha^{-1} Roundup® at 329 L ha^{-1}. Weeds in the spring peas were controlled with a mixture of 1,752 mL ha^{-1} of Basagran, 584 mL ha^{-1} prime crop oil, and 2,336 mL ha^{-1} UAN to produce 235 L ha^{-1}. Wheat and barley were sprayed with 876 mL ha^{-1} of Huskie and 1,241 mL ha^{-1} of Orion to make 890 liters of solution ha^{-1}.

3.5.3 Data Collected

Soil samples were taken twice throughout the season in 30 cm increments extending 120 cm into the soil profile. The first soil sample was taken just before planting, this was a general sample from the trial area. A sample was collected from each plot after cover crop defoliation. Each sample was weighed wet and then dried at 50ºC for two weeks. Both samples were sent to Northwest agricultural consultants in Kennewick, WA for soil analysis. Soil characteristics analyzed included nitrate, ammonium, sulfur, pH, soluble salts, organic matter, phosphorus, and potassium.

Crop establishment was recorded through visual evaluation eight weeks after planting on a scale of 1 to 9, with 9 being associated with the best establishment. Cover crop plant stand and weed counts (plants m^{-1}) were recorded when crop emergence was complete. Stand counts were taken in the most representative area of the plot by counting seedlings from two 1 m rows and 1 m from the plot edge. Two counts were taken from each plot and averaged. Weed counts were taken with a 0.2 m^2 quadrat in the center of the plot. Two counts were taken from each plot and averaged.

Light bar readings were taken four times during the growing season on a monthly basis beginning in mid-June to determine leaf area index. Leaf area index is a dimensionless quantity that characterizes plant canopies. It is defined as the one-sided green leaf area per unit ground surface area (LAI=leaf area/ground area, m_2 m_{-2}).

Above ground cover crop biomass samples were taken at the peak of the growing season approximately 9 weeks after planting using a sickle-bar mower to mow a 1 m^2 area in each plot, 1 m from the plot edge to sustain uniformity. Cover crop fresh weight biomass was weighed in the field using a balance and tripod. Cover crop mixtures were separated into grasses and broadleaves and weighed separately. In addition to bulk fresh weights, sub-samples from each plot biomass were weighed fresh and thereafter air dried at 50ºC for three weeks and re-weighed to determine biomass dry weight and moisture content. Root samples were also taken from crops which produced tap-roots (i.e., winter canola, radish, and turnips). Root samples were collected to a depth of 38 cm. Roots were weighed fresh and then dried at 50ºC for 5 weeks and re-weighed to determine dry weights and root moisture content.

Cover crops were terminated when cover crop plants began to mature and set seed, which was approximately 12 weeks after planting or during the first week of August. Cover crops were defoliated using a 2,4-D, Roundup® mixture combined with a surfactant applied at 1,752 mL ha^{-1}. Two weeks after the herbicide application plots were mowed to a height of 5 cm using a flail mower.

Water infiltration into the soil was then determined from the time it took for 500 ml of water to infiltrate into the ground. An aluminum cylinder at 16 cm in height and 32 cm in diameter was inserted 1 cm into the surface of the soil and 500 ml of water poured into the cylinder and the time recorded when all of the water had completely infiltrated into the soil. Water spread (%) was measured by visually evaluating the percentage circumference of the cylinder where water was observed to spread outwards from the open cylinder rather than percolating into the soil profile. Water spread measure (cm) was recorded as the largest distance from the side of the cylinder to the furthest extent of where the soil was wetted by water.

Post-harvest moisture content, depletion, crop water use, and water use efficiency were calculated using soil sample results. Post-harvest moisture content was calculated by drying down soil samples after harvest. Crop water use was calculated using pre plant moisture and post-harvest soil moisture content. Water use efficiency was calculated using biomass accumulated and soil moisture content during the growing season.

3.5.4 Data Analysis

Statistical Analysis Software (SAS, 2009) was used to analyze the data from this study. The GLM (general linear model) analysis of variance was used within this program. Each set of data that was collected was analyzed separately.

3.6 Results and Discussion

Mean squares from the analyses of variance for seedling stand, crop establishment, weed counts, broadleaf biomass, grass biomass, total biomass and water infiltration of six cover crops (and summer fallow) grown at two locations in two years are shown on Table 3.2. From the analyses, there were significant differences between cover crops for all characters recorded. Year x crop, site x crop and year x site x crop interactions were all significant for seedling stand counts, and total biomass. Similarly some of the crop x environment interactions were significant, but in general these were of lesser overall value compared to the main effect of differences between cover crops. Many interactions were scalar and did not result in changes of relative ranking of the cover crops in the different environments.

3.6.1 Establishment, weed counts, and plant stands

Weed counts, plant establishment and stand counts were significantly higher in 2015 than 2014, and Moscow had significantly higher plant stand counts and establishment scores than Genesee. Similarly, weed infestation counts were significantly higher in Genesee than Moscow.

Highest cover crop seedling stand counts and crop establishment were from winter wheat at both locations and years (Table 3.3). Austrian winter pea seedling stands were low and, peas had the lowest establishment score. Seedling stand counts and crop establishment scores were intermediate for the canola and radish plots. As previously mentioned mixture #1 was planted to have a ratio of 2:3 grasses to broadleaves, however stand counts showed 78% broadleaves to 22% grasses. The broadleaves in this mixture were more competitive than the grasses planted. Weeds were significantly higher in the fallow plots at both locations. In the first year both sites were planted two weeks earlier and in this two week period the weeds were noticeably worse. Highest weed pressure was in fallow, winter canola, Cover crop mixture # 2, and Austrian winter pea.

3.6.2 Cover crop biomass

Broadleaf and grass biomass accumulation was not significantly different between the two growing seasons. However, broadleaf biomass accumulation was significantly higher in Genesee than Moscow, but grass biomass was not significantly different between the two sites (Table 3.4).

Winter wheat cover crop produced significantly higher dry matter above ground biomass (6,499 kg ha^{-1}) than any other crop examined, almost double the total biomass accumulated by the two cover crop mixtures which had the second highest above ground biomass. Radish and winter canola produced similar above ground biomass (2,900 and 3,100 kg ha^{-1}, respectively), while lowest above ground biomass was accumulated by Austrian winter pea.

Highest broadleaf biomass was from radish followed by cover crop mixture #1. It is important to note that in cover crop mixture #1, broadleaves made up 78% of the above ground biomass with the remaining 22% from grasses in the mixture. This mixture was planted as a 3:2 ratio of broadleaf to grass crops, in which the broadleaves appeared more competitive compared to the grasses. In contrast, mixture #2 was planted to a 2:3 ratio of broadleaf to grass crops, and the ratio of broadleaf to grass biomass was close to 1:1, so here the grasses out competed the broadleaf crops.

3.6.3 Root Biomass

Taproot biomass was measured on only radish, and winter canola cover crops and on turnip which was part of mixture #2. Tap root biomass was higher at the Genesee location than at Moscow (Table 3.5). Radish, turnip, and winter canola tap root biomass was 39%, 59%, and 34%, respectively, higher at Genesee than Moscow. Visual representations of the different types of tap roots are shown in Figure 3.1.

3.6.4 Soil test results

Mean squares from the analyses of nitrate, ammonium and total nitrogen in different soil depth after growth and defoliation of six cover crops at two locations and two years are shown in Table 3.6. Fallow plots had significantly higher levels of nitrate (Table 3.7) and total nitrogen (71 kg ha^{-1}) compared to the other cover crops. Fallow ground is never fertilized to reduce costs and weed growth. In this study the higher fallow soil nitrogen was expected as the fallow treatment had nitrogen applied along with the cover crops in the spring. Similarly, highest total soil residual nitrogen was after winter canola, mixture #2, and radish (31, 29 and 26 kg ha^{-1}, respectively) compared to mixture #1 and winter wheat which has lowest total soil nitrogen. There were significant differences in nitrate and ammonium at different soil depth, with marked reduction in ammonium below 30 cm depth (Table 3.8).

3.6.5 Infiltration

The mean squares from the analysis of variance water infiltration showed significant differences between all cover crops and fallow treatment, but there were no significant differences in water infiltration after the six different cover crops. Fallow had a significantly slower infiltration rate when compared to the cover crops. Radish, Austrian winter pea, and winter canola had the fastest infiltration rates but not significantly higher than the other cover crops.

Results from post-harvest soil moisture depletion, crop water use, and water use efficiency are presented in Table 3.10. Post-harvest soil moisture was significantly higher in the fallow plots (16.9%), followed by the Austrian winter pea plots (10.9%), with the lowest being after winter canola cover crop (9.4%). Similarly, soil water depletion was significantly lower in fallow plots. Crop water use was higher for all the cover crops compared to fallow. Water use efficiency was significantly higher for radish, mixture #1, and mixture #2. The lowest water use efficiency was found in the Austrian winter pea plots.

3.7 Conclusions and Recommendations

The potential for cover crops to be included in winter wheat crop rotations depends on the benefits provided to following crops. Most cropping systems might benefit from including cover crops; however, the challenge is deciding which cover crop can best provide these benefits.

In this study winter wheat cover crops should be considered if above ground biomass is of greatest importance. However, including another wheat crop into a system already dominated by wheat would be unlikely to reduce disease or weed infestation. In addition, winter wheat had the worst water infiltration rate, greatest water spread, and lowest soil residual nitrate and total nitrogen levels.

Broadleaf cover crops such as radish and canola provide the opportunity to eliminate grassy weeds and break common pest cycles associated with winter wheat. Among the broadleaf options, radish produced the most biomass, fastest water infiltration rate, and least water spread. Radish, also produced the longest and highest tap root biomass which would control soil compaction. Winter canola produced similar above ground biomass as the mixtures or radish, but reduced tap root biomass.

Both cover crop mixtures produce good plant biomass and water infiltration. It should be noted that managing a cover crop of a single crop species may be easier compared to one where broadleaves and grasses are mixed. In this study some species in the mixtures produced seed set before termination which might cause volunteer problems.

All cover crops used significant amounts of soil moisture and depleted soil moisture markedly relative to the fallow treatment. If soil moisture is the limiting factor in crop productivity it seems unlikely that growers would replace a spring seed crop with a non-harvestable cover crop. However, it will be necessary to determine the positive (and negative) effects of these cover crops on the following winter wheat crops before firm conclusions can be made.

3.8 References

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Tables

Table 3.1 Monthly precipitation and average high and low temperature recorded at the University of Idaho plant Science farms in Moscow and Genesee, Idaho.

	January	February	March	April	May	June	July	August	September	October	November	December	Total
								mm					
Moscow													
2014	70.6	89.2	90.4	57.9	12.5	33.3	14.2	27.7	0.5	3.5	223.7	113.0	736.4
2015	66.3	76.5	88.9	20.3	127.8	13.5	3.0	2.3	146.6	372.1	-	-	917.2
Genesee													
2014	54.6	52.8	78.5	49.0	25.4	30.7	5.8	23.4	11.7	25.7	67.8	81.5	506.9
2015	41.1	73.7	67.6	15.0	62.0	17.0	3.8	8.9	-	-	-	-	289.0
								high and low temperatures					
Moscow								*average C°*					
2014													Average
High	3.7	1.6	10.6	14.7	20.6	22.7	31.9	30.1	25.7	18.8	6.8	4.5	16.0
Low	-2.9	-5.8	-0.2	0.8	4.1	5.5	9.9	10.2	5.9	4.7	-2.4	-2.2	2.3
2015													
High	4.8	10.1	22.8	26.1	21.8	27.8	30.7	30.5	-	-	-	-	21.8
Low	-0.5	0.7	9.4	6.7	5.8	9.0	10.3	9.2	-	-	-	-	6.3
Genesee													
2014													
High	1.9	0.1	8.3	12.0	18.3	20.2	29.5	28.6	23.5	16.7	5.7	3.1	14.0
Low	-3.0	-5.9	-0.8	1.7	6.6	8.8	13.3	13.0	9.4	5.2	-2.6	-2.7	3.6
2015													
High	3.1	7.7	11.6	13.1	19.2	25.6	28.6	28.6	-	-	-	-	17.2
Low	-2.5	-0.2	1.1	1.3	7.2	11.9	13.4	13.4	-	-	-	-	5.7

Table 3.2 Mean squares from the analysis of variance of seedling stand counts, crop establishment, weed counts, broadleaf biomass, grass biomass, total biomass, and water infiltration grown in Moscow and Genesee, Idaho during the growing seasons of 2014 and 2015.

Source	d.f. ^{a}	Stand†	Estab.	Weed	Broad Biomass	Grass Biomass	Total Biomass	Water Infiltration
Year	1	4,709 ***	9.1 ***	6,504 ***	6.3 *	6.6 ^{ns}	1 ^{ns}	-
Rep (Year)	6	183 ^{ns}	2.3 ^{ns}	2,474 ***	1.5 ^{ns}	10.1 ^{ns}	11 ^{ns}	-
Site	1	1,067 ***	11.6 ***	4,699 ***	184.3 ***	0.7 ^{ns}	180 ***	324 ^{ns}
Year*Site	1	152 **	24.1 ***	2,785 ***	155.2 ***	1.2 ^{ns}	211 ***	-
Site*Rep (Year)	6	200 ^{ns}	3.6 ^{ns}	4,017 ***	4.1 *	17.2 ^{ns}	30 ^{ns}	1,005,636 *
Crop	6	25,057 ***	697.1 ***	713 *	275.2 ***	182.2 ***	1,432 ***	9,673,186 ***
Year*Crop	6	7,163 ***	10.4 ***	273 ^{ns}	1.1 ^{ns}	15.7 ^{ns}	61 *	-
Site*Crop	6	1,307 ***	3.2 ^{ns}	799 *	24.1 ***	0.9 ^{ns}	180 ***	2,073,785 **
Year*Site*Crop	6	1,198 ***	6.4 **	397 ^{ns}	19.3 ***	1.7 ^{ns}	103 **	-

d.f^{a}= degrees of freedom

*=.01<P<.05; **=.05<P<0.001;*** =P<0.001; ns=not significant

†stand= seedling stand counts, Estab.=crop establishment, Weed=weed counts, and Broad Biomass= broadleaf biomass; Total Biomass = total above ground biomass; Water Infiltration is time to infiltrate 500 ml of water into the soil.

Table 3.3 Average weed counts, seeding stand counts, crop establishment and water infiltration of six cover crops (and summer fallow). Data are averaged over two sites and two years.

