Exploring Cultivar Response of Soft White Winter Wheat to Nitrogen and Seeding Rates, and
On Farm Testing of Variable Rate Seeding

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Authorization to Submit Thesis

This thesis of Cole W. Senefsky, submitted for the degree of Master of Science with a Major in Plant Science and titled "Exploring Cultivar Response of Soft White Winter Wheat to Nitrogen and Seeding Rates, and On Farm Testing of Variable Rate Seeding," has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

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Abstract

Production of high yielding soft white winter wheat is dependent on synthetic fertilizer. In addition to using variable rate technology for nitrogen application, there is interest in further refining nitrogen use to more efficiently use this expensive input as well as exploring precision technology for other inputs such as seeding rate. In Northern Idaho, trials were established to examine the response of soft white winter wheat cultivars to nitrogen and seeding rates. An additional field trial was planted on the Camas Prairie to study applying variable rate seeding technology within three distinctive production zones. While there were differences among the cultivars, environment and seasonal variation had a significant impact on how cultivars respond to nitrogen and seeding rates. The variable rate seeding trial demonstrated that this technology may be feasible, but further exploration will be necessary to develop a suitable strategy for implementation in diverse environments.

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Dedication

I would like to dedicate this thesis to my beautiful wife Danielle Senefsky. Danielle has been supporting me in all ways possible. She has been there since the beginning and kept on giving me encouragement to keep on working. I would have not been able to do this project and finish if it was not for my wife. I thank you for all the love and support Danielle.

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Chapter 1: Literature Review

1.1 Origins of Wheat

The exact time when wheat (*Triticum aestivum* L.) was domesticated is unknown however, records dating to 5,000 B.C. show that Egyptians created bread from wheat (Gibson and Benson, 2002). Evidence suggest that ancestral forms of modern domestic wheat originated in Syria, Jordan, Turkey and Iraq (Brown and Caligari, 2011). Modern wheat is a very diverse crop with a hexaploid genome. Common wheat was originally derived from wild einkorn (*T. monococcum* L.) with a diploid (AA) genome (Bell, 1987). Einkorn, thought to be the first form of wheat domesticated. Through amphidiploidy, a tetraploid wheat *T. turgidum* ssp. *dicoccum* L. (AABB genome) was formed which also was domesticated and was known as emmer wheat. Eventually there was a second amphidiploidy event between an emmer wheat and a diploid ancestor *T. tauschii* (DD). This cross resulted in the first hexaploid wheat *T. aestivum* ssp. *spelta* (AABBDD) and eventually gave rise to modern common wheat *T. aestivum* ssp. *aestivum* (Cook and Veseth, 1991).

Since the early forms of wheat were cultivated, Western civilization has relied on wheat as a staple food for many centuries (Harlan, 1981). With 17.7 million hectares harvested annually, wheat is the third largest crop produced in the United States (USDA-NASS, 2016). Corn and soybeans are the number one and two most common crop with 35.1 million and 33.5 million hectares, respectively (USDA-NASS, 2016).

1.2 Wheat Production in the PNW

The Pacific Northwest (PWN) consist of Idaho, Oregon and Washington State. All three states offer unique growing conditions and a diversity of cropping systems. As of 2016, Idaho produced 2.4 million metric tons annually. In the same year, Washington produced 3 million metric tons and Oregon produced 1 million metric tons of wheat (USDA-NASS, 2016). About 65% of all wheat produced in Idaho is winter wheat while the remaining consists of spring wheat (USDA-NASS, 2016). Due to the unique growing conditions across the region, multiple classes of wheat can be grown including winter and spring classes of soft white, hard red and hard white. Durum and club are also grown in the area. Production in southern Idaho is mostly reliant on irrigation, while northern Idaho is almost exclusively dryland production. Idaho dryland areas are responsible for 884,000 metric tons of wheat produced annually (USDA-NASS, 2016).

The growing conditions of the PNW are most ideal for production of soft white wheat, with the PNW accounting for 86% of all soft white wheat produced in the United States (WWC, 2009). Of Idaho's soft white wheat produced, over 80% is exported overseas, mostly to Southeast Asian countries along the Pacific Rim (Mortenson, 2014; Vocke, 2015). The soft white wheat has superior baking quality to produce cakes, cookies, biscuits and other pastries. Due to the strong demand for high quality soft white wheat, the PNW will continue to major supplier of this class of wheat.

Northern Idaho and eastern Washington have a Mediterranean climate with most of the precipitation falling from October thru May and relatively dry summers. Precipitation and temperature can vary dramatically in the Northern Idaho due to changes in elevation and proximity to mountains. This results in differences in yield potential and approaches to farming practices.

1.3 Breeding and History of Wheat in the PNW

The PNW offers unique opportunities for breeders to develop cultivars that can adapt to growing conditions and pathogens in Idaho, Oregon and Washington. Specifically, the dryland region of the PNW has vast difference in rainfall and yield potential. This difference necessitates a diversity of cultivars that are adapted to the different regions. While certain cultivars may perform better in low or high rainfall regions, there are many cultivars that are adaptive to a broad range of rainfall regions in the PNW.

At the turn of the century (early 1900's), all of the wheat produced in the PNW was very tall and prone to lodging and shatter. Thus, these cultivars struggled in northern Idaho and offered poor yields (Vogel, 1977). During the middle half of the 20th century, two major events occurred to shape the future of wheat production in the PNW and worldwide. First, the production of synthetic fertilizer (especially nitrogen) came about in the 1930's. The process for nitrogen conversion is known as the Haber-Bosch process (Kandemir et al, 2013). This process uses an iron catalyst to produce synthetic ammonia which can then be used as a nitrogen fertilizer source in agriculture. This process is considered the greatest invention of the 20th century due to the ability to produce abundant nitrogen for agricultural use (Smil, 2001).

The second factor that dramatically impacted wheat production was the introduction of semi-dwarf genes. In 1931, Cecil Salmon sent a very short 'Norin 10' cultivar to Orville Vogel at Washington State (Vogel et al, 1956). Vogel began crossing 'Norin 10' with local cultivars. In 1967, Vogel created semi-dwarf wheat 'Nugaines' (Chase, 1969). This cultivar was instantly the largest grown cultivar in the PNW. With the use of synthetic nitrogen and semi-dwarf wheat, growers dramatically increased yields throughout the dryland production areas.

With the introduction of semi-dwarf wheat to the PNW, Norman Borlaug took those cultivars to Mexico and India in the late 1950's. By the 1960's Borlaug had developed cultivars that were adaptive to those regions (Borlaug, 1968). This in turn helped those two countries end famine and hunger. This movement that Vogel and Borlaug started came to be known as the Green Revolution (Borlaug, 2000).

Today, cultivars grown in the PNW come from two sources. The first are local public Universities and include the University of Idaho, Oregon State University and Washington State University. The other cultivars are developed by international private breeding companies that have facilities located in the PNW. Thus, growers have access to a tremendous diversity of cultivars. While there is an overabundance of new cultivars, there are many older cultivars that are still grown due to unique disease-resistance traits and/or superior adaptability.

1.4 Tillage/Planting Practices

The PNW offers many different types of tillage and planting practices. Many growers use tillage and planting practices based on finances and size of the operation. Farming practice can be broken into three types; either intensive tillage, reduced tillage or direct seed/no-till.

1.4.1 Intensive Tillage

The historical method of field preparation and weed control is intensive tillage. This provides growers with an opportunity to shape the soil surface into a smooth seed bed for optimal planting (Veseth, 1985). Throughout history growers traditionally use a moldboard plow, which involves turning the soil completely over and exposing the soil profiles lower layers. Intensive tillage serves two purposes. First to prepare a seed bed while reducing weeds. Second is to incorporate fertilizer. In most cases a drill for conventional seeding does not place fertilizer down at planting. The moldboard plow is used more for weed control and residue management than seedbed preparation. Use of the moldboard plow in the PNW has declined substantially compared to the early to mid-1900's. Some growers still use the moldboard plow every three or more years to bury the weed seeds deep into the soil. Most growers that do conventional seeding deal with small number of hectare due to cost of upgrading equipment.

1.4.2 Reduced Tillage and Seeding

Starting in the 1960s, there was a rise in environmental concerns related to intensive soil tillage. The biggest impact in northern Idaho and eastern Washington was the loss of topsoil due to erosion (Machado et al, 2007). The region has a Mediterranean climate with most precipitation falling during the winter months. This combined with the steep terrain and loose soil from tillage creates a situation where soils are vulnerable to erosion. The approach to saving the top soil and reducing the erosion came with the integration of conservation practice including reduced (conservation) tillage.

Reduced tillage involves using significantly less tillage with the goal of partial incorporation of crop stubble and weed control. Thus, plowing would not be used and only the top 15 cm or less would be disturbed while using a shank style implement. This idea works to help conserve moisture under the disturbed soil, provide weed control, breaking up disease cycles and reduce soil erosion (Coolman and Hoyt, 1993). Limited tillage also can help reduce the amount of stubble at planting, reducing the risk of plugging drills with residue (Buhler, 1995). Application of fertilizer often occurs at the same time of planting when practicing reduced tillage.

1.4.3 Direct Seeding/ No-tillage

Direct seeding or no-till involves using very minimal disturbance of the soil. Seeding is the only time when the soil will be disturbed and is accomplished as a single pass for seeding and fertilizer application. Direct seeding greatly reduces the chance of erosion by proving maximum crop residue which keeps roots intact which hold the soil together (Hobbs et al, 2008; Huggins and Reganold, 2008). This increases water penetration into the soil and the roots of the stubble help prevent topsoil loss. With direct seeding, residue management is critical, so growers will typically use straw choppers on combines and may mow to break up the stubble. This allows the next seeding operation to work better while providing maximum residue coverage of the soil. Direct seeding relies on different methods for controlling weeds like herbicides, planting date, competition from the crops and heavy residue (Veseth, 1998; Dao, 1987; Young et al, 1994).

1.5 Fertilizer Requirements of Wheat

All cereal crops require the use of fertilizer to maximize yield and end use quality. The different classes of wheat will have different fertilizer requirements based on yield goals and desired grain protein. Determining fertilizer requirements sometimes poses a challenge for growers and researchers. Soil tests provide growers with an idea of what nutrients are available and possible nutrients that are needed for any crop. Growers can obtain needed fertilizers in a dry or liquid form to either be applied on top or below the soil.

All information on nutrients have been obtained from either the Western Fertilizer Handbook (Ludwick et al, 1998) or Mineral Nutrition chapter from Plant Physiology (Briskin and Bloom, 2010) unless otherwise stated.

1.5.1 Nitrogen

Wheat needs nitrogen in the most abundance compared to the other macronutrients. Nitrogen is responsible for producing the bulk of vegetative growth, seed maturation, and root development. It is required for growth, chlorophyll, nucleic acid and enzyme development. In the PNW, growers apply nitrogen to the soil at a single time point or in a combination of methods including before or at planting and with a top dress application in the spring. It is importation to mention that growers in high rainfall regions of northern Idaho will split apply fertilizer between fall and spring for winter wheat. The split application is required to limit nitrogen from being leached out of the soil during the winter months (Mahler 2015).

The required amount of nitrogen depends on first the class of wheat. Secondly, the type of tillage practice (intensive or direct seed) as mineralization efficiency will differ between the two. Finally, the yield potential of the field. These all together will dictate how much nitrogen a grower is going to need in the system. In addition to nitrogen being applied, it is important to determine the potential nitrogen that is currently available in the forms of nitrate and ammonium in the soil as well as estimate the quantity that will be available from mineralization of organic matter in the upcoming growing season.

The different classes of wheat each have different requirements for nitrogen. This is essential for matching potential yield, protein and test weights. Soft white wheat requires lower amounts of N due to low protein needed. N rates of 0.043 to 0.045 kg N/kg grain is about the average for northern Idaho and eastern Washington (Mahler, 2015; Koenig, 2005). Hard red winter wheat and hard white wheat protein must as high as 10-14% to avoid dockage. Thus, a higher amount of N at about 0.050 to 0.055 kg N/kg wheat (Koenig, 2005).

1.5.2 Phosphorus

Phosphorus is considered an important nutrient for wheat. Phosphorus is important for seedling development and root formation. Later while the plant is maturing phosphorus is important for seed production. The ‘North Idaho Fertilizer Guide for Winter Wheat’ (Mahler, 2015) recommended phosphorus rates for wheat is dependent on two things. First the available phosphorus in the soil. Second, the type of tillage practice the grower uses (intensive or direct seed). A major factor for soil availability of phosphorus is pH. As the soil pH becomes closer to 7, phosphorus becomes more available to the plant. Phosphorus being added at planting will help with availability during growth. In northern Idaho, pH is usually below 6 in the upper 30 cm so addition phosphorus is required.

1.5.3 Potassium

Potassium is responsible for opening and closing of stomata by guard cells above the soil. Below the soil, it is a key nutrient for root development, while helping with disease resistance. The soil type plays a major role in the availability of potassium. Soils with high cation exchange capacity are able of holding excess potassium in the soil. Majority of fields in northern Idaho do not need any potassium added to the soil due to higher CEC (>20 meq/100g) and high quantities of residual potassium in the soil (Mahler, 2015).

1.5.4 Sulfur

Sulfur is important for protein synthesis in wheat. Sulfur can leach through the soil profile like nitrogen, but also it can be absorbed from the air if there is an abundance. Also like nitrogen, sulfur is responsible for increasing biomass and yield of the crop (Tisdale et al., 1986). The soils in northern Idaho tend to be deficient in sulfur. In northern Idaho sulfur is usually added at either 22.4 kg ha for deficient soils, 9 kg ha for semi-deficient soils or not added if there is an abundance available (Mahler, 2015).

1.5.5 Micronutrients

There are a host of micronutrients that wheat needs. In most cases these nutrients can be obtained from the soil. An application of micronutrients prior to planting may be necessary to meet crop needs. Depending on availability in the soil, growers can add zinc, boron, calcium, magnesium, iron, manganese, copper, molybdenum, chlorine and nickel. Calcium is important for cell wall, membrane and the formation of new cells. Magnesium is essential for photosynthesis and an activator of many enzymes required for growth. Zinc is important for synthesis of indoleacetic acid in addition to being a plant growth regulator. Iron works in formation of chlorophyll in plant cells. Photosynthesis, respiration and symbiotic nitrogen fixation are reliant on Iron. Manganese is an activator for enzymes in plant growth processes. Copper deficiency interferes with protein synthesis. Boron is involved in differentiation of meristematic cells, while regulating metabolism of carbohydrates in plants. Molybdenum is required for utilization of nitrogen. Also, it plays a role in converting nitrogen into amino acids. Chlorine is required for photosynthetic reactions in plants and chlorine deficiency can lead to physiological leaf spot in some wheat cultivars. It is important for helping with disease resistance and nutritional benefits. Finally, Nickel is part of the enzyme urease, converting urea to ammonia in the plant tissue. Mahler (personal communication, 2015) explains that soils in northern Idaho may be deficient in copper, iron, manganese, molybdenum and boron for winter wheat. Micronutrient are required in very low quantities and low rates are used when applying prior to wheat production.

1.6 Nitrogen Use Efficiency

Nitrogen use efficiency (NUE) is an important concept for crop production. The definition of NUE is the uptake efficiency and utilization efficiency of absorbed nitrogen (Janssen, 1998; Moll et al, 1982). Benincasa (2011) explains NUE as looking at the effect of absorbed nitrogen on crop leaf area, light absorption, photosynthesis, crop growth, biomass partitioning and yield in addition to the original definition.

In a dryland system, the largest single factor to influence NUE in a crop is precipitation. Under irrigation, one can supply adequate moisture to maximize both utilization and up-take of nitrogen. That produces less leaching of nitrogen and ultimately better yields. The main challenge to improving NUE in dryland areas of the PNW is the amount of precipitation received each year. In northern Idaho, it is not common to have precipitation exceeding 600 mm annually, with some areas receiving substantially less precipitation. More than half of the precipitation comes during November through March in the form of either rain or snow. This period coincides with winter wheat being at Feekes growth stages 1 to 3 and the plants are dormant during much of this time. That means the crop is taking up very little nitrogen and the excess nitrogen may be prone to leaching. Growers in dryland areas either apply all fertilizer in the fall or split the application of nitrogen between the fall and spring. Sowers et al (1994) considered applying split applications of nitrogen versus all fall applied nitrogen in winter wheat near Pullman, WA. The study found that split applications of nitrogen between fall and spring shows improved NUE. The work further explored applying less nitrogen in the fall and the remainder in the spring to reduce that lead to reduced leaching and volatilization. In addition to split applications of nitrogen, the timing of the spring application of nitrogen is very important for maximizing yield and returns (Masclaux-Daubresse et al, 2010). Lopez-Bellido et al (2005) found that applying nitrogen prior to stem elongation in the spring is better than all fall applied nitrogen. A major drawback with conducting small plot work in NUE related topics is being able to apply concepts to grower's fields. Across a typical field in northern Idaho there is variation in topography, aspect, soil type and the available nutrients. This can hinder the way crops across a field utilize nitrogen. When conducting small plot work for NUE, the data cannot be extrapolated into full scale field work (Huggins et al, 2012). There needs to be a combination of approaches to improving NUE in the field in both plot research and full scale field work.

In the PNW, growers generally use diverse crop rotations due to the various benefits that they provide for winter wheat. In southern Idaho work involving a preceding crop of potatoes prior to winter wheat provided the best NUE for the wheat due to high amounts of nitrogen left in the soil (Rahimizadeh et al, 2010). In northern Idaho growers plant legume crops (peas, lentils or chickpea) before winter wheat (Fuchs and Hirnyck, 2000; Hammel, 1989), due to legumes ability fix nitrogen in the soil and provide nitrogen for the following crop. Growers can use less nitrogen at planting and still get comparable yields when following a legume versus a non-legume crop (Campbell et al, 1992; Huang and Lantin, 1993; Mahler, 2015). Legumes can improve NUE and the total accumulation of nitrogen in the winter wheat plant is higher due to the greater quantity of plant available nitrogen in the soil (Ghosh et al, 2008; Badaruddin and Meyer, 1994). The available nitrate in the soil is dependent on rotation and the amount of moisture one receives during the growing year (Lopez-Bellido and Lopez-Bellido, 2001).

1.7 Influence of Genetics on NUE

NUE can be influenced by crop rotations, moisture (both irrigation and rain-fed), and nitrogen rates. There is a large portion of research conducted to improve NUE by looking at the genetics of wheat. Le Gouis et al (2000) shows that the older cultivars of wheat have better NUE than newer cultivars. The theory is that older cultivars were bred under low nitrogen inputs. A concept to improve NUE in modern cultivars is to cross older cultivars with newer cultivars to generate lines that can produce greater yields with less nitrogen fertilizer. A drawback to this idea is that older cultivars tend to have lower yield potential any may be subject to lodging. Ortiz-Monastero et al (1997) found that newer semi-dwarf cultivars with no nitrogen added to the soil will out yield the older, taller cultivars. While NUE is lower, newer cultivars are more responsive to nitrogen than the older ones. That is why growers can apply high nitrogen rates and get higher yields in return. Lea and Azevedo (2006) examined the uptake of nitrogen from the soil. They found that it may be challenging to identify genes or traits that are responsible for nitrogen uptake. This is also related to finding genes that could influence NUE of crops. There are genes that are directly related to nitrogen use efficiency (Loudet et al, 2003), but instead of one gene there are many genes involved in NUE thus making it difficult to identify such traits. Aside from the genetics, the greater problem lies with improving NUE without having environmental factors having a major impact (Hirel et al, 2007).

In general, breeders do not breed for improved NUE. Instead the goal is to produce higher yields, improved end-use quality and resistance for disease. Improving yield does not necessarily mean improved NUE. Growers increase nitrogen to increase yield but that does not always optimize yields (Sylvester-Bradley and Kindred, 2009). Sylvester-Bradley and

Kindred (2009) were looking at optimizing nitrogen rates of spring wheat found that yield is directly related to optimal nitrogen rates. In order to find optimal nitrogen rate the authors believe that a more intense model needs to be developed looking beyond yield and NUE in order to find the correct nitrogen rate. Increasing nitrogen rates does not help with improving NUE, instead it decreases NUE within a field (Raun and Johnson, 1999). That places emphasis on pursuing breeding efforts to improve NUE by using low input production practices in combination with using wild parental genes. This may lead to development of cultivars that have improved NUE and good quality under the low input nitrogen situations (Dawson et al, 2008; Muurinen et al, 2006). To get improvements in NUE genetically, there needs to be advances in genomics to help identify genes for those improvements, due to the belief that many genes are involved in the process of NUE (Basra and Goyal, 2001; Fisher et al, 2013)

There are many factors that can influence NUE during the growing season. As Raun and Johnson (1999) mention, the best way to improve NUE is to use many different approaches that increase NUE. This means that using diversified crop rotations, incorporation of legume crops, practicing reduced or no-till, hybrid or improved cultivars, split applications of fertilizer and precision agriculture. Using as many approaches as possible for NUE improvement can help growers in the long run. As suggested by Camara et al (2003), many growers sacrifice long term sustainability for short term profit, especially in dryland growing regions like the PNW. Once the switch to long term sustainability (no-till, reduced nitrogen rated, and crop rotations involving legumes) happens, growers will see the benefit last.

1.8 Seeding Density of Winter Wheat in the PNW

Seeding rate of winter wheat in the PNW can vary depending on the region and grower. Growers tend to plant wheat in units of weight per unit area. This can be troublesome due to the fluctuation of seed size and weight. By planting wheat using a predetermined number of seeds per unit area, a more uniform planting density is ensured. Planting by population density is a good basis for generating enough competition with weeds and providing higher yields (Yenish and Young, 2004; Schillinger, 2005). Growers may go lower or higher depending on environment and equipment available. Locally, growers within northern Idaho plant seeds ranging from 1.2 to 2.5 million seeds/ha (experience with working with growers in northern Idaho). Growers strive to find a seeding rate that promotes more tillering and increases row closure sooner to produce a more competitive stand (Schillinger, 2005).

1.9 End-use quality in wheat

The major driving force for soft white winter wheat are the markets that rely on consistent, high end-use quality. Most soft white winter wheat produced in the PNW is shipped to the Pacific Rim which includes China, Japan, Philippians and others Asian countries (Idaho Wheat Commission, 2016). Much of the exported wheat is milled and used for sponge cakes, cookies, steam bread, biscuits and crackers. Low protein is ideal for producing great quality cookies and sponge cakes (Nagao et al, 1976). High protein wheat soft white wheat generally gets made into crackers while hard red wheat is made into bread. The PNW is unique in that varying level of protein can be produced. Customers order wheat with specific requirements from Portland, OR regarding class, test weight, protein, foreign material and other traits. Customers can choose to mix low protein wheat with high protein low quality wheat to increase the size of the order and make it more cost effective to feed individuals (Ian Burke, personal communication 2015).