	Stand Count†	Establishment	Weed Count	Infiltration
	---plants m^{-3}---	---1 to 9--	---plants m^{-2}--	--litre min^{-1} --
Austrian Winter Pea	19.94 ^{c}	6.19 ^{c}	10.00 ^{ab}	247 ^{b}
Mixture #1	25.20 ^{b}	7.19 ^{ab}	7.79 ^{b}	335 ^{b}
Mixture #2	28.13 ^{b}	7.19 ^{ab}	9.75 ^{ab}	321 ^{b}
Radish	18.85 ^{c}	7.38 ^{a}	7.75 ^{b}	229 ^{b}
Winter Canola	19.78 ^{c}	6.88 ^{b}	13.00 ^{ab}	279 ^{b}
Winter Wheat	54.19 ^{a}	7.44 ^{a}	7.81 ^{b}	344 ^{b}
Summer fallow	-	-	-	1,334 ^{a}
Mean	23.73	7.04	10.09	
s.e. mean	1.09	0.14	1.69	

†Means within columns with different superscript letters are significantly different ($P<0.05$).

Table 3.4 Broadleaf, grass and total above ground dry matter accumulated from six cover crops over two years and two sites.

Crop	Broadleaf Dry Matter†	Grass Dry Matter	Total Dry Biomass
	---------------------- kg ha^{-1}	-------------------------	
Mixture #1	2,438 ^{b}	1,150 ^{b}	3,488 ^{bc}
Mixture #2	2,578 ^{b}	1,247 ^{b}	3,824 ^{b}
Austrian Winter Pea	1,824 ^{c}	-	1,824 ^{d}
Radish	2,671 ^{ab}	-	2,671 ^{c}
Winter Canola	3,166 ^{a}	-	3,166 ^{c}
Winter Wheat	-	6,674 ^{a}	6,566 ^{a}
Average	2,540	3,000	3,600
s.e. mean	191	190	192

†Means within columns with different superscript letters are significantly different ($P<0.05$).

Table 3.5 Average above ground biomass and taproot biomass and total biomass (above ground plus tap root) produced by radish, turnip and canola in cover crop grown at Moscow and Genesee, Idaho and in 2014 and 2015.

	Moscow			Genesee		
	Above ground Biomass	Tap root Biomass	Total Biomass	Above ground Biomass	Tap root Biomass	Total Biomass
	---------------------------------- g plant^{-1} --------------------------------------					
Radish	0.04	0.05	0.09	0.09	0.37	0.46
Turnip	0.02	0.02	0.04	0.04	0.07	0.10
Canola	0.03	0.00	0.03	0.01	0.20	0.21

Table 3.6 Mean squares from the analysis of variance of nitrate (NO$_3$), ammonium (NH$_4$), and total nitrogen results from soil testing in Moscow and Genesee, Idaho 2014-2015.

Source	d.f. [a]	NO3†		NH4		Total N	
Year	1	7,141.2	**	7.4	ns	7,607.2	***
Rep (Year)	2	2,939.5	*	73.8	ns	3,363.3	**
Site	1	4,644.9	**	1.2	ns	4,802.1	*
Year*Site	1	3,173.5	*	12.1	ns	3,577.0	ns
Site*Rep (Year)	2	400.5	ns	47.8	ns	408.6	ns
Crop	10	44,122.1	***	285.8	ns	43,935.8	***
Year*Crop	10	1,923.7	ns	224.1	ns	3,138.4	ns
Site*Crop	10	6,558.6	*	411.8	ns	8,384.5	*
Year*Site*Crop	10	2,386.3	ns	120.9	ns	1,797.0	ns
Depth	3	32,253.6	***	7,024.1	***	57,816.0	***
Crop*Depth	30	20,670.5	**	966.4	ns	21,788.5	*
Year*Depth	3	14,569.2	***	96.8	ns	16,084.7	***
Site*Depth	3	12,911.8	***	132.3	ns	14,438.7	***
Year*Crop*Depth	30	5,848.7	ns	711.8	ns	7,539.0	ns
Site*Crop*Depth	30	15,389.3	*	1,474.3	ns	18,325.6	*
Year*Site*Depth	3	10,997.8	***	82.7	ns	12,193.6	**
Year*Site*Crop*Depth	16	3,224.0	ns	278.2	ns	3,684.9	ns

d.f.[a]= degrees of freedom

† stand= seedling stand; Estab.=crop establishment.

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

Table 3.7 Nitrate (NO_3), ammonium (NH_4) and total nitrogen (N) in top 120 cm of soil after growing and defoliating different cover crops grown at two locations in two years.

Crop	Nitrate (NO_3)†	Ammonium (NH_4)	Total Nitrogen
	-------------------- kg ha^{-1}	--------------------	
Mixture #1	16.40 ^{b}	5.13 ^{a}	21.53 ^{b}
Mixture #2	20.58 ^{b}	8.03 ^{a}	28.62 ^{b}
Austrian Winter Pea	28.65 ^{b}	6.24 ^{a}	34.89 ^{b}
Radish	21.46 ^{b}	4.80 ^{a}	26.26 ^{b}
Winter Wheat	16.33 ^{b}	6.03 ^{a}	21.36 ^{b}
Winter Canola	22.13 ^{b}	8.48 ^{a}	30.58 ^{b}
Fallow	65.62 ^{a}	5.65 ^{a}	71.27 ^{a}
Average	27.31	6.34	33.50
s.e. mean	3.93	1.41	4.58

†Means within columns with different superscript letters are significantly different ($P<0.05$).

Table 3.8 Nitrate (NO_3), ammonium (NH_4) and total nitrogen (N) at different soil depth. Data presented is averaged over six different cover crops grown at two locations in two years.

Soil depth	Nitrate (NO_3)†	Ammonium (NH_4)	Total Nitrogen
--- cm ---	-------------------- kg ha^{-1}	--------------------	
30	47.8 ^{a}	15.6 ^{a}	63.4 ^{a}
60	14.0 ^{c}	7.2 ^{b}	21.2 ^{b}
90	24.9 ^{b}	0.0 ^{c}	24.9 ^{b}
120	20.2 ^{c,b}	0.4 ^{c}	20.6 ^{b}
Average	26.7	5.8	32.5
s.e. mean	2.97	1.03	3.32

†Means within columns with different superscript letters are significantly different ($P<0.05$).

Table 3.9 Mean squares from the analysis of variance of water use measured post-harvest, depletion, crop water use, and water use efficiency

Source	d.f. [a]	PostH†		Depl		CWU		WUE	
Year	1	339.2	***	53.24	***	38.1	***	3,155,606	***
Rep (Year)	2	2.1	ns	2.1	ns	2.1	ns	4669	ns
Site	1	315.0	***	288.2	***	328.0	***	2,692,156	***
Year*Site	1	94.4	***	454.9	***	411.8	***	2,485,694	***
Site*Rep (Year)	2	1.7	ns	1.7	ns	1.7	ns	66,425	ns
Crop	6	1,228.1	***	1,228.2	***	1,228.2	***	5,232,287	***
Year*Crop	6	34.9	**	34.9	**	34.9	**	3,492,311	***
Site*Crop	6	16.3	ns	16.3	ns	16.3	ns	1,756,553	***
Year*Site*Crop	6	10.6	ns	10.6	ns	10.6	ns	1,428,600	***
Depth	3	200.0	***	200.0	***	200.0	***	69,423	ns
Crop*Depth	18	76.6	**	76.6	**	76.6	**	63,070	ns
Year*Depth	3	147.9	***	147.9	***	147.9	***	6,717	ns
Site*Depth	3	36.9	***	36.9	***	36.9	***	7,587	ns
Year*Crop*Depth	18	41.9	ns	41.9	ns	41.9	ns	51,502	ns
Site*Crop*Depth	18	20.7	ns	20.7	ns	20.7	ns	13,784	ns
Year*Site*Depth	2	25.6	**	25.5	**	25.5	**	6,883	ns
Year*Site*Crop*Depth	12	28.5	ns	28.5	ns	28.5	ns	14,594	ns

d.f[a]= degrees of freedom

*=$.01<P<.05$; **=$.05<P<0.001$;*** =$P<0.001$; ns=not significant

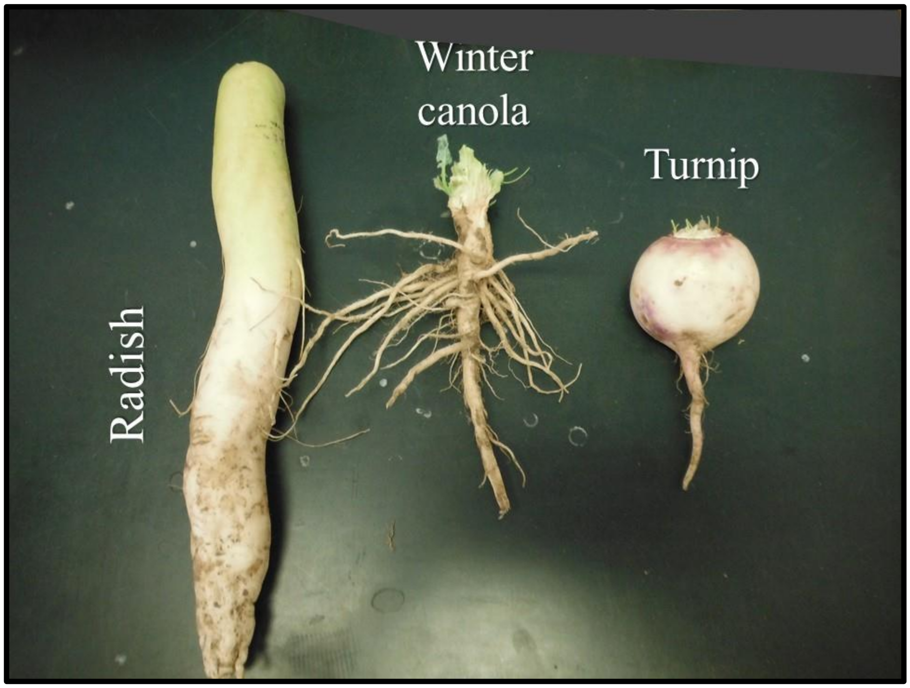
†PostH= Post Harvest moisture content, Depl=soil moisture depletion, CWU=crop water use, and WUE=water use efficiency.

Table 3.10 Duncan grouping for characters post-harvest, depletion, crop water use, and water use efficiency by cover crops growing in Moscow and Genesee, Idaho 2014-2015.

Crop	Post-Harvest†		Depletion		Crop Water Use		Water Use Efficiency	
	--- % ---		--- % ---		-- Scale --		-- Scale --	
Mixture #1	10.14	c	9.64	a	13.03	a	411.40	a
Mixture #2	9.50	c	10.25	a	13.62	a	412.92	a
Austrian Winter Pea	10.90	b	8.88	b	12.27	b	60.83	c
Radish	9.65	c	10.14	a	13.52	a	429.85	a
Winter Wheat	9.66	c	10.20	a	13.57	a	293.41	b
Winter Canola	9.41	c	10.38	a	13.76	a	828.87	b
Fallow	16.91	a	2.87	c	6.25	c	0.00	c
Average	10.88		8.91		12.29		348.18	
s.e. mean	0.25		0.25		0.25		37.71	

†Means within columns with different superscript letters are significantly different ($P<0.05$).

Figure 3.1 Taproots from cover crops grown in 2014, radish (left), canola (middle), and turnip (right).



Chapter 4:

Comparison of Spring-Planted Rotational Crop Options in the Pacific Northwest

4.1 Abstract

Spring planted seed crops commonly grown in Northern Idaho were grown in a study comparing cover crops to fallow in terms of various benefits and subsequent wheat yield. The value and establishment rate of these seed crops helps to determine the difference between growing unharvested cover crops and harvested seed crops that supply immediate returns, in contrast to long term benefits possibly produced by cover crop use. Common seed crops in the region include spring wheat, barley, spring canola, and spring peas. These seed crops were tested using common farming practices in this area in terms of seeding dates, seeding rates, pesticide applications, and harvest methods.

Trials were planted at two locations in northern Idaho, Genesee and Moscow. Data was collected on plant establishment, crop stand, weed infestation, leaf area index, seed yield, and test weights (cereal crops only). Spring wheat was found to be most competitive, moderate yielding and had the highest gross return for this trial. Spring barley was also found to be a suitable seed crop for this region, with the highest yield of the seed crops tested and in turn having the second highest gross return value of the seed crops. Spring canola showed some adaptability and could have value as a broad leaf rotational crop although it had slightly lower gross returns compared to the two cereal crops. Many variables affected the growth of spring peas in this study, which may have decreased the apparent value of spring peas as a seed crop in this region. Overall, conclusions from this research is that all these four seed

crops were well suited for this region.

4.2 Introduction

Many regions of the world have found specific crop rotations in which they are able to produce high yielding crops within their environment. This has in many cases resulted in monoculture cropping systems. Monoculture cropping systems are possible because of improved farm mechanization, better cultivars, inorganic fertilizers, and the use of agrochemicals to control weeds and diseases, which increased efficiency and productivity in these regions (Altieri, 2000). Monoculture systems, like all systems, have advantages and disadvantages. Although the common rotation in the dryland Pacific Northwest does consist of more than one crop, few crops have shown adaptation to the region that can be grown economically with the predominant crop, winter wheat. Understanding common crop rotations in this region can help researchers find alternatives that may provide additional benefits.

4.2.1 Pacific Northwest Agriculture

Cropping systems in the continuous cropping region of the Pacific Northwest (PNW) generally consist of cereal-legume rotations. PNW dryland cropping is defined as that practiced where average annual precipitation is 60 cm or less, and irrigation is not used (Schillinger *et al.*, 2006). The Palouse, a sub-region of the Pacific Northwest, covers roughly 809,371 ha^{-1}, including most of Washington’s Whitman County and western Latah County in Idaho. Sixty percent of the Palouse is cropland (485,622 ha^{-1}) with winter wheat as the main crop. Although wheat-legume rotations provide benefits such as nitrogen fixing, there is an opportunity for biodiversity that can provide benefits during periods of fallow within the current rotation (Hall, 1999). A popular 3-yr rotation is legume-winter wheat-spring wheat, because winter wheat yields following a legume crop are 10% to 20% higher than winter wheat yields following a spring cereal (Guy *et al.*, 1998).

4.2.2 Current Practices in the Pacific Northwest

In the PNW there is 1.3 million hectares of land in a grain-fallow rotation (Brown *et al.*, 2008). Wheat is the dominant crop grown in this region, with both soft white and hard red winter and spring wheat cultivars grown (Schillinger *et al*., 2006). Production of winter and spring wheat became the dominant crops throughout the non-irrigated Inland PNW when it became evident that these crops could be grown profitably over a wide range of climates and soil conditions (Schillinger & Papendick, 2008).

Three year crop rotations of winter wheat-spring barley or spring wheat-grain legume, or a cereal only rotation of winter wheat-spring barley-spring wheat are common in the higher rainfall dryland regions (Schillinger *et al*., 2006). Growers in the region want to increase the intensity of cropping, for example by decreasing the frequency of fallow, and reduce or eliminate tillage (Schillinger *et al*., 2006). In the higher rainfall region where continuous cropping is possible other crops grown include barley (*Hordeum vulgare),* peas (*Pisum sativum),* lentils (*Lens culinaris*), canola (*Brassica napus*) and garbanzo beans (*Cicer arietinum*), which can be grown in rotation with winter wheat.

4.2.3 Problems in the Current System

In all cropping systems there are barriers that can affect production and efficiency of the farming system. Many of the limitations that concern growers in the dryland regions of the

PNW are related to changes in climate and environment. Climate greatly limits the crops that can successfully be grown in this region, resulting in a predominant winter wheat production system. Because of its consistent high yields, winter wheat is the major cash crop, grown in rotation with spring crops of barley, wheat, pea, lentil, garbanzo bean, canola, and condiment mustard grown in the higher rainfall areas (Guy *et al.*, 1998). In 2015, 485,623 ha of wheat were grown in the state of Idaho, followed by barley at 234,718 ha^{-1} (NASS, 2015).

Another concern in the dryland PNW farming region is soil erosion. Due to the severe slopes, the seasonal concentration of precipitation and intensive tillage in winter wheat production systems, wind and water soil erosion are serious environmental concerns. It is difficult to estimate soil losses due to erosion but it has been estimated that 22 Mt ha^{-1} of topsoil annually are lost and that over 224 Mt ha^{-1} of soil is lost from severe slopes due to erosion (Hall, 1999).

Crop-fallow cropping is commonly practiced in central Washington due to low precipitation which occurs mainly over winter. Although fallow is meant to preserve soil moisture that isn’t always the case. Soil moisture can be lost during periods of fallow by evaporation or percolation beyond the rooting depth of winter wheat (Baumhardt and Anderson, 2006); Peterson *et al.,* 2006).

Soil health is another huge concern of growers in the dryland PNW. A trend in farming practices has been toward more intensive cropping, less intensive tillage, and shorter fallow periods. This has been brought about by the development of effective, economic herbicides for weed control during fallow, advances in planting equipment that allow efficient planting in high residue conditions, and improvement in crop genetics. These changes have primarily been driven by economics but also partially by the realization that farming practices that depleted soil nutrients at such a rate were not sustainable (Schlegel *et al*., 2009).

4.3 Proportion of production in the PNW

The Pacific Northwest region is comprised of three states, Idaho, Oregon, and Washington. Table 2.1 (see Chapter 2) compares crop production of these three states. In 2015 in the state of Idaho, harvested 485,622 ha of wheat, which was the highest among the listed seed crops, followed by barley at 234,717 ha. In Oregon, wheat also was the dryland seed crop at 337,912 ha, followed by 19,829 ha of barley. In Washington, wheat was grown on over a million ha in 2015, again followed by barley at 44,515 ha^{-1} (NASS, 2015).

4.4 Research objective

This study compares spring planted crops commonly grown in the PNW. Four crops were grown at two locations over two years. Characteristics analyzed include plant establishment, plant stand, weed infestation, leaf area index, yield, and infiltration.

Specific objectives of this research were:

1. Identify common seed crop characteristics in order to compare alternative crop options.
2. Determine seed crop returns as a basis for alternative crops.

4.5 Materials and Methods

4.5.1 Site Characteristics

Field trials were conducted to test spring seed crops over two years and at two locations in northern Idaho. The first location was the University of Idaho Parker Research Farm in Moscow, Idaho (46°43’N 116°57’W). This location has a Palouse-Latah complex soil type with slopes varying from site to site. During the 2014 growing season this study was grown on a slope of 7 to 25 %, in the second year the field slope was 0-3 percent. The second location was the Kambitsch Research Farm near Genesee, Idaho (46°33'N 116°56'W). Both locations had a Palouse silt loam soil with a slope of 3-7%. Rainfall and average temperatures during this study can be found in Table 3.1.

4.5.2 Treatments and Experimental Design

A randomized complete block design was used with four replicates. At both locations the field had previously been sown to spring barley. Before planting, each location was chisel plowed, harrowed, and fertilized with a 50:50 blend of urea (46-0-0) and ammonium sulfate phosphate (16-20-0-15) to give an overall rate of (31-10-0-7.5) at 336 kg ha^{-1}, approximately 100 N ha^{-1}. Four seed crops were planted to act as a common rotation in this region. Seed crops included spring canola ‘DKL 30-42’, spring barley ‘Lenatah’, spring pea ‘Banner’, and spring wheat ‘Whit.’ Spring canola was planted at a rate of 6 kg ha^{-1}, wheat at 103 kg ha^{-1}, pea at 103 kg ha^{-1}, and barley at 93 kg ha^{-1}.

Crops were planted using a small plot, single cone six row planter. In 2014 the two sites were planted on May 14th. In the second year, the Genesee location was planted on April 27th and the Moscow location on April 30th.

The experimental design used was a randomized complete block design with four replications. Individual plot size was 3.1 m x 9.1 m.

4.5.3 Pest and Weed Control

Prior to planting, weeds were controlled with Round-Up RT3® (Monsanto, 2003), 2-4D (Winfield Solutions, 2003) and crop oil. Warrior II insecticide (Syngenta, 2008) was applied to control diamondback moth (*Plutella xylostella),* aphids (*Aphidoidea),* pea weevil (*Bruchus pisorumand*), and flea beetles (*Alticini*). Following common practices in this region plots were sprayed with weed control agents. Canola was sprayed with Round Up RT3® (Monsanto, 2003) in combination with crop oil. Spring peas were sprayed with Basagran (BASF, 2010), and crop oil. Wheat and barley were sprayed with Huskie (Bayer, 2014), Orion (Syngenta, 2013), and crop oil surfactant.

4.5.4 Data Collected

Soil samples were taken twice throughout the season in 30 cm increments extending 120 cm into the soil profile. The first soil sample was taken before planting followed by a sample taken after harvest. Each sample was weighed wet and then dried at 50ºC for two weeks. Both samples were sent to northwest agricultural consultants in Kennewick, WA for soil analysis. Establishment was recorded through visual evaluation eight weeks after planting on a scale of 1 to 9. Stand and weed counts were evaluated when emergence was complete. Stand counts were taken in the most representative area of the plot by counting seedlings from two 1 m rows and 1 m from the plot edge. Two counts were taken from each plot and averaged. Weed counts were taken with a 0.2 m^2 quadrat in the center of the plot. Two counts were taken from each plot and averaged.

Light bar readings were taken four times during the growing season starting in June, to determine leaf area index. Leaf area index is a dimensionless quantity that characterizes plant canopies. It is defined as the one-sided green leaf area per unit ground surface area (LAI=leaf area/ground area, $m^2/m^{2)}$. LAI (Leaf Area Index) is defined as the area of leaves per unit area of soil surface. It is a valuable measurement in helping to assess canopy density and biomass. The AccuPAR calculates LAI based on the above and below-canopy PAR measurements along with other variables that relate to the canopy architecture and position of the sun (Decagon Devices Inc., Pullman, WA).When plots were mature they were harvested and weighed to determine yield. Test weights were recorded for both wheat and barley.

Water infiltration into the soil was then determined from the time it took for 500 ml of water to infiltrate into the ground. An aluminum cylinder at 16 cm in height and 32 cm in diameter was inserted 1 cm into the surface of the soil and 500 ml of water poured into the cylinder and the time recorded when all of the water had completely infiltrated into the soil. Water spread (%) was measured by visually evaluating the percentage circumference of the cylinder where water was observed to spread outwards from the open cylinder rather than percolating into the soil profile.

Spread was measured by visually evaluating the percentage of water that spread outwards from an open cylinder rather than percolating down into the soil profile.

Measurement was taken from the side of the cylinder and measured in inches from the side of the cylinder and percentage of circumference. Spread can be found in Table 4.6.

4.5.5 Data Analysis

Statistical Analysis Software (SAS, 2009) was used to analyze the data from this study. The GLM (general linear model) analysis of variance was used within this program. Each set of data that was collected was analyzed separately.

4.6 Results

Mean squares from the analysis of variance for seedling stand, crop establishment, and weed counts are presented in Table 4.1.

4.6.1 Stand, weed counts, and crop establishment

Plant stand counts and crop establishment were significantly higher in 2015 compared to 2014, and the Moscow location had significantly higher stand counts and better establishment than Genesee. Stand count for spring wheat was significantly higher than the other seed crops in this study (Table 4.2), followed by barley which was significantly higher than canola or pea. Establishment scores for barley were highest, followed by wheat, canola, and lastly pea. Weed counts were significantly higher at Genesee in 2015 than at the other location. Spring pea and spring canola had significantly more weeds than the other two cereal crops.

4.6.2 Leaf Area Index (LAI)

Mean squares from the analysis of variance of leaf area index (LAI) are presented in Table 4.3. The Genesee site had a significantly higher LAI than the Moscow site, in general this location had more vigorous plants which would explain why the leaves covered more area (Table 4.4). Seed crops in this study showed that there was a slight significance between crops, with spring wheat, barley, and canola all being significantly higher LAI than spring pea. The spring pea plots were thin compared to average plots which would account for this difference. When comparing the first and second reading the first reading had a significantly higher reading. There are many factors that could explain this difference including sunlight at the time of the reading and angle of equipment during reading.

4.6.3 Infiltration and spread

Mean squares from the analysis of variance of infiltration can be found on Table 4.5. No significance difference was found between the Moscow and Genesee locations for water infiltration and water spread. However, there was significance difference between crops for water infiltration (Table 4.6) when comparing crops for infiltration rates. The slowest infiltration rate was found in the barley plots. Spring canola, pea and wheat were equally significant. Spread of water outside of the open cylinder was higher for both the barley and spring pea. Crops with extensive root systems increase channels below the soil surface increasing the ability of water to move through the soil profile.

4.6.4 Residual soil nitrogen

Mean squares from the analyses of residual soil nitrates, ammonium and total nitrogen are presented in Table 4.7. Highest residual soil nitrate and total nitrogen was after the nitrogen fixing pea crop (Table 4.8). Residual soil nitrate and total nitrogen after pea was not statistically higher than after spring wheat. There was no difference in residual soil ammonium after the different crops.

4.6.5 Test weight seed yield and crop value

Mean squares from the analyses of variance of seed test weight (wheat and barley only), seed yield and crop value are presented in Table 4.9. In these analyses many sources of variance showed significance but differences between crops accounted for by far the higher proportion of the total variance.

Test weight was only measured on seed harvested from the barley and wheat plots. 2015 crops had significantly higher test weights than in the year 2014, and test weights from the Moscow site were also significantly higher than those from Genesee. Spring wheat had a significantly higher test weight score than barley (Table 4.10).

The yield did not vary significantly between the year 2014 and 2015, however, Genesee did have a higher seed yield when compared to Moscow (Table 4.10). Wheat (3,643 kg ha^{-1}) and barley (3,866 kg ha^{-1}) produced significantly higher seed yields when compared with spring canola (1,795 kg ha^{-1}), which was significantly higher yielding than pea.

Crop value was based on the crop seed yield x crop price. Highest crop price was from barley ($777) which was not significantly higher than wheat ($720). Value of spring canola ($643) was significantly lower than either cereal crop but significantly higher than from pea ($328).

4.7 Discussion and Conclusion

Weed counts were significantly higher in the pea and canola plots. This can be explained by the quick growth and fibrous roots of the grass species of weeds in these crops. Spring pea plots in this study had a significantly lower establishment rate, which explains the low yield. Establishment for this crop may have been affected by seeding depth.

The leaf area index of canola, wheat and barley crops were significantly higher than the leaf area index for pea. Leaf area index is used to measure the amount of ground cover provided by the crop during the growing season. With increased ground cover, crops are more likely able to compete with weed species while conserving moisture content in the soil. As seen in this study these four seed crops can be grown successfully in this region with a wide variety of benefits. Market predictions for current seasons are important in indicating which crops should be grown to ensure a profitable growing season.

Highest residual soil nitrate and total soil nitrogen was highest after the pea crop. However there was no difference in soil ammonium after any crop and indeed little difference in residual nitrogen between the crops.

Spring wheat and barley both had significantly higher seed yield and crop values compared to canola and pea which had lowest yield and markedly lower crop value than the other crops. These findings are not surprising as the majority of acreage planted in this area is in cereal crops such as these. However, it should be noted that spring pea and canola offer rotational benefits that are not measured in this study. Spring wheat yields in this study were average for this area. Average yield for spring wheat in this area ranges from 1,700 to 4,000 kg ha^{-1} (McClellan, *et al.*, 2012). The average yield in this study for spring wheat was 3,642 kg ha^{-1} (Table 4.10). The value of barley and wheat in this study were significantly higher than pea and canola. This value varies on a yearly basis depending on market prices, but returns for cereal crops are typically higher than those for pea and canola.

The overall conclusion from this study is that spring cereals are highly adapted to the environment of the PNW and indeed the two non-cereal crops examined provided markedly lower, particularly the pea crop, crop value.

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Tables

Table 4.1 Means squares from the analysis of plant stand, weed infestation, and plant establishment.

Source	d.f.[a]	Plant Stand Counts†		Weed Infestation		Estab.	
Year	1.0	470.0	***	22,973.2	***	2.9	*
Rep (Year)	6.0	159.0	ns	5,502.8	**	1.9	ns
Site	1.0	1,861.0	***	11,446.8	***	0.2	ns
Year*Site	1.0	2,358.0	***	9,747.3	***	3.0	*
Site*Rep (Year)	6.0	261.0	ns	5,506.2	**	6.7	*
Crop	3.0	14,556.0	***	8,955.4	**	15.5	***
Year*Crop	3.0	1,210.0	***	9,304.2	**	9.0	**
Site*Crop	3.0	1,296.0	***	2,867.3	*	0.0	ns
Year*Site*Crop	3.0	938.0	***	3,113.6	*	0.6	ns

d.f.[a]= degrees of freedom

† Stand= plants per m^{2}; Weeds= plants mer m^{-3}, establishment=visual evaluation 1 to 9.

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

Table 4.2 Plant stand counts, and plant establishment, and weed infestation counts of four spring seed crops grown at two locations in two years.

Crop	Weed Count† -plants m^{-2} -		Stand Count -plants m^{-2}-		Establishment -1 to 9-	
Spring Barley	8.9	b	41.0	b	7.8	a
Spring Canola	27.2	a	14.6	c	7.2	b
Spring Pea	37.8	a	15.4	c	6.4	c
Spring Wheat	11.2	b	49.2	a	7.3	ab
Mean	21.3		30.0		7.2	
s.e. mean	4.99		1.68		0.57	

†Means within columns assigned different letters are significant (P<0.05).

Table 4.3 Mean squares from the analysis of variance of leaf area index of four seed crops grown at two sites in 2015.