Test weight is another end-use quality that is important. The *United States Standards for Wheat* (USDA, Federal Grain Inspection Service) has a grading system in place for protein, test weight, chipping, weeds and other impurities. Test weight is a volumetric measurement that measures the plumpness of the wheat. Typically, a simple gravity device is used to measure test weight and involves dropping wheat though a funnel into a one-pint sized cup. The excess wheat is removed from above the lip of the cup by passing a stick across the top and the grain weight is recorded. That will give growers a number expressed in pounds per bushel or kilograms per hectoliter. For soft white winter wheat, U.S. Grade No. 1 is 75 kg/hL or greater (60 lb/bu), U.S. Grade No. 2 is 72.5 kg/hL, U.S. Grade No. 3 is 70 kg/hL, U.S. Grade No. 4 is 67.5 kg/hL, and U.S. Grade No. 5 is 63.8 kg/hL. All wheat that is graded below U.S. Grade 5 will be sold as mixed feed. The elevators that are buying the wheat from the growers do not price based on test weight. The idea is that a higher test weight (U.S. Grade No. 1) will be heavier and more plump.

1.10 Precision Agriculture

The largest growing section of agriculture involves the use of technology related to precision. With the help of GPS (global positioning systems), precision agriculture was first introduced to machinery for guidance in the 1980’s (Johnson et al, 1983; Safford, 2000). With the incorporation satellite imaging to provide growers with accurate ways to plant, apply fertilizer and chemicals. This field is always improving to be more affordable and provide high levels of accuracy.

The idea of changing seeding and nitrogen rates to improve yields were reported early as the 1960's, yet the technology we have today was not available then. Growers did know that cultivars and field layouts can influence what seeding and fertilizer rates and how it can influence crop performance (Pendleton and Dungan, 1960). Applying site-specific rates of fertilizer started to make its way into grower's fields by the 1990's as the equipment to make this feasible and cost effective became available (Ferguson et al, 2002; Wollenhaupt and Buchholz, 1993). To implement precision agriculture in a new field, soil sampling and a general understanding of the historical yield is needed (Verhagen et al, 1995; Paz et al, 1999). This is a simple way to start mapping out a field.

Use of variable rate technology (VRT) has shown either a reduction or reallocation of inputs going into growing crops (Ehlert et al, 2004). It requires growers to do on site experiments over years to estimate yield potential across fields (Bullock et al, 2009). With the ability to change fertilizer and seeding rates while planting, use of precision tools can provide great economic returns for growers by reducing fertilizer, pesticides, and fuel consumption (Diacono et al, 2013; Robertson et al, 2012; Isik and Khanna, 2002; Koch et al, 2004).

There are challenges associated with VRT. The biggest is deciding how much fertilizer needs to be applied and where, but a solution is to apply site-specific management zones (Khosla et al, 2001). This approach is to break a field up into different yield potentials (zones) based on historical yields and fertilize the zones accordingly (LaRuffa et al, 2001). Having at least two different zones is enough to do use VRT with fertilizer (Bachmaier and Gandorfer, 2009). Performing VRT with fertilizer will often provide growers with a greater economic return (Meyer-Aurich et al, 2010; Diacono, 2013; Delin et al, 2005). One of the biggest challenges for determining fertilizer rates in dryland areas is unpredictability of precipitation.

Recently there has been an explosion in using optical sensing to evaluate crops for fertilizer applications. This system uses infrared lights that reflect up to the sensor and determine if a crop is stressed or may need fertilizer (Raun et al. 2002). For this to work, one must have a strip of crop that has the full fertilizer rate. The sensor then will compare the full rate to the rest of the field. This application is usually applied during the early spring before the onset of stem elongation. It is important to consider the future weather for what applications are needed. In general, there tends to be greater net return, improved NUE and yield with using optical sensing technology (Biermacher et al, 2008). Optical sensing can be used to evaluate other components besides fertilizer. Flowers et al (2001) used optical sensing to determine tiller density in wheat. It was discovered that this can also help with determining weed, disease, and insect pressure on the crop.

1.11 Variable Rate Seeding

The next aspect of VRT involves the use of seeding rate. In addition to varying nitrogen rates, growers can change seeding rates while planting. This has the same goal as VNR (variable nitrogen rates). Can variable seeding rates improve net return while decreasing inputs? There has been difficulty in making variable rate seeding (VRS) work due to variability across a field and the technology involved with drills. Understanding yield and plant density in relation to the layout of a field is key to performing VRS (Bullock et al, 1998).

Seeding rate influences the tillering rate of wheat plants and the survival rates of the tillers due to less plants having more available nutrients due to a smaller stand (Gooding et al, 2002; Chen et al, 2008). Competition against weeds, efficient use of limited resources (like nitrogen) and impact of yield potential are major influences of VRS. The higher the seeding rate the more competition with weeds, resulting in lower weed densities due to high amounts of seeds being planted (Beavers et al, 2008; Young et al, 2002). Seeding rates do play a role in yield of wheat, with increasing rates showing potential higher yields dependent on growing conditions (Lloveras et al, 2004; Xue and Weiss, 2011; Briggs, 1975). With VRS technology growers may be able to change seeding rates throughout a field and can gain a higher net return, but other factors play a role in the yield (Geleta et al, 2014). Geleta et al (2014) found that environmental factors like moisture and temperature influence the yield and end-use quality of wheat more than VRS. That does not mean VRS cannot work, there can be improved yields, NUE and reducing inputs. It relies on environmental factors more for determining the outcome. Modern seed drills are equipped to perform VRS, but the next step is to determine if VRS will work across a field with variable fertility.

1.12 Objectives

With new cultivars of soft white winter wheat being constantly introduced to northern Idaho, there has been interest in determining if they can respond differently to nitrogen and seeding rates in hopes of creating cultivar specific recommendations for growers. Besides finding optimal yields, is there a difference in economic returns with the different nitrogen and seeding rates? With possible high rates of nitrogen fertilizer, it is of interest to see if and how baking and milling properties are going to be affected. At the same time, there has been interest in exploring variable seeding rate technology. Can variable seeding rate technology improve yield in different fertility zones and make more efficient use of this input?

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Chapter 2: Exploring cultivar response of soft white winter wheat to nitrogen and seeding rates, including determining economic feasibility and influence of nitrogen rates on end-use quality in northern Idaho.

2.1 Introduction

Idaho is responsible for about 2.4 million metric tons of wheat being produced annually. Of that, soft white is the largest class of wheat and 65% comes from winter wheat. Idaho wheat producing areas can be divided into irrigated and dryland. Northern Idaho is reliant on dryland for production of crops. The dryland production is responsible for 884,000 metric tons of wheat in Idaho (USDA-NASS, 2016). The wheat cultivars used in Idaho come from two different sources including public cultivars developed by Universities in the PNW and private cultivars coming from multinational companies.

2.1.1 Nitrogen Fertilizer Use.

Nitrogen fertilizer is one of largest inputs to maintain high yielding wheat. Historically, humans relied on organic (manure) forms of fertilizer. After the introduction of the Haber-Bosch process, abundant quantities of synthetic nitrogen fertilizer became available, making nitrogen fertilizer the largest contributor to producing crops and food (Smil, 2001).

There is substantial worldwide demand for nitrogen fertilizer to meet the goal of providing adequate supplies of food, feed and fiber. There has been a steady increase in the amount of nitrogen fertilizer used. The Food and Agriculture Organization (FAO) reports as of 2014 the global use was 147.2 million metric tons of nitrogen fertilizer (FAO, 2015). Estimated for 2016 the global use was expected to reach 155.0 million metric tons. Predictions suggest that in 2018 the world will consume 161.1 million metric tons of nitrogen fertilizer (FAO, 2015). North American alone uses a vast amount of nitrogen fertilizer. In 2014 North America used 22.4 million metric tons of nitrogen fertilizer and this number was expected to increase to about 26.1 million tons in 2016 (FAO, 2015; IFADATA, 2016). North America nitrogen fertilizer use is not increasing as fast as other regions. FAO (2015) reports North America increasing its nitrogen use by 14.1% from 2014-2018. During the same time, East Asia will likely see a 30.6% increase in nitrogen fertilizer use. With population estimates continuing to increase in the foreseeable future and the demand for food, feed and fiber increasing, the need for synthetic nitrogen fertilizer will rise.

2.1.2 Nitrogen-use Efficiency.

The amount of nitrogen to add to a crop during the growing season is dependent on several factors. These include the residual nitrate and ammonium forms of nitrogen within the soil profile, potential mineralizable nitrogen in the form of organic matter and the inherent ability of the plant to take up and utilize nitrogen. This last factor is known as the nitrogen-use efficiency (NUE) (Janssen, 1998; Moll et al, 1982). The year-to-year variations of annual precipitation makes it difficult to predict how crops are going to respond to nitrogen applications. Water plays a significant role in how much nitrogen a crop uptakes and how the crop will utilize the nitrogen (Asseng et al, 2001).

Individual cultivars may utilize nitrogen differently. Le Gouis et al (2000) looked at 39 commercial cultivars winter wheat in France to determine whether they respond differently to nitrogen. The authors found that older cultivars tend to utilize nitrogen more effectively at lower rates. The newer cultivars responded to high rates of fertilizer better than the old cultivars. Older cultivars had improved NUE at low rates of nitrogen where newer cultivars did not. The new cultivars of wheat had far superior yields compared to the older cultivars. Le Gouis et al (2000) believes that breeding using older cultivars in crosses with modern cultivars can help improve NUE in the resulting cultivars. In contrast, Ortiz-Monasterio et al (1997) compared older tall wheat to new semi-dwarf wheat. NUE was dramatically improved with semi-dwarf wheat with or without nitrogen and no lodging was observed. Barraclough et al (2010) showed that new cultivars of wheat need high inputs of nitrogen to produce high yield and to meet quality. The wheat cultivars used in their study had high NUE capabilities, but needed more nitrogen to achieve the desired qualities. What is essentially one of the most important factors to determining the yield of the crop is NUE (Weih et al, 2011). Weih et al (2011) mentions that focus on NUE needs to start at the beginning of cultivar development for specific improvements in NUE. Growers in the PNW have access to many different types of soft white winter wheat cultivars that each have different yield and quality potentials. With many choices of cultivars, it may not be apparent if NUE has been improving. Most breeders do not look for traits related to NUE, but operate their programs using a standard fertilizer rate to improve other qualities like yield and test weight in new cultivars (Gaju et al, 2011; Barraclough et al, 2010). Le Gouis (2011) reported that breeders are attempting to improve NUE in wheat through genetics. Cultivars with improved NUE can likely be developed, but there environmental factors may have more influence on NUE than genetics (LeGouis, 2011). The environmental factors all relate to moisture and temperature which impact conversion of nitrogen and wheat’s ability to uptake and use nitrogen.

Since breeding for better NUE in crops may be difficult, other methods have been used to improve NUE. Kanampiu et al (1997) examined application of different nitrogen rates in winter wheat cultivars of Oklahoma. Poor NUE was found to be related to excess nitrogen being lost in the soil to leaching. Thus reducing the quantity of nitrogen will in turn minimize the risk of leaching (Kanampiu et al 1997). Another approach is to use split applications of nitrogen. Sowers et al (1994) looked into split applications of nitrogen versus all fall applied in the PNW. When all nitrogen was fall applied, the high precipitation over the winter months led to significant leaching. However, by split applying nitrogen between the fall and spring, leaching decreased and NUE improved in wheat. The idea revolves around being able to manage nitrogen applications in order to increasing NUE for crops. That is particularly hard when applying all the fertilizer in the fall versus split applications (Raun and Johnson, 1999).

Hirel et al (2007) explored the possibilities of genetics to improve cultivars for better NUE. Cultivars do have different abilities to utilize nitrogen, but a cultivar of concepts should be used to improve NUE like split applications and realistic yield goals (Dawson et al, 2008; Zhu et al, 2011).

2.1.3 Seeding Density in Wheat.

Along with the ability to apply different rates of nitrogen across a field at planting, growers can apply different rates of seed. Several considerations need to be considered when identifying seeding rates including being able to provide competition against weeds and improving yield. In one study seeding rate did not affect yield when looking at five cultivars of wheat (Carr et al, 2003). The production of spikes, kernel weight, number of seeds per spike and number of tillers per plant change with increasing seeding rates, while wheat yield did not change. This shows that under certain conditions that wheat can adapt to seeding rate changes and produce similar yields at multiple seeding rates (Carr et al, 2003).

Other studies found that certain cultivars differed in yield in response to changes in seeding rate (Briggs, 1975; Blue et al, 1990). Though in Briggs (1975) study involved looking at seven spring wheat cultivars and how they respond to seeding date and seeding rate. Only one cultivar showed response to seeding rate by yield, the others did not. Blue et al, (1990) studied the effect of seeding rate, planting date and phosphorus at three locations in Nebraska on hard red winter wheat. The one cultivar had yield that responded to seeding rate. Though that cultivar's response to seeding rate the change in yield was not as large compared to fertilizer and planting dates influences on cultivars. Arduini et al (2006) saw that three seeding rates (200, 250 and 400 seeds m^{-2}) resulted in increasing yield of wheat with increasing seeding rate. There was not a significant interaction of cultivar and seeding rate. Instead separate interactions of cultivar yield and seeding rate yield was significant. The impact of seeding rate on yield may be more dependent on environment and cultivar than the actual seeding rate.

Standard seeding rates in the PNW are based on weight and range from 78-112 kg ha^{-1} (Fuchs and Hirnyck, 2000), with growers picking a single seeding rate and planting entire fields or farms with that rate. However, as seed costs increase and growers look to adapt new technology, some are beginning to seed on a plant density basis versus mass of seed and others are becoming interested in the concept of variable rate seeding.

2.1.4 Economic Feasibility of Nitrogen.

Whether modifying seeding rates or incorporating new technology to better utilize fertilizers or pesticides, many decisions come down to the economic impact of the operation or input. As of December 2016, the value of soft white wheat was very low (under $148/metric ton) (USDA-ERS, 2017). Adding more nitrogen typically produces higher yields, though the economic return may not be proportional to the yield increase. Vaughan et al (1990) found that the timing and rate of nitrogen application influences the return. Split applications and lower rates were found to be more profitable than all fall or high rates of nitrogen. With rising cost of inputs like fertilizer, pesticides, fuel, machinery and the uncertainty of wheat prices, maximizing wheat yields by applying high amounts of nitrogen fertilizer does not necessarily translate to a greater economic return (Baker et al, 2004).

2.1.5 End-use Baking Quality of Soft White Winter Wheat.

Milling qualities of soft white winter wheat (SWWW) are very important for the end-users of the product. Many of the markets for PNW SWWW in Southeast Asia exist due to the long history of very high quality and uniform wheat from the region. To maintain these markets, standards for baking quality must be met to insure the buyers are getting exactly what they require. The first indication for growers is low protein (<10.5%) in SWWW. Protein is a great indicator of milling and baking properties relating to the consistency of dough after mixing (Xue and Weiss, 2011). Wheat protein influences the elasticity of the dough. Xue and Weiss (2011) indicate that low protein is essential for cakes and pastries to produce the ‘delicate’ texture and taste.

2.1.6 Objectives.

With multiple private breeding companies and several public Universities developing wheat for the region, there is no shortage of cultivars to choose from. However, with the wide diversity of cultivars with different genetic backgrounds, there is likely to be fundamental differences in how these cultivars respond to inputs. The objectives for this project were to 1) explore cultivar response of soft white winter wheat to nitrogen and seeding rates to determine whether cultivar specific optima can be identified, 2) identify the optimal nitrogen rate taking economic returns into consideration, and 3) evaluate the influence of nitrogen rates on the milling and baking quality of soft white winter wheat.

2.2 Material and Methods.

2.2.1 Locations

During the 2014-2015 growing season, field trials were established at two locations. One site was located near Genesee, Idaho and the second location near Peck, Idaho. For the second year of the study, these two locations were maintained and a third site was established near Cavendish, Idaho.

The 2014-2015 location for this trial was located 17.1 km north of Genesee, Idaho. The site was located at 46.5927 N, -117.0177 W at an elevation of 816 m. The plot was planted into a Westlake-Latahco Complex, which is mostly comprised of silt loam (NRCS 2016). The previous crop was spring peas and the trial was seeded on October 22, 2014. The trial in 2015-2016 was near the previous site, located 16.9 km north of Genesee on Thorn Creek Road (46.5997 N, -116.9852 W) at an elevation of 841 m. The soil type was a Latah-Silt Loam, similar in composition to the first year. The previous crop for this location was chickpea and the plot was planted on October 16, 2015. The annual average precipitation for this location is 63.5 cm.

The 2014-2015 growing season for the second location was located 8.9 km south of Peck, Idaho off Melrose Grade. The site was located at 46.4186 N, -116.4266 W with an elevation of 957 m. The trial was planted on October 26, 2014 into a Southwick-Driscoll complex which is composed of silt loam (NRCS, 2016). The annual rainfall is 64 cm (NRCS). The previous crop was spring feed barley. The 2015-2016 trial was located 8.9 km south of Peck, Idaho off Gerdie School Road (46.4131 N, -116.4122 W) with an elevation of

950 m. The annual rainfall remains the same as the 2014-2015 Peck trial. The trial was planted on October 14, 2015 into a Southwick Silt loam with the 0-2.5 cm layer having slightly decomposed plant material then all the horizons below contain silt loam (NRCS, 2016). The previous crop was spring pea.

The third location in 2015-2016 is located 6.9 km southeast of Cavendish, Idaho on South Road (46.5325 N, -116.405 W). This trial was planted on October 12, 2015. The site has an elevation of 931 m with a Taney ashy silt loam (NRCS, 2016). The annual precipitation is 71.1 cm. The previous crop before planting was spring pea.

2.2.2 Nitrogen, Phosphorus and Sulfur Rates

Fertility rates were based on the standard recommendations for soft white winter wheat in the *Northern Idaho Fertilizer Guide for Winter Wheat* (Mahler, 2015). Phosphorus and sulfur rates were the same for all locations and years. Nitrogen is the only factor that was varied in the study. To keep the rates standardized across all locations, a standard rate of 0.042 kg nitrogen kg^{-1} of wheat was multiplied by the total expected yield (kg ha^{-1}) for each location. This was set as the 100% rate and was based on an expected yield of 6725, 5380, and 5380 kg ha^{-1} for Genesee, Peck and Cavendish, respectively. Additional rates of nitrogen included 60, 80 and 120% during the 2014-2015 growing season and 0, 60, 80, 120 and 140% during the 2015-2016 growing season. The residual (nitrate and ammonium) and mineralizable nitrogen available in the soil profile was determined by collecting a pre-plant soil test from each location by 30 cm increments to a depth of 120 cm. Samples were sent to Northwest Agricultural Consultants (Kennewick, Washington) for analysis (Table 2.1). Mineralizable nitrogen was determined by the quantity of organic matter in the soil and the type of soil management used (tillage versus direct seeding). All locations in this study were reduced tillage or direct seed. The equation used to find the appropriate application rate of nitrogen is as follows: N to apply = Total N need based on potential yield – (mineralizable N + soil test N). In addition, if the previous crop was legumes, subtract nitrogen based on yield weight, if previous crop was cereals additional nitrogen will need to be added based on yield.

2014-2015 Growing Season

Genesee. The expected yield goal for Genesee was 6,725 kg ha^{-1}. Using the standard rate of 0.042 kg N kg $grain^{-1}$, the total nitrogen requirement was 282 kg N ha^{-1}. For the 2014-2015 growing season, the organic matter was 4.9% which is equivalent to 57 kg N ha^{-1} $year^{-1}$ of mineralizable nitrogen. Soil test nitrogen was determined to be 80 kg ha^{-1} nitrate and 11 kg ha^{-1} ammonium or a total of 91 kg N ha^{-1} available in the soil. The previous crop was spring peas with a yield of 2,242 kg ha^{-1}. That means there is 17 kg ha^{-1} of nitrogen per acre available from the decomposition of the residue. Using the equation outlined above, the quantity of nitrogen to apply to achieve the standard nitrogen rate is: 282 kg N ha^{-1} – (57 kg ha^{-1} for mineralizable N + 91 kg ha^{-1} for soil test nitrogen) - 17 kg ha^{-1} = 117 kg ha^{-1} of nitrogen which was applied to the strips designated at 100% (typical nitrogen rate for north Idaho). For the additional nitrogen rates, 6725 kg ha^{-1} was multiplied by 0.025 kg N kg $grain^{-1}$ (60%), 0.033 kg N kg $grain^{-1}$ (80%) or 0.050 N kg kg $grain^{-1}$ (120%) to determine the total nitrogen requirement for each rate. The rates of nitrogen applied are in Table 2.2.

Peck. The same concept was used to determine the nitrogen rates for Peck. In both years of the study, the expected winter wheat yield for the Peck location was 5,380 kg ha^{-1}. Using the standard nitrogen rate of 0.042 kg N kg $grain^{-1}$, the total nitrogen requirement was equal to 226 kg N ha^{-1}. The organic matter was 3.76% (Table 2.1), so the mineralizable nitrogen under a reduced tillage system was set to 57 kg ha^{-1} year^{-1} (Mahler, 2016). The quantity of nitrate and ammonium available from the soil test was 41 kg ha^{-1}. The previous crop was barley (2,242 kg ha^{-1}), so additional nitrogen will be required to account for nitrogen consumed in the decomposition of the straw. Therefore, an additional 17 kg ha^{-1} of nitrogen was required bring the total to be applied for the 100% rate to 144 kg N/ha. The other nitrogen rates were 135 kg ha^{-1} (60%), 178 kg ha^{-1} (80%) and 269 kg ha^{-1} (120%) of nitrogen. The rates of applied nitrogen are in table 2.2.

For both locations, it was determined that 44.8 kg phosphorus/ha and 22.4 kg of sulfur ha^{-1} were required and these were applied uniformly across both locations. The locations have sufficient potassium so there was no need to add the mineral to the soil. Dry, granular fertilizer was used and included: urea (46-0-0-0, N-P-K-S), ammonium phosphate (11-52-0-0) and ammonium sulphate (20-0-0-24). All fertilizer was applied at planting through a Flexi-Coil Stealth opener with paired rows which places a band of fertilizer approximately 4 cm vertically and 6 cm horizontally from the seed rows. For both Genesee and Peck, the 60% fertilizer rate had all nitrogen, phosphorus and sulfur banded below the seed. The remaining rates (80, 100, and 120%) had a portion added in the fall at planting and 44.8 kg ha^{-1} of nitrogen applied in the spring.