Source	d.f. [a]	LAI†	
Site	1	95.6	***
Rep (Site)	6	6.0	*
Crop	3	41.6	***
Site *Crop	3	3.3	ns
Date	1	3.8	**
date* crop	3	3.2	**
site*date	1	6.1	**
site*date*crop	2	2.6	*

d.f.[a]= degrees of freedom

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

†LAI=Leaf area index

Table 4.4 Leaf area index of crops of four seed crops grown at two sites in 2015.

Crop	LAI†	
Spring Barley	3.1	a
Spring Canola	3.0	a
Spring Pea	2.0	b
Spring Wheat	3.3	a
Mean	2.9	
s.e. mean	0.13	

Means within columns assigned different letters are significant (P<0.05).

†LAI=Leaf area index

Table 4.5 Mean squares of the analysis of variance of infiltration of four seed crops grown at two sites in 2015.

Source	d.f.[a]	Infiltration†	
Site	1	324.6	ns
Rep (Site)	6	1,005,636.6	*
Crop	10	9,673,186.9	***
Site*Crop	10	2,073,785.3	**

d.f[a]= degrees of freedom.

† LAI=Leaf area index

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

Table 4.6 Water infiltration and spread data show inches and percentage of spread for seed crops during infiltration test of four seed crops grown at two sites in 2015.

Crop	Infiltration†		Spread	
	----liters/sec----		--inches--	--%--
Barley	869.3	a	1.1	10
Spring Canola	766.3	b	0.5	20
Spring Pea	484.5	c	1.1	16
Spring Wheat	736.9	b	0.7	10
Mean	714.3		0.8	14.0
s.e.	96.4			

†Means within columns assigned different letters are significant (P<0.05).

Table 4.7 Mean squares from the analysis of variance of nitrate, ammonium, and total nitrogen of four seed crops grown at two sites in 2015.

Source	d.f. ^{a}	NO_3†		NH_4		Total N	
Year	1	240.98	ns	305.39	ns	1,088.95	ns
Rep (Year)	2	3,802.19	*	1212.24	*	9,300.79	*
Site	1	1,533.11	ns	244.15	ns	553.64	ns
Year*Site	1	9855.7	***	46.56	ns	8547.43	**
Site*Rep (Year)	2	1159.49	ns	717.91	*	52.67	ns
Crop	3	7,070.53	*	626.39	ns	5,984.79	ns
Year*Crop	3	695.84	ns	794.39	ns	1,682.18	ns
Site*Crop	3	5,563.89	*	797.48	ns	6,598.31	*
Year*Site*Crop	3	1,115.70	ns	1,037.68	*	3,659.56	ns
Depth	3	16,697.48	***	3,064.57	***	33,375.00	***
Crop*Depth	9	3,884.28	ns	136.31	ns	5,071.79	ns
Year*Depth	3	3,310.73	ns	374.86	ns	2,788.45	ns
Site*Depth	3	1,213.03	ns	88.68	ns	1,745.66	ns
Year*Crop*Depth	9	2,132.07	ns	263.96	ns	2,912.08	ns
Site*Crop*Depth	9	1,428.80	ns	473.60	ns	3,143.51	ns
Year*Site*Depth	3	1,952.16	ns	219.39	ns	3,289.30	ns
Year*Site*Crop*Depth	9	31.58	ns	18.31	ns	83.47	ns

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

†NO_3=Nitrate, NH_4=Ammonium, Total n=Total Nitrogen.

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

Table 4.8 Soil nitrate, ammonium and total nitrogen for seed crop plots at two locations in two years. Data presented are averaged over samples taken from four soil depth.

	Nitrate†	Ammonium	Total Nitrogen
	-------------------------------	kg/ha^{-1}	------------------------
Barley	18.1 c	9.0 a	27.2 b
Spring Canola	20.0 c	6.7 a	26.7 b
Spring Pea	41.7 a	7.0 a	48.7 a
Spring Wheat	30.3 ab	7.9 a	38.2 ab
Mean	27.5	7.7	35.2
s.e.	5.1	2.1	5.7

Means within columns assigned different letters are significant ($P<0.05$).

†NO_3=Nitrate, NH_4=Ammonium, Total N=Total Nitrogen.

Table 4.9 Mean squares from the analyses of variance of test weight, seed crop yield, and gross seed crop value of four spring seed crops grown at two locations in two years.

Source	d.f. ^{a}	Test Weight†	Yield	Value
Year	1	1.5 ^{ns}	4,011 ^{ns}	14,837 ^{ns}
Rep (Year)	6	2.7 ^{ns}	443,860 ^{ns}	39,493 ^{ns}
Site	1	8.4 **	6,396,532 ***	415,633 ***
Year*Site	1	6.1 *	5,693,998 ***	269,145 ***
Site*Rep (Year)	6	10.9 ^{ns}	926,997 ^{ns}	28,768 ^{ns}
Crop	3	59,559.0 ***	86,831,234 ***	1,929,491 ***
Year*Crop	3	28.9 **	6,053,962 ***	427,142 ***
Site*Crop	3	23.9 **	5,621,112 ***	327,674 ***
Year*Site*Crop	3	39.2 ***	6,350,053 ***	121,623 *

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

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

†Test Weight= test weight of cereal yields, yield=seed crop yields, value=value of seed crops.

Table 4.10 Test weight, seed crop yield, and seed crop value of four spring seed crops grown at two locations in two years.

	Test Weight† --lb/bu^{-1}--	Yield --kg/ha^{-1}--	Value --$/ha^{-1}--
Spring Barley	55.9 ^{b}	3,866.2 ^{a}	777.5 ^{a}
Spring Canola	-	1,795.4 ^{b}	642.9 ^{b}
Spring Pea	-	1,142.6 ^{c}	328.0 ^{c}
Spring Wheat	66.7 ^{a}	3,642.7 ^{a}	720.2 ^{a}
Mean	61.3	2,611.7	617.2
s.e.	0.25	109.00	24.26

Means within columns assigned different letters are significant ($P<0.05$).

†Test Weight= test weight of cereal yields, yield=seed crop yields, value=value of seed crops.

Chapter 5:

Subsequent Winter Wheat Crop

5.1 Abstract

Winter wheat is produced on the largest acreage in the Inland Pacific Northwest (PNW) and there are few alternative crops that can be grown economically in this region. Over the past few years there has been interest in the use of cover crops to make intensive wheat production more sustainable. Water is a critical component in the productivity of crops in the region, and as fall rains are scarce, there is little possibility of establishing cover crops in the fall and planting seed crops the following spring. If cover crops are to be introduced in the higher rainfall regions of the PNW then they must be grown as an alternative to growing a spring grain crop. In order for new cover crops to be accepted by growers they must be shown to enhance sustainability and have reasonable economic feasibility. In this chapter six cover crops are compared to four spring planted seed crops and the productivity and profitability of the following soft white winter wheat is examined to determine whether any of the cover crops have sufficient rotational benefits to account for loss of farm revenue by replacing a cash crop with a cover crop. This study shows that there may be short-term and long-term benefits to each of the cover crops examined, and winter wheat yields after cover crops were enhanced. However, it is difficult to ignore the basic economic information collected here. Seed crops ideally result in profits for the farm, while cover crops cost money to grow and yet have no immediate cash return (unless considered for forage). The results of this study suggest that soil health could indeed be positively impacted by the adoption of cover crops, with better water infiltration and soil nutrient availability after cover crops compared to spring seed crops grown in rotation with winter wheat. Environmental benefits and soil health should

be an important consideration in our farming systems. Overall, however, it is difficult to see with the current financial situation on our farms how growers could adopt cover crops on a large scale and routinely include them in crop rotations with the associated reduced profits. The short-term improvement in winter wheat profitability is hardly large enough to justify the cost.

5.2 Introduction

Cereal production is highly profitable therefore an important part of dryland agriculture in the PNW (Schillinger and Papendick, 2008). Few alternative crop species have shown adaptability or economic feasibility in the region when compared to the returns possible with winter and spring wheat. However, some have questioned the long-term sustainability of intensive wheat production and recent interest has been generating into using cover crops to broaden plant diversity and stewardship of the farming system. In order to introduce new cover crops into this region, it is important to examine how cover crops can be grown in this region and to measure their effect on subsequent wheat crops.

5.2.1 Dryland Agriculture in the Pacific Northwest

The dryland cropping region in the inland PNW is situated contiguously in eastern and central Washington, the Idaho panhandle, and in eastern and north-central Oregon and the intermountain region of southeastern Idaho, northern Utah, and western Montana, where an approximate 4,380,000 ha of land devoted to dryland cropping (Schillinger *et al*., 2006). Dryland wheat farming has been practiced in many parts of the world for centuries, but it is only about 100 years old in the northwestern United States (Granatstein, 1992).

Dryland agriculture in the PNW is divided into three systems: (1) low, (2) intermediate, and (3) high precipitation. The low precipitation (less than 30 cm annual precipitation) dryland cropping region in east-central Washington and north-central Oregon covers 1,556,421 ha, and is by far the largest cropping zone in the western United States (Schillinger *et al.*, 2003). The low precipitation region is almost entirely limited to a winter wheat-fallow rotation where the fallow is necessary to preserve soil moisture content for winter wheat. The PNW intermediate (30-45 cm annual precipitation) region comprises of about 971,246 ha in dryland crop production (Schillinger *et al.,* 2003). Intermediate rainfall regions are similar in that they often follow a crop-fallow rotation, but also have the ability to allow for continuous cropping. Crops in this rotation would include spring wheat, barley (*Hordeum vulgare*), yellow mustard (*Sinapis alba*), and camelina (*Camelina sativa*). The lowest acreage of these crops in the PNW is the high rainfall region. This zone receives more than 45 cm of annual precipitation and comprises 819,488 ha^{-1} of dry-farmed cropland (Schillinger *et al.*, 2003). This higher rainfall region allows greater crop diversity in rotation crops such as spring wheat, barley, pea (*Pisum sativum*), lentils (*Lens culinaris),* or garbanzo bean (*Cicer arietinum*), spring canola (*Brassica napus*), and Indian mustard (*B. juncea*).

In 2015 in the state of Idaho, wheat was planted on 485,623 ha^{-1}, which was highest among the other listed seed crops, followed by barley at 234,717 ha^{-1} (see Chapter 2, Table 2.1). In Oregon wheat was also the highest produced dryland seed crop at 337,912 followed by 19,829 ha^{-1} of barley. Washington has the highest wheat land area at 1,044,089 ha^{-1} in 2015, again followed by barley at 44,515 ha^{-1} (NASS, 2015).

The topography is gently rolling hills over the entire low-precipitation region that is essentially a plateau of basalt dissected by canyons and coulees carved by a series of cataclysmic glacial outburst floods about 15,000 years ago (Schillinger and Papendick, 2008). Farming is commonly performed on up to 30% slopes with some slopes as steep as 45% (Busacca, 1991).

Crop rotations in the higher precipitation regions of the PNW are generally more varied than the intermediate or low precipitation regions, and although cereal grain crops (wheat and spring barley) are predominant, legumes (pea, lentils or garbanzo bean) and spring canola are common rotation options. Winter wheat yields following a legume crop are 10% to 20% higher than winter wheat yields following a spring cereal (Guy and Gareau, 1998). Popular 3-yr crop rotations include winter wheat-spring wheat-legume or winter wheat-spring wheat-*Brassica*, while 4-year rotations of winter wheat-spring wheat-barley-legume or winter wheat-spring wheat-barley-*Brassica* (Schillinger *et al*., 2008). Spring barley or spring wheat make up 40% of spring rotation crops, while peas, lentils, or garbanzo beans account for a further 40% of spring crops, and other crops, including canola, grass seed or fallow account for the remaining 20% (Papendick, 1996).

5.2.2 Problems with PNW cropping system

Continuous small-grain cereal production, with limited rotational crop options can have negative effects on farm sustainability. In rain-fed agriculture, especially in semiarid regions, a continuing problem for producers is erratic precipitation and subsequent yield variability (Baumhardt and Andersen, 2006). In single crop intensive systems water and wind erosion can increase due to lack of crop residue due to intensive tillage. Both winter and spring wheats are intensively grown in the PNW, and can result in wheat crops following wheat crops. Grassy weeds increase significantly in intensive cereal production systems, and require increased herbicide applications. Diversifying crops in rotations can moderate the effect of drought on crop yield by improving water-use efficiency (Baumhardt and Andersen, 2006).

A widespread trend in farming practices has been toward more intensive cropping, less intensive tillage, and shorter fallow periods. This has been brought about by the development of effective, economic herbicides for weed control during fallow, advances in planting equipment to allow efficient planting in high residue conditions, and improvements in crop genetics. These changes have primarily been driven by economics but also partially by the realization that farming practices that depleted soil nutrients at such a rate were not sustainable (Schlegel *et al*., 2013). Insufficient nutrients in the soil often lead to the over use of inorganic fertilizers. Insufficient nutrients in the soil often lead to the over use of inorganic fertilizers. Nutrients can enter surface and ground waters through misapplication, movement of treated soils, return irrigation flows, runoff from agricultural fields, storm water runoff, and leaching through soils (Mahler *et al.*, 2011). The problems associated with the current system can help direct us toward appropriate solutions for this region.

5.2.3 Possible Solutions

Conservation tillage is defined as leaving at least 30% of crop residue on the soil surface, such as wheat stubble, for planting the next crop to reduce soil erosion and runoff (Minnesota Department of Agriculture, 2016). In the PNW, according to the 2012 Census of Agriculture, 8.98% of farmers are practicing no till farming, which involves planting crops directly into residue (Dobberstein, 2014). This method is one example of better management that could positively affect a monoculture cropping system.

Another possible solution to reduce problems associated with a monoculture system is to introduce alternative crops into the rotation. Many problems associated with an intensified cereal production systems are caused by the continuous planting of grassy species. Broadleaf crops in a cereal rotation would increase the options for pesticide application. The taproot often associated with broadleaf crops such as canola can help break up plow pans.

Cover crops can provide many benefits that would help alleviate many of the problems that have been found with a monoculture system. As previously mentioned there are three different rainfall levels in the PNW. It should be mentioned that cover crops would not necessarily be a productive means of fixing problems in each of these rainfall areas. For example, in the low rainfall regions it would be highly unlikely that cover crops could replace fallow in the crop rotation. This rotation would likely not be able to manage the loss of moisture that would come with the use of cover crops. In the intermediate rainfall regions it would be more likely that cover crops could be implemented. If these cover crops were used to replace fallow and terminated before moisture content in the soil was too low it could provide many benefits to this system. In the high rainfall regions cover crops may be feasible but the cost associated with replacing a seed crop would need to be studied before being implemented on a large scale.