2015-2016 growing season

As in the previous growing season, soil samples were taken to determine the available nutrients in the soil. The same rates used during the 2014-2015 growing season were applied (60, 80, 100 and 120%) along with two additional rates (0 and 140%). The

140% is equivalent to 0.058 kg N kg grain^{-1}. A third location also was added in Cavendish, Idaho.

Genesee. As with the previous season, 6,725 kg ha^{-1} will be used as the yield goal, meaning the total nitrogen requirement for the 100% rate is 282 kg ha^{-1}. The nitrogen requirement for the other rates include 0 (0%), 168 kg ha^{-1} (60%), 221 kg ha^{-1} (80%), 336 kg ha^{-1} (120%) and 392 kg ha^{-1} (140%). The site was previously chickpea (1905 kg ha^{-1}) so there is 9 kg ha^{-1} of nitrogen available in addition to the soil available nitrogen (56 kg ha^{-1}) and mineralizable nitrogen (57 kg ha^{-1}). The rates of applied nitrogen are shown in Table 2.2.

Peck. Yield is similar to the previous season, 5,380 kg ha^{-1} was used as the field goal for this location. Therefore, the 100% rate required 226 kg N ha^{-1}. The total nitrogen requirements for the other rates included 0 (0%), 135 kg ha^{-1} (60%), 178 kg ha^{-1} (80%), 269 kg ha^{-1} (120%), 312 kg ha^{-1} (140%). The soil profile contained 114 kg ha^{-1} of available nitrogen and there was an estimated 57 kg ha^{-1} of mineralizable nitrogen. The previous crop was spring peas with (897 kg ha^{-1}), so there also was 3 kg ha^{-1} of available nitrogen from the legume residue. No additional nitrogen was added to the 60% rate due to the high residual soil nitrogen quantities at the Peck site. Therefore, the 60% rate could not be achieved as this was equivalent to the 0% rate. The rates of applied nitrogen are in table 2.2.

Cavendish. The yield potential for Cavendish was determined to be 5,380 kg ha^{-1}. Therefore, the rates of nitrogen required for this trial were the same as those described for Peck. The soil samples showed a residual of 57 kg nitrogen ha^{-1}, mineralizable nitrogen was estimated to be 57 kg N ha^{-1} and the previous crop was spring pea (1793 kg ha) providing an additional 9 kg N ha^{-1} from the crop residue. As with Peck, the 60% rate did not have any nitrogen added due to high amounts of residual nitrogen in the soil. The rates of applied nitrogen are in table 2.2.

All sites for the 2015-2016 growing season were fertilized with 33.6 kg phosphorus/ha and 22.4 kg sulfur ha^{-1}. Although potassium was not needed based on the soil analyses, potash was used at the sulfur source as opposed to ammonium sulfate to accommodate the 0-applied nitrogen rate. The sources of fertilizer came from the following: urea (46-0-0-0, N-P-K-S), triple super phosphate (0-45-0-0) and potash (0-0-50-18). The fertilizer was banded below the seed as previously described using dry, granular material. All nitrogen was applied at planting. For this chapter, the nitrogen rates will be expressed as 0, 60, 80, 100, 120, and 140%.

2.2.3 Cultivars

In both years (2015 and 2016), there were six cultivars used. Three cultivars or lines were selected from the University of Idaho Winter Wheat Breeding program and included: UI-WSU Huffman, IDN01-10704A and IDN02-29001A. The other three cultivars were from private companies. The cultivars were SY-Ovation (Syngenta), LCS Artdeco (Limagrain Cereal Seed), and LCS Drive (LWW12-7105). These three cultivars were all derived from European germplasm, so have a genetic background that is distinct from the University of Idaho material.

2.2.4 Seeding Rate

Three different seeding rates were used. The rates were based on a plant density per hectare using 247 seeds m^{-2} as the standard seeding rate. The rates used in the study were 247, 198, and 148 seeds m^{-2}. The highest seeding rate is typical for most locations in northern Idaho.

2.2.5 Experimental Design

To evaluate the impact of nitrogen and seeding rate, a split-plot design was implemented, with nitrogen rates as the main plot. The sub-plots included cultivar and seeding rate randomized within the main plot. The study was established using five replications at each location. Individual plot dimension are 1.524 m x 6.096 m. The trial was planted with a direct seed drill equipped with five Flexicoil® Stealth™ openers with paired rows and spacing of 25.4 cm center to center. Seed was planted at 2.54 cm depth with fertilizer was banded below.

All seed was treated with standard fungicide and insecticide products which consisted of Vibrance Extreme at 182 mL 100 kg^{-1} of seed and Gaucho at 240 mL 100 kg^{-1} of seed before planting. The growers conducted all in-season herbicide applications for weed control and fungicides for stripe rust control when necessary.

2.2.6 Data Collected

For both years, a stand count was collected at all locations and for all plots. An average of three stands count (0.5m row^{-1}) was used to determine the seeding rate after emergence in the month of February. In early June, ten plants were collected from all plots to determine the number of tillers produced. In the 2016 spike counts were recorded from three locations within each plot as opposed to earlier season tiller counts by counting the number of spikes in 0.5 m of linear row. All plots were harvested with a Wintersteiger Nurserymaster Elite™ (Wintersteiger, Inc.; Salt Lake City, UT) small combine. Total grain yield was determined for each plot and a subsample was collected to determine the test weight using a Cox funnel (Seedburo Equipment Company, Des Plaines, IL). An additional test weight with moisture and protein was collected using a FOSS Infratec™ NOVA Grain

Analyzer (FOSS, Eden Prairie, MN). One-thousand seed weight was recorded using a Model 750-2C Counting System (International Marketing and Design Corp, San Antonio, TX). Seed weight, spike count and plot weight was used to determine number of seeds per spike. Nitrogen use efficiency was determined by using the grain yield (kg ha) divided by total amount of nitrogen in the soil (added nitrogen, mineralizable nitrogen, and measured nitrate and ammonium prior to planting) (Sowers et al, 1994; Moll et al, 1982).

2.2.7 Economic Return of all Sites and Years

Economic return of the grain harvested in 2015 and 2016 was generated using the price of nitrogen, phosphorus, sulfur, seed price for planting, price of soft white wheat and general fuel/machine cost. The 2015 weighted average farm price for soft white wheat at market was $250.27 per metric ton (Bond, 2017). Data was obtained from the USDA-ARS website in cooperation with Norm Ruhoff (University of Idaho Agriculture Economist) who takes the data and compiles it onto a spreadsheet. All input prices were generated from averages for 2014 since that is when the trial was planted. The price of fertilizer is: nitrogen - $1.45 per kg, phosphorus - $1.21 per kg, and sulfur - $0.66 per kg (Patterson and Painter 2014). Seed price for planting is estimated at $0.52 per ha (Jeff Sayer, Primeland, personal communication). Pesticide, machine usage, fuel and general labor was estimated using enterprise budgets to total $292.52 per ha (Painter 2016). For the grain harvested in 2015, a premium was offered for soft white wheat at a rate of $0.10 for each 0.1% below a protein content of 10.5%. Anything lower than 8.6% did not receive the premium (Jeff Sayer, Primeland, personal communication).

The average price for the grain harvested in 2016 was $202.49 per metric ton (Bond, 2017). All inputs were generated from 2015 data since that is when planting took place. The price of fertilizer is: nitrogen - \$1.26 per kg, phosphorus - \$1.21 per kg and sulfur - \$0.62 per kg (Patterson et al 2016). Seed price was the same as the 2014 prices which is \$0.52 per kg (Jeff Sayer, Primeland, personal communication). Pesticide, machinery, fuel and general labor was estimated using an enterprise budget to a total of \$292.52 per ha (Painter 2016).

2.2.8 Baking and Milling Quality

A 300 g sub-sample was taken from all sites and years to analyze for baking and milling quality. Due to the labor involved in this analysis, only samples from the high seeding rate (247 seeds/ha^2) and replications 1 through 4 were used from each site. Samples were sent to the University of Idaho Wheat Quality Lab in Aberdeen, Idaho under direction of Katherine O'Brien. All samples were milled and analyzed for flour protein, flour yield, flour ash, break flour yield, and kernel hardness conducted using USDA required equipment.

2.2.9 Data Analyzed

Data were analyzed using an analysis of variance. Mean comparison was performed using Fisher's least significant difference ($0.05 > P > 0.01$; $0.01 > P > 0.001$; $P < 0.001$). All data were analyzed using SAS version 9.4 (SAS Institute Inc., Cary, NC).

Table 2.1. Soil fertility sample results determined by Northwest Agricultural Consultants.

Location/Year	NO_3	NH_4	Sulfur	pH	Organic Matter	P	K
	-kg ha^{-1}-	-kg ha^{-1}-	-ppm-	-%-	-%-	-ace, ppm-	-ace, ppm-
2014-2015							
Genesee	80	11	2	6.1	4.90	6.1	241
Peck	31	8	4	5.0	3.76	2.8	110
2015-2016							
Cavendish	85	13	1	5.2	3.65	1.3	108
Genesee	41	15	2	5.7	3.45	2.5	174
Peck	95	19	2	5.2	3.62	2.6	126

[z] Each value is the combined nutrient availability from each of the four 30 cm soil samples to a depth of 120 cm.

Table 2.2. Quantity of nitrogen applied at each location and year to achieve 60, 80, 100, 120 or 140% of the recommended nitrogen rate.

Location Year^{-1}	60%	80%	100%†	120%	140%
	kg ha^{-1}				
2014-2015					
Genesee	3	56	117	171	-
Peck	56	99	147	190	-
2015-2016					
Cavendish	0	14	62	105	148
Genesee	46	99	160	214	270
Peck	0	4	52	95	138

†The 100% rate is based on the recommended rate for soft white winter wheat in northern Idaho of 0.042 kg N/kg expected grain yield

2.3 Results

2.3.1 Agronomy Trial

As expected, nitrogen rates and cultivar have the largest influence on many of the traits evaluated. While seeding rate also has a significant influence, the impact was minor compared to nitrogen and cultivar. Mean square values (analysis of variance) are conducted for each of the variables and locations including main effects and interactions. Mean square from the analysis of variance of each of the traits analyzed are presented in Appendix A (Tables A.1 – A.5).

Nitrogen rate had a significant impact on stand in three of the five site years. Stand count at Genesee 2015 showed a significant linear increase in stand with increasing nitrogen rates. The lowest stand was produced at the 60% nitrogen rate with 88 plants m^{-2}, while the highest stand was produced with 120% rate with 27 plants m^{-2} (Table 2.3). At Peck 2015, there was not a clear trend in stand when looking at nitrogen rates. The highest stands were produced with 60 and 120% rate with 104 and 107 plants m^{-2}, respectively (Table 2.3). The third site to have a significant difference in nitrogen rates was Genesee 2016. The highest stand was observed with the 0% rate, while the other nitrogen rates were not significantly different from each other. No significant differences in stand count with respect to nitrogen rate were evident at Cavendish or Peck in 2016.