There are many cover crop options depending on region and climate. In the higher rainfall region of the inland PNW cover crop options would include tropical grasses, broadleaves such as radish and canola, and legumes. In this two year study we examined six cover crops (two of which were mixtures). Grass species were Sudan grass, triticale, pearl millet, foxtail millet, winter wheat and oats. Broadleaf species included Austrian winter peas, winter canola, radish, buckwheat, and turnip. These cover crops were chosen based on their ability to adapt to this region and produce adequate biomass. This study was based on the idea that cover crops could be included in a crop rotation in the high rainfall region of the Palouse.

5.2.4 Research objectives

The objective of this research was to determine the rotational effects of seed and cover crops on the yield and quality of subsequent winter wheat crops in the high rainfall regions of the PNW. The specific objectives of this research include:

1. Compare water use and nutrient potential of cover crops compared to spring seed crops.
2. Evaluate yield potential of winter wheat following cover and seed crops.
3. Determine the economic feasibility of including cover crops by replacing existing spring seed crops in a winter wheat rotation system.

5.3 Materials and Methods

5.3.1 Site Characteristics and Treatments

A study was planted at two locations, Moscow and Genesee, both in Idaho, to compare the yield and quality of a winter wheat crop following a variety of cover and seed crops in the fall of 2014 and 2015. The first location was the University of Idaho Parker Research Farm in Moscow, Idaho (46°43’N 116°57’W). This location has a Palouse-Latah complex soil type with slopes varying from site to site. During the 2014 growing season this study was grown on a slope of 7-25 %, while in the second year the field slope was 0-3%. The second location was the Kambitsch Research Farm near Genesee, Idaho (46°33'N 116°56'W). Both years of this study were located on a Palouse silt loam soil with a slope of 3-7%. Rainfall and average temperatures during this study can be found in Chapter 3, Table 3.1.

Information pertaining to the cover and seed crops planted in rotation with winter wheat can be found in Chapter 3 (cover crops) and Chapter 4 (seed crops).

After termination of cover crops and harvest of the seed crops, this trial was cultivated and winter wheat was planted in October of 2014 and 2015 using GPS coordinates to ensure proper planting over the previous cover and seed crop trials. Prior to planting soil tests were performed to determine necessary fertilizer applications at each location. During the growing season additional fertilizer was applied on a plot by plot basis to ensure even fertilizer distribution. The target fertilizer rate was 303 kg ha^{-1}. Both sites were planted to variety WB.1529, treated with Dividend Extreme® fungicide (Syngenta, 2014). At the Moscow location prior to planting the field was mowed and harrowed using a Great Plains double disc planter set at 14 cm row spacing. The Genesee location was direct seed into mowed residue using a JD single disc no-till drill with row spacing of 25 cm. Both locations were seeded at a rate of 2,000,000 seeds ha^{-1}. Seeding depth was set to the standard 2.5 cm.

Seed pricing for seed crops was determined using the 2013 direct seed budget for Northern Idaho (Painter, 2013). Seed pricing for cover crops were supplied by Mark Mustoe at Clearwater Seed Company. Spraying and fertilizer application costs were calculated using the 2014 Crop Input Price Summary (Patterson and Painter, 2014). Operating costs such as planting, harvest, and cultivation were determined using the, Custom Rates for Idaho Agricultural Operations 2010-2011 (Patterson and Painter, 2011). Fertilizer prices were provided by Roy Patten farm manager of the Moscow, Idaho Parker Research Farm (Patten, personal communication).

5.3.2 Experimental Design

This winter wheat trial was planted in a randomized complete block design over the previously mentioned trials. Previously mentioned trials included cover and seed crops planted at Moscow and Genesee with six cover crops, four spring crops, and a summer fallow treatment.

5.3.3 Data Collected

Establishment scores were assessed on a scale of 1 to 9. Soil samples were taken to determine nutrient levels and moisture content of the soil prior to planting and after harvest. Plots were visually analyzed for disease pressure and treated accordingly. Plant heights were collected after heading using a meter stick to calculate height in centimeters. Wheat tillering was estimated by, counting wheat heads in a 1m row of each plot.

Wheat was harvested according to the previous year's crops using a Wintersteiger small plot combine and seed yield was recorded. Test weights were recorded from each plot. A sample of seed was sent for quality analysis (grain protein, flour yield, break flour yield, and cookie diameter) at the University of Idaho Wheat Quality Laboratory, in Aberdeen, Idaho.

5.3.4 Data Analyzed

Data were analyzed using Statistical Analysis Software, specifically the general linear model and Duncan's multiple range tests (SAS, 2009).

5.4 Results and discussion

5.4.1 Pre-Harvest Traits

Previous crop had little effect on the following winter wheat crop's tillering, crop establishment or plant height. Wheat after radish did have significantly more tillering compared to tillering after Cover crop Mixture #2 (Table 5.1). Winter wheat established significantly better in the fall when planted after summer fallow, radish, and mixture #1.

5.4.2 Soil fertility

Mean squares from the analysis of variance of nitrate, ammonium and total nitrogen showed significant differences between crops for nitrate and total nitrogen but no difference in ammonium (Table 5.2).The highest levels for soil nitrate and total nitrogen were in the fallow ground over either cover crops or seed crops, suggesting that all crops were reducing soil nitrogen content. Not surprising the total nitrogen after spring pea and Austrian winter pea were highest, due most likely to nitrogen fixation, but it should also be noted that neither of these crops grew vigorously so little nitrogen may have been depleted in comparison to the other cover crops.

Nitrate, ammonium and total nitrogen were all significant when related to soil depth, with significantly higher levels in all samples in the shallower soil profiles (Table 5.3). Nitrate concentrations were highest in the 0-30 cm sample, with the other depths showing no significance. Ammonium concentrations were significantly higher in the top 30 cm of the soil profile. Total nitrogen was significantly higher in the top 30 cm.

5.4.3 Soil moisture content

Mean squares from the analyses of variance of post growth soil moisture content, soil moisture depletion, crop water use, and crop water use efficiency all showed significant differences between crops and between different soil depth and many interactions existed between factors (Table 5.4). As expected, the highest soil moisture content was found in the fallow treatment (Table 5.5). Post-growth soil moisture after pea and Austrian winter pea were higher than most other crops. It should be noted though that the difference in post-growth soil moisture only ranged from a high of 11.8% after pea to 9.0% after spring wheat seed crops. Post season soil moisture in cover crops was similar to that from the seed crops.

Soil moisture depletion in the fallow treatment was significantly lower than any of the cover or seed crops. As expected, the legume crops pea and Austrian winter pea had least soil moisture depletion while spring wheat and spring canola seed crops and radish, mixture #2, winter wheat and winter canola cover crops were all equally high in soil moisture depletion. A similar pattern was found for crop water use as was found for water depletion (table 5.6).

It is difficult to compare water use efficiency of seed and cover crops as one was harvested for seed and the other for above ground biomass. However, among the cover crops, highest water use efficiency was for radish, Mixture #1, Mixture #2, and lowest for Austrian winter pea. Water use efficiency in the two spring cereal crops was significantly higher than spring canola and pea. (Table 5.6)

5.4.4 Water Infiltration into the soil

Water infiltration into fallow ground was significantly (and markedly) slower compared to all cover or seed crops (Table 5.8). There was no significant difference in water infiltration after any of the cover crops. Water infiltration into the soil after cover crops was on average significantly faster (273 liter sec^{-1}) than after the seed crops (714 liter sec^{-1}).

5.4.5 Wheat seed yield

Significant differences were found for wheat test weight, seed yield, and returns after variable input cost (Table 5.9) of the different two year rotations examined. As the price of wheat was based on 2013 prices, the wheat yield and wheat gross return (wheat yield x commodity price) are the same across treatments, thus only wheat yield will be presented to avoid duplication. After the spring and cover crops, winter wheat yield seed yield ranged from a low of 6,998 kg ha^{-1} when planted after spring barley crop, to a high of 7,831 kg ha^{-1} when planted after a radish cover crop. Wheat yield after the three single species broadleaf cover crops (i.e. radish, winter canola and Austrian winter pea) were significantly higher than wheat after a winter wheat cover crop. In general wheat yield after the cover crops (7,648 kg ha^{-1}) was similar to that from planting winter wheat onto fallow ground and both were significantly higher than after the seed crops (7,164 kg ha^{-1}). Test weights were significantly higher in the spring canola and mixture 2 plots (Table 5.10).

5.4.6 Variable input costs and returns after variable input costs

Variable input costs of six cover crops, four spring crops, summer fallow and soft white winter wheat are presented in Table 5.11. Variable input costs of the cover crops ranged from a low of \$592 ha^{-1} for winter wheat to a high of \$734 ha^{-1} for Mixture #2 (Table 5.11). The biggest difference between variable input costs of the cover crops was the price of the cover crop seed, which ranged from \$60 ha^{-1} for winter wheat (cover crop) seed to a high of \$202 ha^{-1} for mixture #2. All cover crop variable input costs exceeded the variable input cost of summer fallow. Average variable input costs for the seed crops (\$642) were very similar to the average variable input crops of the cover crops examined (\$662).

Significant difference were found between variable input costs of the cover crops and seed crops, returns after variable costs of cover and seed crop returns, winter wheat returns after variable input costs, and 2-year returns after variable input costs (total over two years) of possible cover crop-winter wheat and seed crop-winter wheat rotations examined (Table 5.12). In the analyses of each variable the effects of crops was highly significant and accounted for a very high proportion of the total variability.

Returns after variable input costs from the cover crops were all negative, as was that for summer fallow, albeit to a lesser value (Table 5.13). Returns after variable input costs of seed crop from pea also was negative and hence gross returns from pea did not cover the variable input costs of growing the crop. Highest returns after variable input costs for seed crops was from spring barley (\$208 ha^{-1}), followed by spring wheat (\$105 ha^{-1}), and then spring canola (\$100 ha^{-1}). Higher winter wheat yields were obtained following cover crops compared to seed crops, resulted in higher winter wheat returns after variable input costs, with an average winter wheat returns after variable input costs of \$1,269 ha^{-1}, compared to \$1,152 ha^{-1} for the seed crops. Amongst the cover crop-winter wheat rotations, highest winter wheat gross return was from winter wheat grown after Austrian winter pea (\$1,436 ha^{-1}). Similarly, among the seed crop-winter wheat rotations, highest winter wheat gross returns were winter wheat grown after pea (\$1,334 ha^{-1}). It should be noted that Figure 5.13 reflects variable input costs in this study specifically, which may vary from grower to grower.

Averaged over a two year rotation the cover crop-winter wheat rotations produced returns after variable input costs of \$302 ha^{-1} year^{-1},and the seed crop-winter wheat rotation produced returns after variable input costs of \$578 ha^{-1} year^{-1}, with returns after variable input costs from summer fallow-winter wheat in between at \$494 ha^{-1} year^{-1}. Highest year return after variable input costs was found for the spring barley-winter wheat rotation (\$648 ha^{-1} year^{-1}), followed by spring canola-winter wheat rotation (\$622 ha^{-1} year^{-1}).

5.4.7 Wheat Quality

Winter wheat quality results did not show any obvious pattern of increased or decreased quality following either seed or cover crops (Table 5.14). Grain protein was significantly higher following winter wheat and fallow. Flour yield was significantly higher following the spring canola seed and Mixture #2 cover crops, with the lowest flour yield after spring barley seed crops. Flour ash was higher following winter wheat but little difference was observed from any treatment. Grain hardness was higher following Mixture #2 and there were no significant differences for cookie diameter.

Significant differences were found for winter wheat seed yield following after seed and cover crops and wheat yields after cover crops were general higher, although not always significantly so. Cover crops do not have good net returns over operating costs; however, environmental benefits such as increased soil organic matter through greater crop biomass and nutrient cycling were not included in our calculations. It should be noted that variable input costs in this study were based on custom rates and crop prices in the year of 2013, both of these could greatly fluctuate in a different year with equipment owned by the grower. Water infiltration rates into the soil after the cover crops was markedly higher compared to the seed crops and much faster compared to summer fallow. Greater water infiltration could result in more moisture available for crops and can reduce runoff and hence soil erosion. Lack of root channels and soil compaction in summer fallow could explain some of the poor water infiltration into fallow ground. Radish cover crops had the quickest water infiltration rate and 0% water spread. The obvious conclusion would be that the deep penetrating and aggressive radish tap roots are having a desired effect. Soil nutrients were consistently higher in the fallow plots.

Crop water use results indicated that spring wheat used the most water throughout the growing season, while summer fallow used the least. In combination water use efficiency proved that the most efficient cover crops in this study were radish, Mixture #1 and Mixture #2.

Overall this study shows that there may be many short and long-term benefits to each of the cover crops examined, and winter wheat yields after cover crops were enhanced. However, it is difficult to ignore the basic economics. Seed crop return after variable input costs, one would hope, would add to the farm profits, while cover crops cost money to grow and yet have no immediate cash return. This study suggested that soil health could indeed be improved positively through adoption of cover crops with better water infiltration and soil nutrient availability after cover crops compared to spring seed crops grown in rotation with wheat. Environmental benefits and soil health should be an important part of our consideration in our farming systems. Overall, however, it is difficult to see with the current financial situation on our farms how growers could adopt cover crops on a large scale and to include these routinely in crop rotations with the associated reduced profits. The short-term improvement in winter wheat profitability is hardly large enough to justify the potential loss of farm returns caused by replacing a spring seed crop with a cover crop.

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Tables

Table 5.1 Number of wheat tiller (heads m^{-1}), wheat establishment rating, and plant height after heading following four spring seed crops, six cover crops and summer fallow at two sites in 2015.

		Wheat Heads† -- m^{-1} --		Establishment ------1 to 9-----		Height --- cm ---	
Seed Crops	Barley	48.5	ab	6.8	cd	89.4	ab
	Spring Canola	46.4	ab	7.1	cd	89.4	ab
	Spring Pea	51.5	ab	7.1	cd	88.8	ab
	Spring Wheat	51.1	ab	6.8	d	86.9	ab
Cover Crops	AWP	50.1	ab	8	b	90	ab
	Mixture 1	52.1	ab	8.1	ab	89.4	ab
	Mixture 2	45.8	b	7.8	bc	88.8	ab
	Radish	56	a	8.1	ab	91.3	a
	Winter Wheat	47.9	ab	7.8	bc	86.9	b
	Winter Canola	43.8	b	7.9	b	90	ab
	Fallow	44.9	b	8.8	a	91.3	a
	Mean	48.92		7.66		89.29	
	s.e. mean	3.054		0.22		1.12	

†Means within columns assigned different letter are significant ($P<0.05$)

† Wheat Heads = number of wheat tillers, Establishment = wheat establishment rating, and Height = plant height after heading.

Table 5.2 Mean squares from the analysis of variance of nitrate (NO_3), ammonium (NH_4), and total nitrogen (N) in soil analyses from three soil depth, following four spring seed crops, six cover crops and summer fallow at two sites in 2015.