As expected, there was a significant increase in stand with increasing seeding rate at all site years (Table 2.4). Based on the target seeding rate, the plant populations per square meter were expected to be 148 (low rate), 198 (moderate rate) and 247 plants m^{-2} (high rate). The lowest seeding rate resulted in a density between 82 plants m^{-2} (Genesee 2015) and 132 plants m^{-2} (Genesee 2016), while the highest seeding rate resulted in a stand between 112 plants m^{-2} (Genesee 2015) and 178 plants m^{-2} (Genesee 2016).

Plant density for individual cultivars showed variation in ability to germinate after planting, with no clear trend observed at each site (Table 2.5). At Genesee 2015, all cultivars resulted in a stand of 100 to 102 plants m^{-2} except for LCS Drive which produced only 80 plants m^{-2}. At Peck 2015 all cultivars except IDN02-29001A produced stands of at least 94 plants m^{-2}, while IDN02-29001A produced only 90 plants m^{-2}. In 2016, the average plant stand was higher than observed in 2015 due to a significant cold event in November of 2014. UI-WSU Huffman and IDN01-10704A had the lowest stand across all three 2016 sites. The cultivar with the highest stand at Genesee 2016 was IDN02-29001A with 167 plants m^{-2}, and LCS Artdeco achieved the highest stand at Peck 2016 and Cavendish 2016 with 132 and 163 plants m^{-2}, respectively.

Data on the number of tillers per plant were only collected in 2016. This data indicates that nitrogen rate and seeding rate both influenced the number of tillers. There were no significant interactions between nitrogen rate and seeding rate. In Genesee, a low of 2.5 tillers plant^{-1} was observed at the 0% nitrogen rate, while the highest (3.4 tillers plant^{-1}) was seen at the 140% rate (Table 2.6). A similar number of tillers was produced at the 0 to 100% nitrogen rates at Peck, while the highest number of tillers plant^{-1} occurred at the 140% nitrogen rate with 2.1 tillers plant^{-1} (Table 2.6). At Cavendish, a quadratic relationship was observed. The 0 to 80% rates at Cavendish all produced a similar number of tillers per plant, with the highest tiller count observed at the 120% nitrogen rate (2.7 tillers plant^{-1}and the 140% rate resulting in a lower tiller count of 2.4 tillers plant^{-1} (Table 2.6).

A significant response of tiller counts to seeding rate occurred at Cavendish and Genesee. At each site the highest seeding rate produced the lowest number of tillers per plant at 1.9 and 2.8 for Cavendish and Genesee, respectively (Table 2.7). The lowest seeding rate had the highest number of tillers plant^{-1} of 2.1 and 3.2 for Cavendish and Genesee, respectively.

The number of tillers differed between the three locations with the highest amount of tillering at Genesee and the lowest at Peck (Table 2.8). Similar trends among cultivars were observed at each location. The entry IDN 02-29001A had the smallest number of tillers at all locations. IDN 01-10704A produced the highest number of tillers plant^{-1} of 2.3, 3.3 and 2.0 at Cavendish, Genesee and Peck, respectively. Peck had the smallest spread between cultivars of 0.3 tillers plant^{-1}. Genesee had a range of 0.4 tillers/plant while Cavendish had the largest difference between entries with 0.6 tillers plant^{-1}. The total number of tillers per plant and range between entries at these locations highlights the influence of environment on the ability of winter wheat to produce tillers.

Like the number of tillers per plant, a count of the number of spikes just before harvest was collected only in 2016 (Table 2.9). There were no significant interactions between variables. The highest number of spikes per meter was observed at Genesee with similar counts at Cavendish and Peck. All sites showed a linear response with increasing nitrogen rates increasing the number of spikes. The 0% nitrogen rates at Peck and Cavendish had a similar number of spikes. As observed with tiller counts, the 140% nitrogen rates produced the highest number of spikes with 93, 144, and 93 spikes m^{-2} row at Cavendish, Genesee and Peck, respectively.

Contrary to the number of tillers per plant, increasing the seeding rate resulted in a higher number of spikes m^{-2}. The highest seeding rate produced significantly more spikes at all three sites (Table 2.10). Individual cultivars responded similarly with respect to spike counts for all 2016 trials. UI-WSU Huffman produced the highest number of spikes for Cavendish and Genesee, while SY Ovation resulted in the highest number of spikes at Peck (Table 2.11).

Table 2.3. Impact of nitrogen rate on plant density of soft white winter wheat in northern Idaho.

Nitrogen Rate	Genesee 2015	Peck 2015	Cavendish 2016	Genesee 2016	Peck 2016
- % -	plants m^{-2}				
0	-	-	145	165 ^{a}	106
60	88 ^{b}	104 ^{a}	-	150 ^{b}	-
80	95 ^{ab}	90 ^{b}	143	157 ^{ab}	113
100	96 ^{ab}	100 ^{ab}	145	150 ^{b}	113
120	106 ^{a}	107 ^{a}	150	158 ^{ab}	109
140	-	-	145	150 ^{b}	109

Means followed by the same letter within each column is not significantly different using Fishers' LSD ($P<0.05$)

Table 2.4. Impact of seeding rate on plant density of soft white winter wheat in northern Idaho.

Seeding Rate	Genesee 2015	Peck 2015	Cavendish 2016	Genesee 2016	Peck 2016
- seeds m^{-2} -	plants m^{-2}				
247	112 ^{a}	113 ^{a}	161 ^{a}	178 ^{a}	126 ^{a}
198	99 ^{b}	104 ^{b}	148 ^{b}	156 ^{b}	109 ^{b}
148	82 ^{c}	86 ^{c}	129 ^{c}	132 ^{c}	95 ^{c}

Means followed by the same letter within each column is not significantly different using Fishers' LSD ($P<0.05$).

Table 2.5. Impact of cultivar on stand count of soft white winter wheat in northern Idaho.

Cultivar	Genesee 2015	Peck 2015	Cavendish 2016	Genesee 2016	Peck 2016
	-----------------------------plant m^{-2}--------------------------				
IDN 01-10704A	102 ^{a}	104 ^{a}	129 ^{c}	139 ^{c}	93 ^{c}
IDN 02-29001A	102 ^{a}	90 ^{b}	150 ^{b}	167 ^{a}	112 ^{b}
LCS Artdeco	100 ^{a}	103 ^{a}	161 ^{a}	158 ^{b}	133 ^{a}
LCS Drive	80 ^{b}	106 ^{a}	145 ^{b}	164 ^{ab}	113 ^{b}
SY Ovation	101 ^{a}	102 ^{a}	161 ^{a}	161 ^{ab}	121 ^{b}
UI-WSU Huffman	101 ^{a}	98 ^{ab}	127 ^{c}	141 ^{c}	87 ^{c}

Means followed by the same letter within each column is not significantly different using Fishers' LSD (P<0.05).

Table 2.6. Impact of nitrogen rate on tiller count of soft white winter wheat in northern Idaho.

Nitrogen Rate	Cavendish 2016	Genesee 2016	Peck 2016
- % -	-------------- number plant^{-1} --------------------		
0	1.9 ^{c}	2.5 ^{d}	1.7 ^{b}
60	-	2.7 ^{d}	-
80	2.0 ^{bc}	2.9 $_{c}$	1.7 ^{b}
100	2.0 $_{bc}$	3.1 $_{bc}$	1.8 ^{b}
120	2.7 ^{a}	3.3 ^{ab}	2.0 ^{a}
140	2.4 ^{b}	3.4 ^{a}	2.1 ^{a}

Means followed by the same letter within a column are not significantly different using Fishers' LSD (P<0.05).

Table 2.7. Impact of seeding rate on tiller count of soft white winter wheat in northern Idaho.

Seeding Rate	Cavendish 2016	Genesee 2016	Peck 2016
- seeds m^{-2} -	---------------- number plant^{-1} ------------		
247	2.0 ^{b}	2.8 ^{c}	1.9
198	2.1 ^{a}	3.0 ^{b}	1.9
148	2.2 ^{a}	3.2 ^{a}	1.9

Means followed by the same letter within a column are not significantly different using Fishers' LSD (P<0.05).

Table 2.8. Impact of cultivar on tiller count of soft white winter wheat in northern Idaho.

Cultivar	Cavendish 2016	Genesee 2016	Peck 2016
	------------------ number plant^{-1}	---------------	
IDN 01-10704A	2.4 ^{a}	3.3 ^{a}	2.0 ^{a}
IDN 02-29001A	1.7 ^{d}	2.8 ^{b}	1.7 ^{b}
LCS Artdeco	2.3 ^{ab}	2.9 ^{b}	1.8 ^{a}
LCS Drive	2.2 ^{b}	3.2 ^{a}	1.9 ^{a}
SY Ovation	2.2 ^{b}	2.9 ^{b}	1.9 ^{a}
UI-WSU Huffman	1.9 ^{c}	2.9 ^{b}	2.0 ^{a}

Means followed by the same letter within a column are not significantly different using Fishers' LSD (P<0.05).

Table 2.9. Impact of nitrogen rate on spike counts of soft white winter wheat in northern Idaho.

Nitrogen Rate	Cavendish 2016	Genesee 2016	Peck 2016
- % -	----------------------	spikes m^{-2}	-------------------
0	276 ^{c}	366 ^{e}	297 ^{c}
60	-	398 ^{d}	-
80	287 ^{c}	466 ^{c}	298 ^{c}
100	323 ^{b}	510 ^{b}	305 ^{c}
120	339 ^{b}	554 ^{a}	341 ^{b}
140	369 ^{a}	569 ^{a}	365 ^{a}

Means followed by the same letter within a column are not significantly different using Fishers' LSD (0.05).

Table 2.10 – Impact of seeding rate on spike counts of soft white winter wheat in northern Idaho.

Seeding Rate	Cavendish 2016	Genesee 2016	Peck 2016
- seeds m^{-2} -	-------------------	spikes m^{-1}	------------------
247	328 ^{a}	490 ^{a}	336 ^{a}
198	319 ^{ab}	472 ^{b}	322 ^{b}
148	310 ^{b}	470 ^{b}	306 ^{c}

Means followed by the same letter within a column are not significantly different using Fishers' LSD (P<0.05).

Table 2.11 – Impact of cultivar on spike counts of soft white winter wheat in northern Idaho.

Cultivar	Cavendish 2016	Genesee 2016	Peck 2016
	-------------------	spikes m^{-1}	------------------
IDN 01-10704A	308 ^{c}	480 ^{b}	309 ^{cd}
IDN 02-29001A	308 ^{c}	483 ^{c}	296 ^{d}
LCS Artdeco	322 ^{abc}	487 ^{ab}	333 ^{ab}
LCS Drive	312 ^{bc}	476 ^{b}	331 ^{ab}
SY Ovation	335 ^{a}	476 ^{b}	342 ^{a}
UI-WSU Huffman	328 ^{ab}	502 ^{a}	318 ^{bc}

Means followed by the same letter within a column are not significantly different using Fishers' LSD ($P<0.05$).

For all sites and years there was a greater mature plant height with increasing nitrogen rates (Table 2.12). In every example, the highest nitrogen rate (120 or 140%) produced the tallest plants. No lodging was observed for any of the sites and years.

Peck 2016 was the only site to have seeding rate significantly influence height. Increasing the seeding rate from 148 to 247 seeds m^{-2} increased the height of the wheat plants by 1.1 cm (Table 2.13). Although not significant, the 198 or 247 seeds m^{-2} rates resulted in the tallest plants.