Source	d.f. [a]	NO_3		NH_4		Total N	
Year	1	9,598.5	***	201.5	ns	12,581.7	***
Rep (Year)	2	6,175.7	**	197.4	ns	8,581.6	**
Site	1	2,883.6	*	145.8	ns	4,326.3	*
Year*Site	1	22.9	ns	58.5	ns	154.6	ns
Site*Rep (Year)	2	783.3	ns	22.6	ns	647.8	ns
Crop	10	52,070.7	***	1,112.5	ns	51,369.0	***
Year*Crop	10	2,477.2	ns	1,212.9	ns	5,397.0	ns
Site*Crop	10	14,541.3	**	1,257.1	ns	17,070.6	*
Year*Site*Crop	10	13,141.5	*	1,095.5	ns	15,608.1	*
Depth	3	41,453.7	***	9,564.1	***	78,430.0	***
Crop*Depth	30	26,331.5	*	1,089.5	ns	29,043.5	ns
Year*Depth	3	13,326.9	***	211.4	ns	13,172.9	**
Site*Depth	3	9,855.0	**	132.9	ns	11,390.4	**
Year*Crop*Depth	30	10,001.0	ns	1,187.3	ns	12,921.0	ns
Site*Crop*Depth	30	20,249.5	ns	1,915.5	ns	24,963.3	ns
Year*Site*Depth	3	12,819.3	***	121.5	ns	15,043.4	**
Year*Site*Crop*Depth	16	3,521.5	ns	425.4	ns	4,408.1	ns

d.f.[a]= degrees of freedom.

* = $0.01<P<0.05$; ** = $0.001<P<0.01$; *** = $P<0.001$.

†NO_3=Nitrate, NH_4=Ammonium, and Total N=Total nitrogen.

Table 5.3 Soil nitrate, (NO_3), ammonium (NH_4), and total nitrogen (N) following four spring seed crops, six cover crops and summer fallow at two sites in 2015. Data presented are the sum from 3 different soil depths.

		Nitrate†	Ammonium	Total Nitrogen
		kg/ha		
Seed Crops	Barley	18.1 ^{c}	9 ^{a}	27.2 ^{c,d}
	Spring Canola	20 ^{c}	6.7 ^{a}	26.7 ^{c,d}
	Spring Pea	41.7 ^{b}	7 ^{a}	48.7 ^{b}
	Spring Wheat	30.3 ^{c,b}	7.9 ^{a}	38.2 ^{c,b}
Cover Crops	AWP	28.7 ^{c}	6.2 ^{a}	34.9 ^{c,b,d}
	Mixture 1	16.4 ^{c}	5.1 ^{a}	21.5 ^{d}
	Mixture 2	20.6 ^{c}	8 ^{a}	28.6 ^{c,d}
	Radish	21.5 ^{c}	4.8 ^{a}	26.3 ^{c,d}
	Winter Wheat	16.3 ^{c}	5 ^{a}	21.4 ^{d}
	Winter Canola	22.1 ^{c}	8.4 ^{a}	30.6 ^{d}
	Fallow	65.6 ^{a}	5.7 ^{a}	71. 2 ^{a}
	Mean	27.4	6.7	30.4
	s.e.	4.3	1.71	4.97

†Means within columns assigned different letter are significant ($P<0.05$).

Table 5.4 Soil nitrate, ammonium, and total nitrogen at four soil depth. Data presented are averaged over four spring seed crops, six cover crops and summer fallow at two sites and two years.

Depth	Nitrate†	Ammonium	Total Nitrogen
	kg/ha		
30	47.7 ^{a}	16.7 ^{a}	64.4 ^{a}
60	16.9 ^{b}	7.8 ^{b}	24.7 ^{b}
90	22.6 ^{b}	0 ^{c}	22.6 ^{b}
120	20.1 ^{b}	0.3 ^{c}	20.3 ^{b}
Mean	26.8	6.2	33
s.e. mean	2.53	1.01	2.97

†Means within columns assigned different letter are significant ($P<0.05$).

Table 5.5 Mean squares from the analysis of variance of post-harvest soil moisture, soil moisture depletion, crop water use, and water use efficiency following four spring seed crops, six cover crops and summer fallow at two sites and two years. Analyses are based on data collected on only two replicates.

Source	d.f. [a]	PostH[†]	Depl	CWU	WUE
Year	1	437.5 ***	14 *	7.2 ns	1,768,251.10 ***
Rep (Year)	2	5.7 ns	5.7 ns	5.7 ns	9,463.50 ns
Site	1	385.2 ***	363.6 ***	405.8 ***	1,471,326.50 ***
Year*Site	1	93.7 ***	409.5 ***	372.3 ***	1,300,602.90 ***
Site*Rep (Year)	2	0.4 ns	0.4 ns	0.4 ns	44,880.50 ns
Crop	10	1,421.80 ***	1,421.80 ***	1,421.80 ***	5,462,945.30 ***
Year*Crop	10	101.4 **	101.4 **	101.4 **	3,766,755.40 ***
Site*Crop	10	64.8 *	64.8 *	64.8 *	2,142,190.30 ***
Year*Site*Crop	10	27.7 ns	27.7 ns	27.7 ns	1,724,745.80 ***
Depth	3	222.3 ***	222.3 ***	222.3 ***	102,060.80 ns
Crop*Depth	30	195.9 **	195.9 **	195.8 **	248,101.90 ns
Year*Depth	3	164.4 ***	164.4 ***	164.4 ***	5,545.30 ns
Site*Depth	3	96 ***	96 ***	96 ***	7,183.20 ns
Year*Crop*Depth	30	209.1 **	209.1 **	209.1 **	318,528.90 ns
Site*Crop*Depth	30	239.4 ***	239.4 ***	239.4 ***	82,508.50 ns
Year*Site*Depth	3	34.3 *	34.3 *	34.3 *	5,614.20 ns
Year*Site*Crop*Depth	30	44 ns	44 ns	44 ns	15,612.90 ns

d.f.[a]= degrees of freedom.

* = 0.01<P<0.05; ** = 0.001<*P*<0.01; *** = P<0.001.

[†] PostH = post-harvest soil moisture, Depl = soil moisture depletion, CWU = crop water use, WUE = water use efficiency.

Table 5.6 Average post-harvest soil moisture, soil moisture depletion, crop water use, and water use efficiency of four spring seed crops, six cover crops and summer fallow at two sites and two years. Data presented are averaged over 4 soil depths.

	Crop	Post-Harvest†	Depletion	Crop Water Use	Water Use Efficiency
		-- % --	-- % --	-- % --	
Seed Crops	Barley	10.8 ^{c}	9.2 ^{cd}	12.5 ^{cd}	326 ^{b}
	Spring Canola	9.9 ^{cde}	10 ^{abc}	13.4 ^{abc}	147.4 ^{c}
	Spring Pea	11.8 ^{b}	8.1 ^{e}	11.5 ^{e}	144.3 ^{c}
	Spring Wheat	9 ^{e}	10.7 ^{a}	14.1 ^{a}	285.1 ^{b}
Cover Crops	AWP	10.9 ^{bc}	8.9 ^{de}	12.3 ^{de}	60.8 ^{d}
	Radish	9.7 ^{de}	10.1 ^{abc}	13.5 ^{abc}	429.9 ^{a}
	Mixture 1	10.1 ^{cd}	9.6 ^{bcd}	13 ^{bcd}	411.4 ^{a}
	Mixture 2	9.5 ^{de}	10.3 ^{abc}	13.6 ^{abc}	412.9 ^{a}
	Winter Wheat	9.6 ^{de}	10.2 ^{abc}	13.6 ^{abc}	293.4 ^{b}
	Winter Canola	9.4 ^{de}	10.4 ^{ab}	13.8 ^{ab}	282.9 ^{b}
	Fallow	16.9 ^{a}	2.9 ^{f}	6.3 ^{f}	24 ^{d}
	Mean	10.9	9.9	13.3	315.2
	s.e. mean	0.34	0.34	0.34	26.19

†Means within columns assigned different letters are significant ($P<0.05$).

† Post-Harvest = post-harvest soil moisture, Depletion = soil moisture depletion.

Table 5.7 Duncan grouping for post-harvest, moisture depletion, crop water use, and water use efficiency by soil sample depth. Data averaged over four seed crop and six cover crops and summer fallow.

Depth (cm)	Post-Harvest†		Depletion		Crop Water Use		Water Use Efficiency	
30	9	d	10.7	a	14.1	a	229	b
60	9.9	c	9.8	b	13.2	b	250.8	b
90	11	b	8.7	c	12.1	c	249.1	b
120	13.7	a	3.4	d	9.7	d	316.3	a
Mean	10.9		8.15		12.3		261.3	
s.e. mean	0.33		0.33		0.33		26.19	

†Means within columns assigned different letters are significant ($P<0.05$).

† Post Harvest = post-harvest soil moisture, Depletion = soil moisture depletion.

Table 5.8 Average water infiltration and water spread of four spring seed crops, six cover crops and summer fallow at two sites and two years.

	Crop	Infiltration†		Spread	
		-- sec/L^{-1}--		-cm-	-- % --
Seed Crops	Barley	869	b	2.8	10
	Spring Canola	766	bc	1.27	20
	Spring Pea	484	cd	2.79	16
	Spring Wheat	737	bc	1.8	10
Cover Crops	AWP	248	d	2.54	20
	Mixture 1	335	d	2.54	10
	Mixture 2	322	d	2.54	15
	Radish	229	d	0	0
	Winter Wheat	345	d	3.81	10
	Winter Canola	279	d	1.27	25
	Fallow	1,334	a	5.6	76
	Mean	540.8		2.42	19.3

‡Means within columns assigned different letters are significant ($P<0.05$).

†Infiltration=liters/sec^{-1}

Table 5.9 Mean squares from the analysis of variance of wheat grain test weight, wheat seed yield (kg ha^{-1}), winter wheat gross returns (wheat yield x commodity price) following four spring seed crops, six cover crops and summer fallow at two sites in 2015.

Source	d.f.^{a}	Test Weight†		Seed Yield		Gross Returns	
Site	1	440	***	122,002,304.30	***	3,133,165.60	***
Rep (Site)	6	3.2	ns	3,540,327.40	**	128,104.40	**
Crop	10	29.3	***	7,963,635.10	***	302,505.60	***
Site*Crop	10	10.6	**	5,377,358.70	**	214,248.90	***

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

†Test weight=wheat grain test weight, Seed Yield=wheat seed yield (kg ha^{-1}), Gross returns=wheat crop yield x commodity price.

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

Table 5.10 Wheat test weight, wheat seed yield (bu acre^{-1}), wheat seed yield (kg acre^{-1}), winter wheat gross return (\$ acre^{-1}), and gross return (\$ ha^{-1}) following four spring seed crops, six cover crops and summer fallow at two sites in 2015.

	Crop	Test Weight†		Seed Yield		Seed Yield		Gross Return		Gross Return	
		--- lb bu^{-1} ---		-bu acre^{-1} -		- kg ha^{-1} -		-- \$ acre^{-1} --		--\$ ha^{-1} --	
Seed Crops	Barley	67.8	de	91.8	d	6,998.8	d	589.3	d	1,414.2	d
	Spring Canola	69.2	a	95.1	cd	7,358.9	cd	610.0	cd	1,463.9	cd
	Spring Pea	68.8	ab	94.6	cd	7,288.0	cd	607.0	cd	1,456.8	cd
	Spring Wheat	68.6	bc	91.3	d	7,013.9	d	585.3	d	1,404.8	d
Cover Crops	AWP	68.5	bc	101.3	a	7,752.4	a	649.5	a	1,558.8	a
	Mixture 1	68.2	cd	98.7	abc	7,532.8	abc	633.3	abc	1,519.9	abc
	Mixture 2	69.2	a	100.0	abc	7,740.9	abc	641.5	abc	1,539.6	abc
	Radish	68.4	bc	102.3	a	7,831.9	a	656.1	a	1,574.5	a
	Winter Wheat	67.3	e	95.8	bcd	7,212.1	bcd	614.4	bcd	1,474.4	bcd
	Winter Canola	69.0	ab	101.4	a	7,818.7	a	650.3	a	1,560.7	a
	Fallow	68.2	cd	101.0	ab	7,679.8	ab	647.7	ab	1,554.4	ab
	Mean	68.5		97.6		7,475.3		625.9		1,502.0	
	s.e mean	0.19		1.73		139.32		11.13		26.72	

† Means within columns assigned different letters are significant (P<0.05).

Table 5.11 Variable input costs of six cover crops, four spring seed crops and a soft white winter wheat crop.

Input Item	Spring planted Cover Crops						Summer Fallow	Spring Seed Crops				Soft White Winter Wheat
	Austrian Winter Pea	Radish	Mixture #1	Mixture #2	Winter Canola	Winter Wheat		Spring Barley	Spring Canola	Spring Pea	Spring Wheat	
	$ ha^{-1}											
Fertilizer	288.31	288.31	288.31	288.31	288.31	288.31	288.31	288.31	288.31	288.31	288.31	326.17
Seed Cost	187.79	109.71	157.52	202.00	60.69	60.04	-	53.37	88.61	187.79	54.61	47.44
Herbicides	27.06	27.06	27.06	27.06	27.06	27.06	27.06	47.81	14.04	15.62	47.81	0.00
Insecticides	9.44	9.44	9.44	9.44	9.44	9.44	-	9.44	9.44	9.44	9.44	9.44
Cultivation	94.24	94.24	94.24	94.24	94.24	94.24	94.24	94.24	94.24	94.24	94.24	94.24
Planting	48.26	48.26	48.26	48.26	48.26	48.26	48.26	48.26	48.26	48.26	48.26	48.26
Pesticide Application	22.86	22.86	22.86	22.86	22.86	22.86	22.86	22.86	22.86	22.86	22.86	22.86
Harvest	-	-	-	-	-	-	-	51.89	51.89	51.89	51.89	51.89
Mow	42.01	42.01	42.01	42.01	42.01	42.01	-	-	-	-	-	-
Total input cost	719.97	641.88	689.70	734.17	592.86	592.22	480.73	616.18	617.64	718.41	617.42	600.30

Table 5.12 Mean Squares from the analysis of variance of seed and cover crop variable input costs, seed and cover crop returns after variable input costs, winter wheat returns after variable input costs, 1-year returns (averaged over two years) after variable input costs of seed or cover crops-winter wheat rotation, and 2-year returns (total over two years) after variable input costs of seed or cover crops-winter wheat rotation.

Source	d.f. ^{a}	Seed/Cover crop variable input cost	Seed/Cover crop returns after variable input costs	Winter Wheat returns after variable input costs	1-year returns after variable input costs	2-year returns after variable input costs
Site	1	29.5 ***	1,228.7 $^{\text{ns}}$	3,183,871.7 ***	747,905.2 ***	2,991,620.8 ***
Rep (Site)	6	0.0 $^{-}$	3,595.9 $^{\text{ns}}$	119,108.4 **	30,067.5 *	120,269.8 $^{\text{ns}}$
Crop	10	1,629,839.2 ***	10,405,768.0 ****	1,138,659.2 ***	1,762,719.7 ***	7,050,878.8 ***
Site*Crop	10	2,734.2 ***	60,472.6 ****	214,507.0 ***	57,929.0 **	231,715.9 **

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

* = 0.01<P<0.05; ** = 0.001<*P*<0.01; *** = P<0.001.

Table 5.13 Seed and cover crop variable input costs, seed and cover crop returns after variable costs, winter wheat returns after variable input costs, 1-year returns (averaged over two years) after variable input costs of seed or cover crop-winter wheat rotations, and 2-year returns (total over two years) after variable input costs of seed or cover crop-winter wheat rotations.

	Crop	Seed/Cover crop variable input cost†	Seed/Cover crop returns after variable input costs	Winter wheat returns after variable input costs	1-year returns after variable input costs	2-year returns after variable input costs
		---------- \$ ha^{-1} ----------				
Seed Crops	Barley	636.6 ^{g}	207.7 ^{a}	1,088.2 ^{e}	647.9 ^{a}	1,296.0 ^{a}
	Spring Canola	638.8 ^{f}	100.1 ^{b}	1,099.8 ^{e}	621.7 ^{ab}	1,243.4 ^{ab}
	Spring Pea	647.4 ^{c}	-438.1 ^{d}	1,333.8 ^{b}	447.8 ^{d}	895.7 ^{d}
	Spring Wheat	646.9 ^{d}	104.8 ^{b}	1,087.0 ^{e}	595.9 ^{b}	1,191.8 ^{b}
Cover Crops	AWP	640.3 ^{e}	-640.3 ^{f}	1,435.8 ^{a}	397.8 ^{e}	795.5 ^{e}
	Mixture 1	690.5 ^{b}	-690.5 ^{g}	1,302.9 ^{bcd}	306.2 ^{f}	612.4 ^{f}
	Mixture 2	845.4 ^{a}	-845.4 ^{h}	1,322.6 ^{bc}	238.6 ^{g}	477.2 ^{g}
	Radish	590.2 ^{j}	-590.2 ^{e}	1,248.5 ^{cd}	329.2 ^{f}	658.3 ^{f}
	Winter Wheat	617.0 ^{h}	-617.0 ^{ef}	1,234.5 ^{d}	308.9 ^{f}	617.7 ^{f}
	Winter Canola	605.3 ^{i}	-605.3 ^{ef}	1,068.2 ^{e}	231.5 ^{g}	463.0 ^{g}
	Fallow	240.0 ^{k}	-239.9 ^{c}	1,228.4 ^{d}	494.2 ^{c}	988.5 ^{c}
	Mean	618.0	-386.7	1,222.7	420.0	839.9
	s.e. mean	0.50	13.91	26.69	15.28	30.57

† Means within columns assigned different letters are significant ($P<0.05$).

Table 5.14 Average wheat grain quality (grain protein, grain flour yield, flour ash, break flour yield, grain hardness, and cookie diameter) when grown following four spring seed crops, six cover crops and summer fallow at two sites in 2015.

		Protein†	Flour Yield	Flour Ash	Break Flour Yield	Grain Hardness	Cookie Diameter
		----%----	---%---	---%---	---%---	---%---	---cm---
Seed Crops	Barley	9.5 ab	64.3 c	0.31 ab	40.5 c	25.5 ab	9.0
	Spring Canola	8.1 e	67.3 a	0.30 c	42 ab	25.5 ab	9.0
	Spring Pea	8.9 cd	66.1 aba	0.30 c	41.2 bc	25 ab	9.0
	Spring Wheat	9.3 abc	65.3 bc	0.31 ab	41.3 abc	25.3 ab	8.9
Cover Crops	AWP	9.0 bc	66.4 ab	0.31 ab	41.8 ab	23.8 b	8.9
	Mixture 1	9.2 abc	66.4 ab	0.31 ab	42 ab	25.5 ab	8.9
	Mixture 2	8.5 de	67.2 a	0.30 b c	42.3 a	24.5 ab	9.0
	Radish	8.9 c	66.2 ab	0.31 ab	41.5 ab	26.3 a	8.9
	Winter Wheat	9.6 a	65.5 b c	0.31 a	41.7 ab	24.3 ab	8.9
	Winter Canola	8.4 e	66.6 ab	0.30 c	41.8 ab	23.8 b	8.9
	Fallow	9.6 a	65.4 bc	0.31 ab	41 bc	26.3 a	9.0
	Mean	9.0	66.1	0.3	41.6	25.1	8.9
	s.e. mean	0.14	0.38	2.5	0.31	0.69	0.07

†Means within columns assigned different letters are significant (P<0.05).

Chapter 6:

Conclusions and Recommendations

A trial was conducted to test the adaptability of spring planted cover crops in the high rainfall regions of the Pacific Northwest (PNW). Six different cover crops (winter wheat, Austrian winter pea, winter canola, radish, cover crop Mixture #1 [mixture of triticale, buckwheat, radish, Austrian winter pea, and Sudan grass], and cover crop Mixture #2 [radish, turnip, oats, pearl millet, and foxtail millet] were grown in field trials along with four seed crops (spring wheat, barley, canola, and pea), and a no crop summer fallow treatment, at two locations. Crops were monitored throughout the growing season. Above ground biomass and root biomass (tap root crops only) was recorded on all cover crops and seed yield recorded on the seed crops. The following year the complete trial area was planted to winter wheat and harvested according to the previous year crop.

The specific objectives for this research include:

1. Compare establishment, crop stand, weed presence, above ground and root biomass of different cover crops, and determine the effects of cover crops on soil moisture content, water infiltration rate, and nutrient availability (Chapter 3).
2. Compare establishment, crop stand, weed presence on different spring see crops, and determine the effects of these seed crops on soil moisture content, water infiltration rate, and nutrient availability, and to compare yield potential and potential crop return of different seed crops (Chapter 4).
3. Determine the effect of cover and seed crops on productivity and profitability of following wheat crops (Chapter 5).

The potential for cover crops to be included in winter wheat crop rotations depends on the benefits provided in a crop rotation. Each cropping system has a use for cover crops, the challenge is deciding which cover crop can provide the necessary benefits.

In this study winter wheat should be considered as a cover crop if above ground biomass production is of greatest importance. However, including another wheat crop into a system already dominated by wheat would be unlikely to reduce disease or weed infestation. In addition, winter wheat had the lowest spread, infiltration rate, nitrate, and total nitrogen rates. Broadleaves such as radish and canola provide the opportunity to eliminate grassy weeds and break common pest cycles associated with winter wheat. Amongst the broadleaf options, radish produced the most biomass, fastest water infiltration rate, and least water spread. Some of the broadleaf crop species, particularly radish, also produced high tap root biomass which would held control soil compaction, although the tap roots did not have a significant impact on water infiltration. Winter canola produced similar above ground biomass as the mixtures or radish, but reduced tap root biomass.

Managing a cover crop of a single crop species, however, may be easier to manage compared to one where broadleaves and grasses are mixed. All cover crops used significant amounts of soil moisture and depleted soil moisture markedly over that in the fallow treatment. If soil moisture is the limiting factor in crop productivity it seems unlikely that replacing a spring seed crop with a non-harvestable cover crop would be favorable. However, it will be necessary to determine the positive (and negative) effects of these cover crops on the following winter wheat crops before firm conclusions can be made.

Spring wheat and barley both produced significantly higher yield and crop return value compared to spring canola, while spring pea produced negative crop returns. Although this data supports the fact that a large majority of the acreage planted in this area is in cereal crops, it should be noted that spring pea and canola offer rotational benefits that are unseen in this study.

Weed counts were significantly higher in the pea and canola plots. This can be explained by the quick growth and fibrous roots of these grass species. As well as the fast growing nature of the weeds competing with these crops. Spring pea plots in this study had a significantly lower establishment rate which explains the low yield. Establishment may have been effected by seeding depth. Spring wheat yields in this study were higher than average for this area. Average yield for spring wheat in this area ranges from 1,700 to 4,000 kg/ha $^{-1}$. The average yield in this study for spring wheat was 3,642 kg/ha. The value of barley and wheat in this study were significantly higher than pea and canola. This value varies on a yearly basis depending on market prices.

Leaf area index of spring canola, spring wheat and barley were significantly higher than pea. Leaf area index is used to measure the amount of ground cover provided by the crop during the growing season. With increased ground cover, crops are more likely able to out compete weed species while conserving moisture content in the soil. As seen in this study these four seed crops can be grown successfully in this region with a wide variety of benefits. Market predictions for upcoming seasons are important in indicating which crops should be grown to ensure a profitable growing season.

Significant differences were found for winter wheat seed yield following seed and cover crops and wheat yields after cover crops were general higher, although not always significantly so. Returns after variable input costs from cover crops were all negative; however, environmental benefits such as increased soil organic matter through greater crop biomass are difficult to add a value to, and were not included in our calculations. Water infiltration rates into the soil after the cover crops was markedly higher compared to the seed crops and much faster compared to summer fallow. Greater water infiltration could result in more moisture available for crops and can reduce runoff and hence soil erosion. Lack of root channels and soil compaction in summer fallow could explain some of the poor water infiltration into fallow ground. Radish cover crops had the quickest water infiltration rate and 0% water spread. The obvious conclusion would be that the deep penetrating and aggressive radish tap roots are having a desired effect. Soil nutrients were consistently higher in the fallow plots.

Crop water use results indicated that spring wheat used the most water throughout the growing season, while summer fallow used the least. In combination water use efficiency proved that the most efficient cover crops in this study were radish, Mixture #1 and Mixture #2.

Overall this study shows that there may be many short and long-term benefits to each of the cover crops examined, and winter wheat yields after cover crops were enhanced. However, it is difficult to ignore the basic economic information collected here. Return after variable input costs of seed crops, one would hope, adds to the farm profits, while cover crops cost money to grow and yet have no immediate cash return.

Obviously, crop economic results are highly dependent on crop prices which vary year to year and even month to month. In this economic analyses we used local crop prices from 2013 where wheat price was \$0.23 kg^{-1} (~\$6.28 bu^{-1}); barley \$0.12 kg^{-1} (~\$112 ton^{-1}); canola \$0.396 kg^{-1} (~\$0.18 lb^{-1}); and pea \$0.287 kg^{-1} (~\$13.05 lb^{-1}). In general, crop prices in 2016 were lower, but particularly low for wheat compared to the other crops under investigation. Crop prices in 2016 were 0.167 kg^{-1} (~\$4.55 bu^{-1}) for wheat, a 27% reduction from 2013; \$0.128 kg^{-1} (~\$119 ton^{-1}) for barley, a 7% increase from 2013; \$0.370 kg^{-1} (~\$0.17 lb^{-1}) for canola, a 7% reduction from 2013; and \$0.271 kg^{-1} (~\$12.32 lb^{-1} for pea, a 6% reduction from 2013. Reduced crop prices in 2016 of course resulted in a reduced 2-year return after variable input costs for all the seed crop-winter wheat and cover crop-winter wheat rotations. However the relative values were surprisingly similar (Table 6.1). In both scenarios barley-winter wheat was most profitable followed by canola-winter wheat. The greater reduction in wheat price from 2013 to 2016 meant that spring wheat-winter wheat rotation was most effected and in 2016 this rotation was not significantly more profitable (return after variable input costs) than fallow-winter wheat. However, the changes in relative rankings was somewhat slight and the correlation between 2-year return after variable input costs in the two years (r = 0.978) accounted for 96% in the variation between crop rotation returns over years.

This study suggested that soil health could indeed be improved positively by adoption of cover crops with better water infiltration and soil nutrient availability after cover crops compared to spring seed crops grown in rotation with wheat. Indeed highest winter wheat yields were found following cover crops compared to seed crops. Environmental benefits and soil health should be an important consideration in our farming systems. Overall, however, it is difficult to see with the current financial situation on our farms how growers could adopt cover crops on a large scale and to include these routinely in crop rotations with the reduced return after variable input costs found here. Using 2013 crop prices the 2-year return after variable input costs from a spring seed crop-winter wheat rotation was $1,157, and that from a cover crop-winter wheat rotation had 2-year return after variable input costs of only $604, or an average difference or farmer loss of $553 over 2 years. Using 2016 crop prices the 2-year return after variable input costs from a spring seed crop-winter wheat rotation was markedly lower at $707, but the average cover crop-winter wheat rotation 2-year return after variable input costs with these crop prices was reduced to $184, or an average difference or farmer loss of $523 over the two years. Therefore the short-term improvement in winter wheat profitability from including cover crop to replace seed crops is hardly large enough to justify the potential loss of return after variable input costs caused by replacing a spring seed crop with a cover crop.

Table 6.1 Two-year after variable input costs of spring seed crop or cover crop plus following wheat crop based on 2013 and 2016 crop prices.

		Gross Two-Year Return after variable input costs†	
	Crop	2013 prices	2016 prices
		--------------- $ ha^{-1} -------------	
Seed Crops	Barley	1,296 ^{a}	961 ^{a}
	Spring Canola	1,243 ^{ab}	789 ^{b}
	Spring Pea	896 ^{d}	482 ^{d}
	Spring Wheat	1,192 ^{b}	595 ^{c}
Cover Crops	AWP	796 ^{e}	366 ^{e}
	Mixture 1	612 ^{f}	194 ^{f}
	Mixture 2	477 ^{g}	53 ^{g}
	Radish	658 ^{f}	225 ^{f}
	Winter Wheat	618 ^{f}	188 ^{f}
	Winter Canola	463 ^{g}	79 ^{g}
	Fallow	989 ^{c}	560 ^{c}
	Mean Seed crop	1,157	707
	Mean Cover crop	604	184
	Difference	553	523
	Mean all crops	840	408
	s.e. mean	31	24

†Costs per unit were generated using local 2013 prices and projected 2016 prices from 2016 Distribution Grain Rotations Budget.

Appendix:

Subsequent Winter Wheat Production Following Seed and Cover Crops

Table A.1 Amount and cost per unit of variable input cost for Austrian winter pea cover crops grown in the PNW.