Each individual cultivar has a different height potential. Table 2.14 shows that LCS Drive was consistently the shortest cultivar with an average of 68.6 cm, while IDN 01-10704A was the tallest cultivar across all sites with an average height of 84.8 cm. The remaining cultivars difference in heights varied across environments.

Yield varied across sites with the Genesee sites having the greatest productivity in each year (Table 2.15). Of the three locations, Cavendish had the lowest yield. Observed yields were similar between 2015 and 2016, but tended to be slightly higher in 2015. Genesee 2015, Cavendish 2016, Genesee 2016, and Peck 2016 all showed a linear increase in yield with increasing nitrogen rates. Peck 2015 showed a quadratic response to nitrogen rate where the 100% nitrogen rate produced an average of 5,728 kg ha while the 120% nitrogen rate produced a lower yield of 5,705 kg ha. In 2016, the highest grain yields were observed for the 140% nitrogen rate at all locations.

Both 2015 sites showed the highest seeding rate tended to produce the greatest grain yields. At Genesee 2015, Peck 2015 and Peck 2016 the highest seeding rate produced the highest grain yield of 7,753; 5,241 and 5,148 kg ha^{-1}, respectively (Table 2.16) and each significantly higher than the yield produced by the lowest seeding rate. The seeding rates at Cavendish 2016 and Genesee 2016 had little impact on grain yield.

The impact of cultivar on yield varied by location (Table 2.17). In Genesee (2015 and 2016) the highest yielding cultivar was IDN 01-10704A with 7,823 and 7,343 kg ha^{-1}, respectively. UI-WSU Huffman and IDN 02-29001A produced the second highest yields in Genesee both years. LCS Drive, LCS Artdeco and SY Ovation were the lowest yielding cultivars in both years at Genesee. At Peck 2015, Peck 2016 and Cavendish 2016, all lower producing sites compared to Genesee, LCS Artdeco was the highest yielding cultivar with 5,349; 5,326 and 4,182 kg ha^{-1}, respectively. UI-WSU Huffman tended to perform poorly at Peck, being the lowest yielding cultivar in both years of the study. Cultivars IDN 01-10704A, IDN 02-29001A and UI-WSU Huffman were significantly lower yielding than LCS Artdeco at Cavendish 2016.

No significant two-way interactions were observed at the Cavendish 2016 or Peck 2016 sites regarding yield. However, a cultivar by nitrogen rate interaction occurred at Genesee 2016 and Peck 2015, and a three-way interaction of cultivar by nitrogen rate by seeding rate was evident at Genesee 2015. Figure 2.1-2.3 shows cultivar by nitrogen rate influence on yield for all sites and years. At Peck 2015 most cultivars did not continue to increase in yield at the 120% rate. The exception is SY Ovation which responded to the highest nitrogen input. At Genesee 2016, all cultivars responded to increasing nitrogen rates except for LCS Artdeco. The Genesee 2015 site had two cultivars, IDN 01-10704A and UI-WSU Huffman, with reduced yields at the 120% rate, while the other cultivars continued to respond to increasing nitrogen rates. All Cavendish and most of Peck 2016 cultivars increased in yield with increasing nitrogen rates. At Peck 2016, the only cultivar to decrease in yield compared to the lower nitrogen rates was LCS Artdeco at 140%.

Optimal nitrogen rate was determined for each site year from yield using polynomial regression equations (Table 2.18). SY Ovation consistently responded to the maximum nitrogen rate resulting in the highest yield for all site years. IDN 01-10704A had the lowest optimal nitrogen rate at 104% in both Genesee and Peck during 2015 growing season. UI-WSU Huffman showed a similar response with 110% nitrogen rate giving the optimal yield at Genesee and Peck 2015. Nearly all cultivars in the 2016 sites had a maximum yield at the 140% nitrogen rate with the exception of LCS Artdeco at Genesee and Peck where the optimal nitrogen rate was 128 and 129%, respectively.

Nitrogen use efficiency (NUE) in wheat can give an indication of how effectively a plant uptakes nitrogen and utilizes it. This NUE was calculated using only the applied nitrogen and the yield. The other components to NUE were not used in this equation. The lowest nitrogen rates at all sites had higher NUE values which decreased as the nitrogen rate increased (Figure 2.4). Genesee 2015, Peck 2015 and Genesee 2016 showed each NUE decreasing stepwise with no rates having the same value. Cavendish 2016 and Peck 2016 had less severe response. At both sites 0 and 80% nitrogen rates had the same NUE. The 100 to 140% rates had reduced NUE relative to the lower nitrogen rates, but these higher nitrogen rates did not differ from each other. Genesee 2016 had the overall highest NUE at the 0% nitrogen rate with a value greater than 39 kg wheat kg N^{-1}. While Cavendish 2016 had the overall lowest NUE at the 140% rate of about 19 kg wheat kg N^{-1}.

Cultivar influenced the outcome of NUE with each site having different results. Genesee 2015 and Genesee 2016 had the two highest NUE among all site years (Figure 2.5). IDN 01-10704A and UI-WSU Huffman had the highest NUE for Genesee 2015 and Genesee 2016. The NUE for LCS Artdeco was the highest for Cavendish 2016, Peck 2015 and Peck 2016. LCS Drive NUE was lowest at all sites except Peck 2015.

Table 2.12. Impact of nitrogen rate on height of soft white winter wheat in northern Idaho.

Nitrogen Rate	Genesee 2015	Peck 2015	Cavendish 2016	Genesee 2016	Peck 2016
- % -	--	----------------	cm	----------------	--
0	-	-	71.0 c	72.3 d	74.7 bc
60	76.1 d	75.0 d	-	76.3 c	-
80	78.5 c	80.4 c	72.5 c	80.2 b	73.7 c
100	80.6 b	83.3 b	76.5 b	81.3 ab	75.6 b
120	82.6 a	84.6 a	78.1 b	82.3 ab	80.2 a
140	-	-	81.7 a	82.8 a	81.1 a

Means followed by the same letter under each column are not significantly different using Fishers' LSD (P<0.05)

Table 2.13. Impact of seeding rate on height of soft white winter wheat in northern Idaho.

Seeding Rate	Genesee 2015	Peck 2015	Cavendish 2016	Genesee 2016	Peck 2016
- seeds m^{-2} -	--	----------------	cm	----------------	--------------------------------
247	79.3	80.5	76.0	79.7	77.6 a
198	79.7	81.1	76.0	78.8	77.3 ab
148	79.6	80.9	75.9	79.1	76.5 b

Means followed by the same letter within one column are not significantly different using Fishers' LSD (P<0.05).

Table 2.14. Impact of cultivar on height of soft white winter wheat in northern Idaho.

Cultivar	Genesee 2015	Peck 2015	Cavendish 2016	Genesee 2016	Peck 2016
	---------------------------------- cm	-------------------------------------			
IDN 01-10704A	89.4 ^{a}	89.4 ^{a}	79.3 ^{a}	84.1 ^{a}	83.3 ^{a}
IDN 02-29001A	83.4 ^{b}	83.8 ^{bc}	78.7 ^{a}	81.7 ^{b}	80.2 ^{b}
LCS Artdeco	73.5 ^{d}	75.6 ^{d}	74.3 ^{b}	76.9 ^{d}	74.4 ^{d}
LCS Drive	65.4 ^{e}	69.1 ^{e}	70.1 ^{c}	70.5 ^{e}	68.6 ^{e}
SY Ovation	78.7 ^{c}	82.7 ^{c}	77.8 ^{a}	79.5 ^{c}	79.0 ^{b}
UI-WSU Huffman	86.1 ^{b}	84.3 ^{b}	75.8 ^{b}	82.6 ^{ab}	77.2 ^{c}

Means followed by the same letter within each column are not significantly different using Fishers' LSD (P<0.05).

Table 2.15. Impact of nitrogen rate on yield of soft white winter wheat in northern Idaho.

Nitrogen Rate	Genesee 2015	Peck 2015	Cavendish 2016	Genesee 2016	Peck 2016
- % -	----------------------------------	kg ha^{-1}	----------------------------		
0	-	-	3,285 ^{d}	4,839 ^{f}	4,663 ^{b}
60	6,485 ^{d}	4,213 ^{c}	-	5,365 ^{e}	-
80	7,289 ^{c}	5,133 ^{b}	3,630 ^{cd}	6,254 ^{d}	4,678 ^{b}
100	7,699 ^{b}	5,728 ^{a}	4,051 ^{c}	6,841 ^{c}	4,925 ^{b}
120	8,047 ^{a}	5,705 ^{a}	4,499 ^{b}	7,506 ^{b}	5,775 ^{a}
140	-	-	5,079 ^{a}	7,962 ^{a}	5,981 ^{a}

Means followed by the same letter within each column is not significantly different using Fishers' LSD (P<0.05).

Table 2.16. Impact of seeding rate on yield of soft white winter wheat in northern Idaho.

Seeding Rate	Genesee 2015	Peck 2015	Cavendish 2016	Genesee 2016	Peck 2016
- seeds m^{-2} -	------------------------------------		kg ha^{-1}	-----------------------------	
247	7,753 ^{a}	5,241 ^{a}	4,102	6,524	5,314 ^{a}
198	7,274 ^{b}	5,225 ^{ab}	4,113	6,354	5,233 ^{a}
148	7,320 ^{b}	5,133 ^{b}	4,108	6,509	5,070 b

Means followed by the same letter within one column are not significantly different using Fishers' LSD (P<0.05).

Table 2.17. Impact of cultivar on yield of soft white winter wheat in northern Idaho.

Cultivar	Genesee 2015	Peck 2015	Cavendish 2016	Genesee 2016	Peck 2016
	--------------------------------	--------- kg ha^{-1}	----------------	----------------	------------
IDN 01-10704A	7,823 ^{a}	5,195 ^{b}	4,126 ^{b}	7,343 ^{a}	5,323 ^{ab}
IDN 02-29001A	7,544 ^{abc}	5,156 ^{b}	4,142 ^{b}	6,818 ^{b}	5,245 ^{b}
LCS Artdeco	7,305 ^{c}	5,349 ^{a}	4,305 a	6,176 ^{c}	5,498 ^{a}
LCS Drive	6,771 ^{d}	5,287 ^{ab}	3,979 c	5,473 ^{e}	4,884 ^{c}
SY Ovation	7,483 ^{bc}	5,187 ^{b}	3,984 c	5,883 ^{d}	5,325 ^{ab}
UI-WSU Huffman	7,776 ^{ab}	5,001 ^{c}	4,112 b	7,027 ^{b}	4,959 ^{c}

Means followed by the same letter within each column is not significantly different using Fishers' LSD ($P<0.05$).

Table 2.18. Nitrogen rate to achieve maximum yield for soft white winter what in northern Idaho.

Cultivar	Genesee 2015	Peck 2015	Cavendish 2016	Genesee 2016	Peck 2016
	----------------------------	---------- %	----------------	----------------	------------
IDN 01-10704A	104	104	140	140	140
IDN 02-29001A	120	114	140	140	140
LCS Artdeco	120	110	140	128	129
LCS Drive	120	120	140	140	140
SY Ovation	120	120	140	140	140
UI-WSU Huffman	110	110	140	140	140

Optimal nitrogen rates were determined using polynomial regression of $y = a + b_1x + b_2x^2$ for each cultivar and site year.

Nitrogen rate percentage is based on average rate of 100% = 0.042 kg N/kg wheat.