Austrian winter pea	Unit per Acre†	Unit	Cost per Unit	Cost per Acre
Fertilizer ($ acre):	80	lb.	$1.45	$116.68
Seed Cost ($ acre):	211	lb.	$0.36	$76.00
Pesticides ($ acre):				
2,4-D	32	oz.	$0.15	$4.76
Roundup	14	oz.	$0.41	$5.68
Surfactant	1.5	oz.	$0.34	$0.51
Warrior II	1.96	oz.	$1.70	$3.31
M90 (Surfactant)	1.5	oz.	$0.34	$0.51
Total				$14.77
Custom ($ acre):				
Cultivate	-	acre	-	$38.14
Planting	-	acre	-	$19.53
Pesticide application	-	acre	-	$9.25
Mow	-	acre	-	$17.00
Total				$83.92

† Cost per units were generated using the 2014 Northern Idaho Enterprise Budget, Bulletin 729 custom Rates, Clearwater seed prices.

Table A.2 Amount and cost per unit of variable input cost for radish cover crops grown in the PNW.

Radish	Unit per Acre	Unit	Cost per Unit	Cost per Acre
Fertilizer ($ acre):	80	lb.	$1.45	$116.68
Seed Cost ($ acre):	36	lb.	$1.25	$44.40
Pesticides ($ acre):				
2,4-D	32	oz.	$0.15	$4.76
Roundup	14	oz.	$0.41	$5.68
Surfactant	1.5	oz.	$0.34	$0.51
Warrior II	1.96	oz.	$1.70	$3.31
M90 (Surfactant)	1.5	oz.	$0.34	$0.51
Total				$14.77
Custom ($ acre):				
Cultivate	-	acre	-	$38.14
Planting	-	acre	-	$19.53
Pesticide application	-	acre	-	$9.25
Mow	-	acre	-	$17.00
Total				$83.92

† Cost per units were generated using the 2014 Northern Idaho Enterprise Budget, Bulletin 729 Custom Rates, Clearwater seed prices.

Table A.3 Amount and cost per unit of variable input cost for Mixture #1 cover crops grown in the PNW.

Mixture #1	Unit per Acre	Unit	Cost per Unit	Cost per Acre
Fertilizer ($ acre):	80	lb.	$1.45	$116.68
Seed Cost ($ acre):	15	lb.	$4.25	$63.75
Pesticides ($ acre):				
2,4-D	32	oz.	$0.15	$4.76
Roundup	14	oz.	$0.41	$5.68
Surfactant	1.5	oz.	$0.34	$0.51
Warrior II	1.96	oz.	$1.70	$3.31
M90 (Surfactant)	1.5	oz.	$0.34	$0.51
Total				$14.77
Custom ($ acre):				
Cultivate	-	acre	-	$38.14
Planting	-	acre	-	$19.53
Pesticide application	-	acre	-	$9.25
Mow	-	acre	-	$17.00
Total				$83.92

† Cost per units were generated using the 2014 Northern Idaho Enterprise Budget, Bulletin 729 Custom Rates, Clearwater seed prices.

Table A.4 Amount and cost per unit of variable input cost for Mixture #2 cover crops grown in the PNW.

Mixture #2	Unit per Acre	Unit	Cost per Unit	Cost per Acre
Fertilizer ($ acre):	80	lb.	$1.45	$116.68
Seed Cost ($ acre):	16	lb.	$5.18	$81.75
Pesticides ($ acre):				
2,4-D	32	oz.	$0.15	$4.76
Roundup	14	oz.	$0.41	$5.68
Surfactant	1.5	oz.	$0.34	$0.51
Warrior II	1.96	oz.	$1.70	$3.31
M90 (Surfactant)	1.5	oz.	$0.34	$0.51
Total				$14.77
Custom ($ acre):				
Cultivate	-	acre	-	$38.14
Planting	-	acre	-	$19.53
Pesticide application	-	acre	-	$9.25
Mow	-	acre	-	$17.00
Total				$83.92

† Cost per units were generated using the 2014 Northern Idaho Enterprise Budget, Bulletin 729 Custom Rates, Clearwater seed prices.

Table A.5 Amount and cost per unit of variable input cost for winter canola cover crops grown in the PNW.

Winter Canola	Unit per Acre	Unit	Cost per Unit	Cost per Acre
Fertilizer ($ acre):	80	lb.	$1.45	$116.68
Seed Cost ($ acre):	3.8	lb.	$6.50	$24.56
Pesticides ($ acre):				
2,4-D	32	oz.	$0.15	$4.76
Roundup	14	oz.	$0.41	$5.68
Surfactant	1.5	oz.	$0.34	$0.51
Warrior II	1.96	oz.	$1.70	$3.31
M90 (Surfactant)	1.5	oz.	$0.34	$0.51
Total				$14.77
Custom ($ acre):				
Cultivate	-	acre	-	$38.14
Planting	-	acre	-	$19.53
Pesticide application	-	acre	-	$9.25
Mow	-	acre	-	$17.00
Total				$83.92

† Cost per units were generated using the 2014 Northern Idaho Enterprise Budget, Bulletin 729 Custom Rates, Clearwater seed prices.

Table A.7 Amount and cost per unit of variable input cost for winter wheat cover crops grown in the PNW.

Winter Wheat	Unit per Acre	Unit	Cost per Unit	Cost per Acre
Fertilizer ($ acre):	80	lb.	$1.45	$116.68
Seed Cost ($ acre):	101	lb.	$0.24	$24.30
Pesticides ($ acre):				
2,4-D	32	oz.	$0.15	$4.76
Roundup	14	oz.	$0.41	$5.68
Surfactant	1.5	oz.	$0.34	$0.51
Warrior II	1.96	oz.	$1.70	$3.31
M90 (Surfactant)	1.5	oz.	$0.34	$0.51
Total				$14.77
Custom ($ acre):				
Cultivate	-	acre	-	$38.14
Planting	-	acre	-	$19.53
Pesticide application	-	acre	-	$9.25
Mow	-	acre	-	$17.00
Total				$83.92

† Cost per units were generated using the 2014 Northern Idaho Enterprise Budget, Bulletin 729 Custom Rates, Clearwater seed prices.

Table A.8 Amount and cost per unit of variable input cost for fallow in the PNW.

Fallow	Unit per Acre	Unit	Cost per Unit	Cost per Acre
Pesticides ($ acre):				
2,4-D	32	oz.	$0.15	$4.76
Roundup	14	oz.	$0.41	$5.68
Surfactant	1.5	oz.	$0.34	$0.51
Total				10.95
Custom ($ acre):				
Pesticide application	-	acre	-	$9.25
Total				$9.25

† Cost per units were generated using the 2014 Northern Idaho Enterprise Budget, Bulletin 729 Custom Rates, Clearwater seed prices.

Table A.9 Amount and cost per unit of variable input cost for spring wheat seed crops grown in the Pacific North West.

Spring Wheat	Unit per Acre	Unit	Cost per Unit	Cost per Acre
Fertilizer ($ acre):	80	lb.	$1.45	$116.68
Seed Cost ($ acre):	83	lb.	$0.26	$21.60
Pesticides ($ acre):				
Huskie	12	oz.	$0.89	$10.70
Orion	17	oz.	$0.51	$8.65
Warrior II	1.96	oz.	$1.70	$3.31
M90 (Surfactant)	1.5	oz.	$0.34	$0.51
Total				$23.17
Custom ($ acre):				
Cultivate	-	acre	-	$38.14
Planting	-	acre	-	$19.53
Pesticide application	-	acre	-	$9.25
Harvest	-	acre	-	$21.00
Total				$87.92

† Cost per units were generated using the 2014 Northern Idaho Enterprise Budget, Bulletin 729 Custom Rates, Direct Seed Budget.

Table A.10 Amount and cost per unit of variable input cost for spring canola seed crops grown in the Pacific North West.

Spring Canola	Unit per Acre	Unit	Cost per Unit	Cost per Acre
Fertilizer ($ acre):	80	lb.	$1.45	$116.68
Seed Cost ($ acre):	3.26	lb.	$11.00	$35.86
Pesticides ($ acre):				
Round Up	14	oz.	$0.41	$5.68
Warrior II	1.96	oz.	$1.70	$3.31
M90 (Surfactant)	1.5	oz.	$0.34	$0.51
Total				$9.50
Custom ($ acre):				
Cultivate	-	acre	-	$38.14
Planting	-	acre	-	$19.53
Pesticide application	-	acre	-	$9.25
Harvest	-	acre	-	$21.00
Total				$87.92

† Cost per units were generated using the 2014 Northern Idaho Enterprise Budget, Bulletin 729 Custom Rates, Direct Seed Budget.

Table A.11 Amount and cost per unit of variable input cost for spring pea seed crops grown in the Pacific North West.

Spring Pea	Unit per Acre	Unit	Cost per Unit	Cost per Acre
Fertilizer ($ acre):	80	lb.	$1.45	$116.68
Seed Cost ($ acre):	245	lb.	$0.31	$76.00
Pesticides ($ acre):				
Basagran	1.5	pints	$0.41	$5.68
Crop Oil	0.5	pints	$1.28	$0.64
Warrior II	1.96	oz.	$1.70	$3.31
M90 (Surfactant)	1.5	oz.	$0.34	$0.51
Total				$10.14
Custom ($ acre):				
Cultivate	-	acre	-	$38.14
Planting	-	acre	-	$19.53
Pesticide application	-	acre	-	$9.25
Harvest	-	acre	-	$21.00
Total				$87.92

† Cost per units were generated using the 2014 Northern Idaho Enterprise Budget, Bulletin 729 Custom Rates, Direct Seed Budget.

Table A.12 Amount and cost per unit of variable input cost for spring barley seed crops grown in the Pacific North West.

Spring Barley	Unit per Acre	Unit	Cost per Unit	Cost per Acre
Fertilizer ($ acre):	80	lb.	$1.45	$116.68
Seed Cost ($ acre):	85	lb.	$0.26	$22.10
Pesticides ($ acre):				
Huskie	12	oz.	$0.89	$10.70
Orion	17	oz.	$0.51	$8.65
Warrior II	1.96	oz.	$1.70	$3.31
M90 (Surfactant)	1.5	oz.	$0.34	$0.51
Total				$23.17
Custom ($ acre)				
Cultivate	-	acre	-	$38.14
Planting	-	acre	-	$19.53
Pesticide application	-	acre	-	$9.25
Harvest	-	acre	-	$21.00
Total				$87.92

† Cost per units were generated using the 2014 Northern Idaho Enterprise Budget, Bulletin 729 Custom Rates, Direct Seed Budget.

Table A.13 Amount and cost per unit of variable input cost for winter wheat seed crops grown in the Pacific North West.

Winter Wheat	Unit per Acre	Unit	Cost per Unit	Cost per Acre
Fertilizer ($ acre):	80	lb.	$1.65	$132.00
Seed Cost ($ acre):	80	lb.	$0.24	$19.20
Pesticides ($ acre):				
Huskie	12	oz.	$0.89	$10.70
Orion	17	oz.	$0.51	$8.65
Warrior II	1.96	oz.	$1.70	$3.31
M90 (Surfactant)	1.5	oz.	$0.34	$0.51
Total				$23.17
Custom ($ acre)				
Cultivate	-	acre	-	$38.14
Planting	-	acre	-	$19.53
Pesticide application	-	acre	-	$9.25
Harvest	-	acre	-	$21.00
Total				$87.92

† Cost per units were generated using the 2014 Northern Idaho Enterprise Budget, Bulletin 729 Custom Rates, Direct Seed Budget.

Table A.14 Summary of variable input cost of Austrian winter pea, radish, mixture #1, mixture #2, winter canola, winter wheat fallow, spring wheat, spring canola, spring pea, winter wheat as a cover crop and winter wheat as a seed crop.

Input Item	Austrian Winter Pea	Radish	Mixture #1	Mixture #2	Winter Canola	Winter Wheat	Fallow	Spring Wheat	Spring Canola	Spring Pea	Winter Wheat
	$ acre^{-1}										
Fertilizer	116.68	116.68	116.68	116.68	116.68	116.68	116.68	116.68	116.68	116.68	132.00
Seed Cost	76.00	44.40	63.75	81.75	24.56	24.30	-	21.60	35.86	76.00	19.20
Herbicides	10.95	10.95	10.95	10.95	10.95	10.95	10.95	19.35	5.68	6.32	
Insecticides	3.82	3.82	3.82	3.82	3.82	3.82	-	3.82	3.82	3.82	3.82
Cultivation	38.14	38.14	38.14	38.14	38.14	38.14	38.14	38.14	38.14	38.14	38.14
Planting	19.53	19.53	19.53	19.53	19.53	19.53	19.53	19.53	19.53	19.53	19.53
Pesticide Application	9.25	9.25	9.25	9.25	9.25	9.25	9.25	9.25	9.25	9.25	9.25
Harvest	-	-	-	-	-	-	-	21.00	21.00	21.00	21.00
Mow	17.00	17.00	17.00	17.00	17.00	17.00	-	-	-	-	-
Total input cost	291.37	259.77	279.12	297.12	239.93	239.67	194.55	249.37	249.96	290.74	242.94

† Cost per units were generated using the 2014 Northern Idaho Enterprise Budget, Bulletin 729 Custom Rates, Clearwater seed prices, and Direct Seed Budget.

Table A.14 Summary of variable input cost of Austrian winter pea, radish, mixture #1, mixture #2, winter canola, winter wheat fallow, spring wheat, spring canola, spring pea, winter wheat as a cover crop and winter wheat as a seed crop.

Input Item	Austrian Winter Pea	Radish	Mixture #1	Mixture #2	Winter Canola	Winter Wheat	Fallow	Spring Wheat	Spring Canola	Spring Pea	Winter Wheat
	$\$\ \mathrm{ha}^{-1}$										
Fertilizer	288.31	288.31	288.31	288.31	288.31	288.31	288.31	288.31	288.31	288.31	326.17
Seed Cost	187.79	109.71	157.52	202.00	60.69	60.04	-	53.37	88.61	187.79	47.44
Herbicides	27.06	27.06	27.06	27.06	27.06	27.06	27.06	47.81	14.04	15.62	0.00
Insecticides	9.44	9.44	9.44	9.44	9.44	9.44	-	9.44	9.44	9.44	9.44
Cultivation	94.24	94.24	94.24	94.24	94.24	94.24	94.24	94.24	94.24	94.24	94.24
Planting	48.26	48.26	48.26	48.26	48.26	48.26	48.26	48.26	48.26	48.26	48.26
Pesticide Application	22.86	22.86	22.86	22.86	22.86	22.86	22.86	22.86	22.86	22.86	22.86
Harvest	-	-	-	-	-	-	-	51.89	51.89	51.89	51.89
Mow	42.01	42.01	42.01	42.01	42.01	42.01	-	-	-	-	-
Total input cost	\$719.97	\$641.88	\$689.70	\$734.17	\$592.86	\$592.22	\$480.73	\$616.18	\$617.64	\$718.41	\$600.30

† Cost per units were generated using the 2014 Northern Idaho Enterprise Budget, Bulletin 729 Custom Rates, Clearwater seed prices, and Direct Seed Budget.