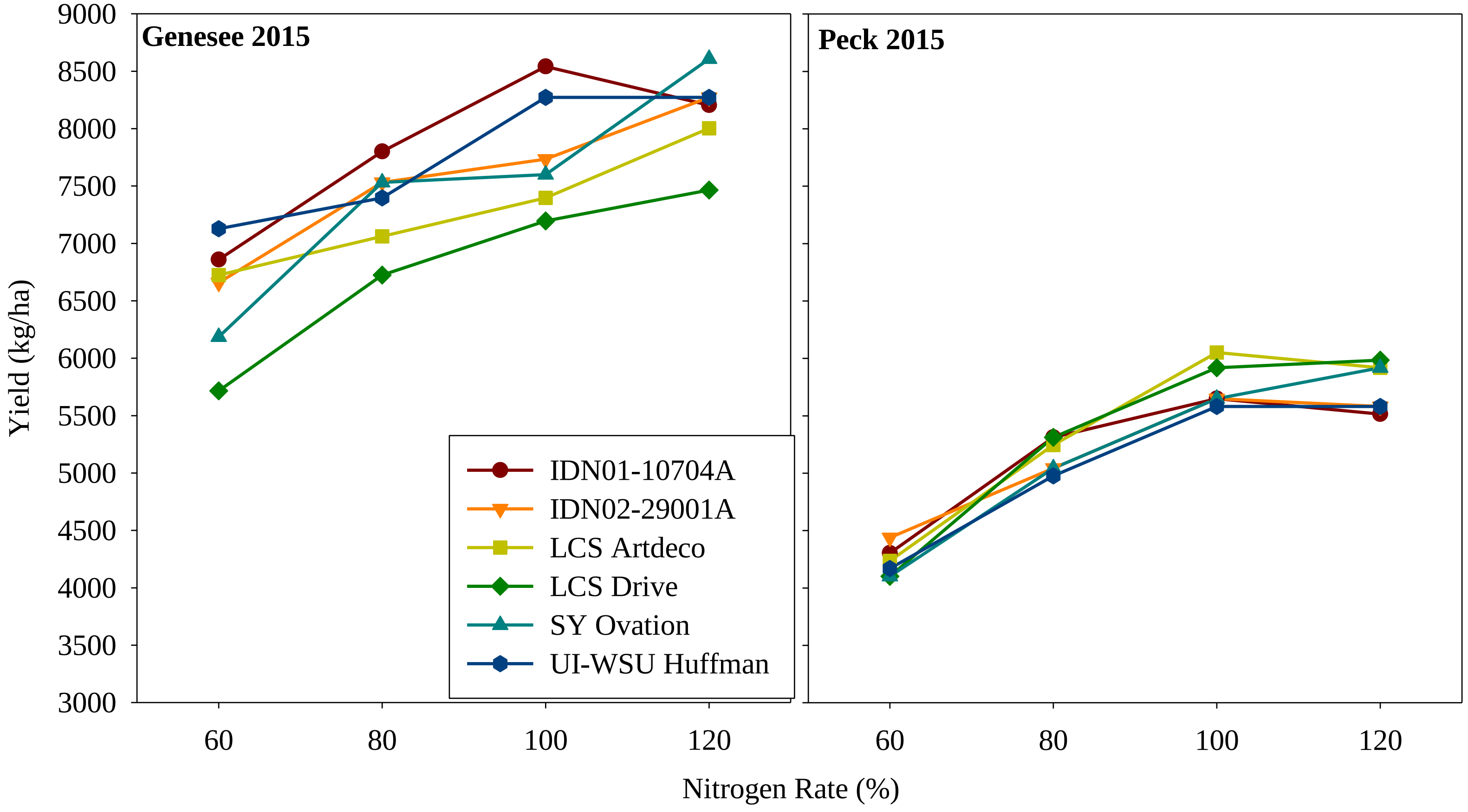

Figure 2.1. Impact of cultivar by nitrogen rate on yield at Genesee and Peck 2015. Nitrogen rate is expressed as percentage where 100% = 0.042 kg N/kg wheat.

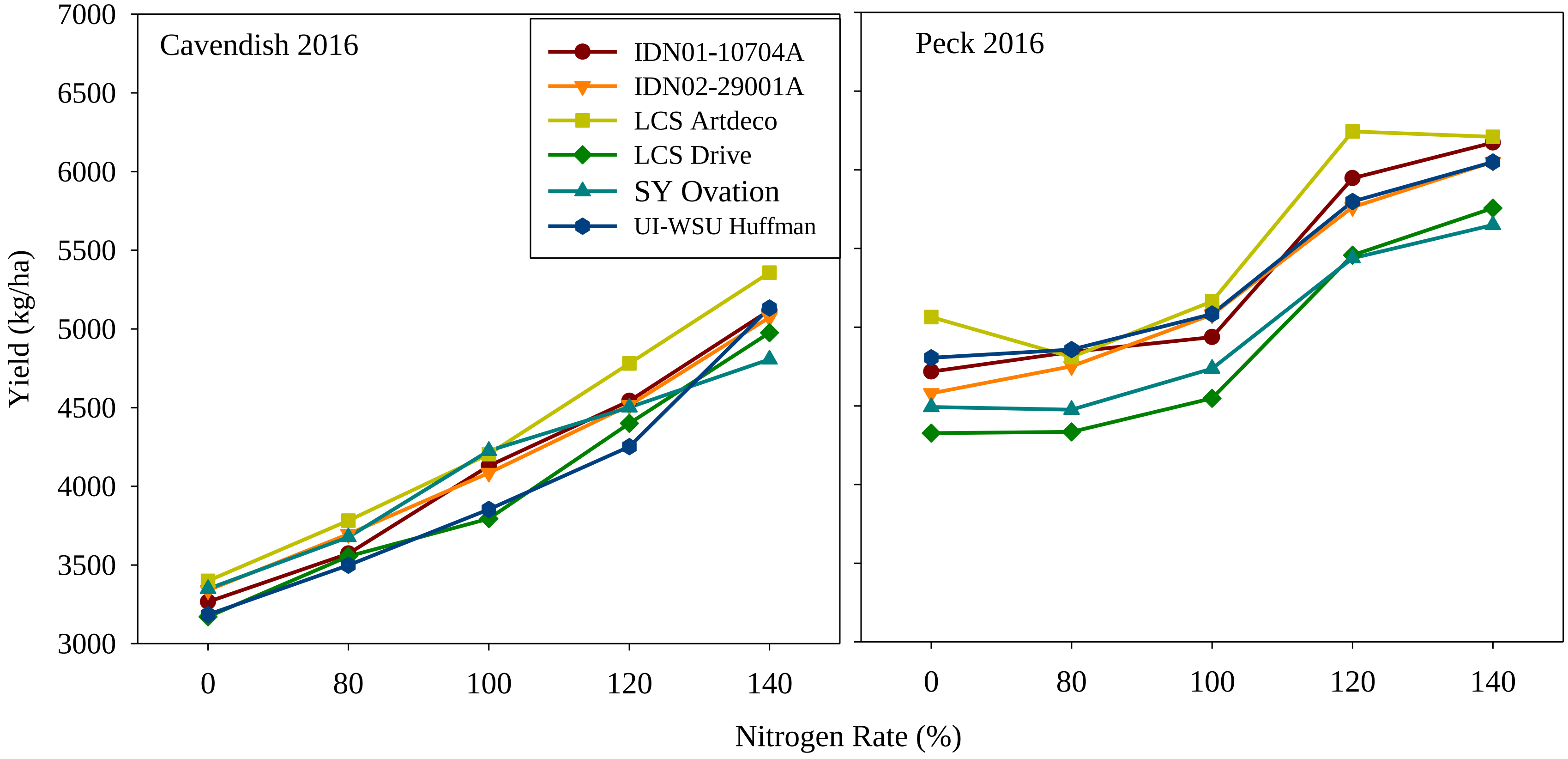

Figure 2.3. Impact of cultivar by nitrogen rate on yield at Cavendish and Peck 2016. Nitrogen rate is expressed in percentage where 100% = 0.042 kg N/kg wheat.

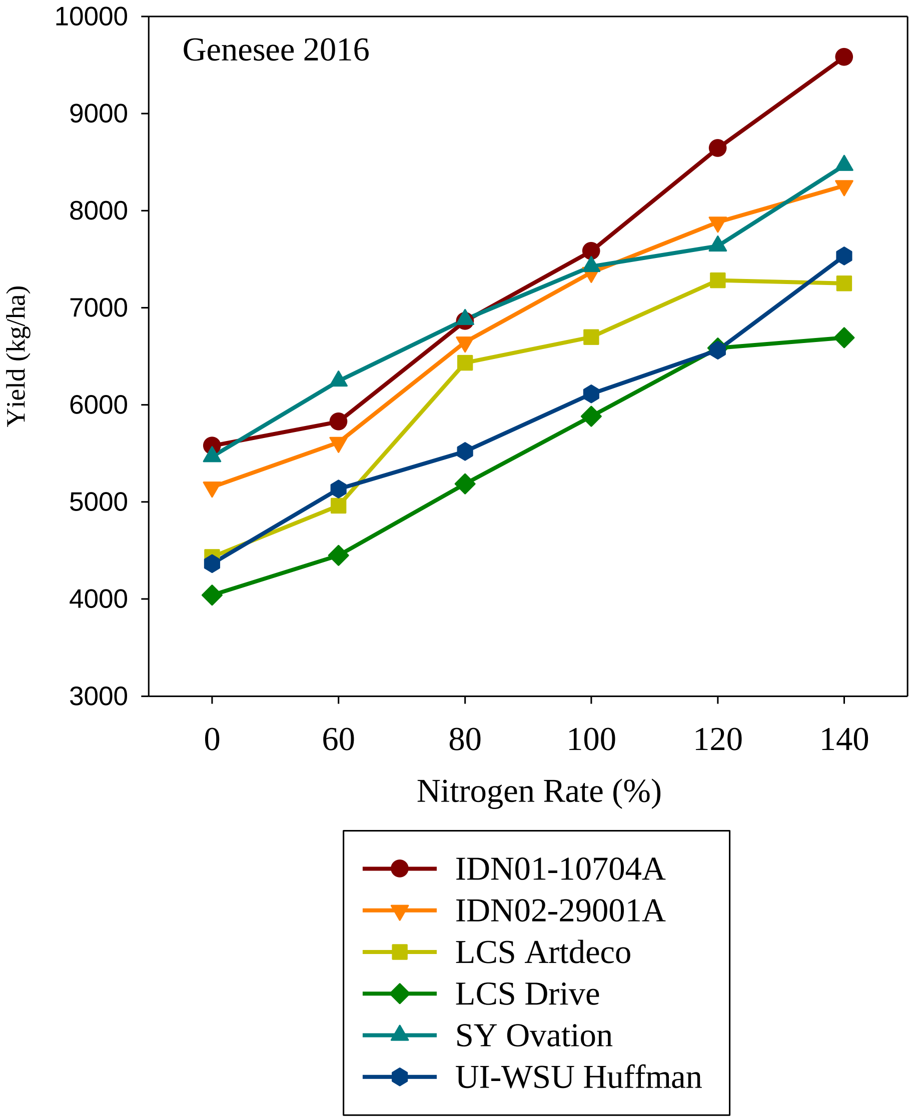

Figure 2.3. Impact of cultivar by nitrogen rate on yield at Genesee 2016. Nitrogen rates are expressed in percentage with 100% = 0.042 kg N/kg wheat.

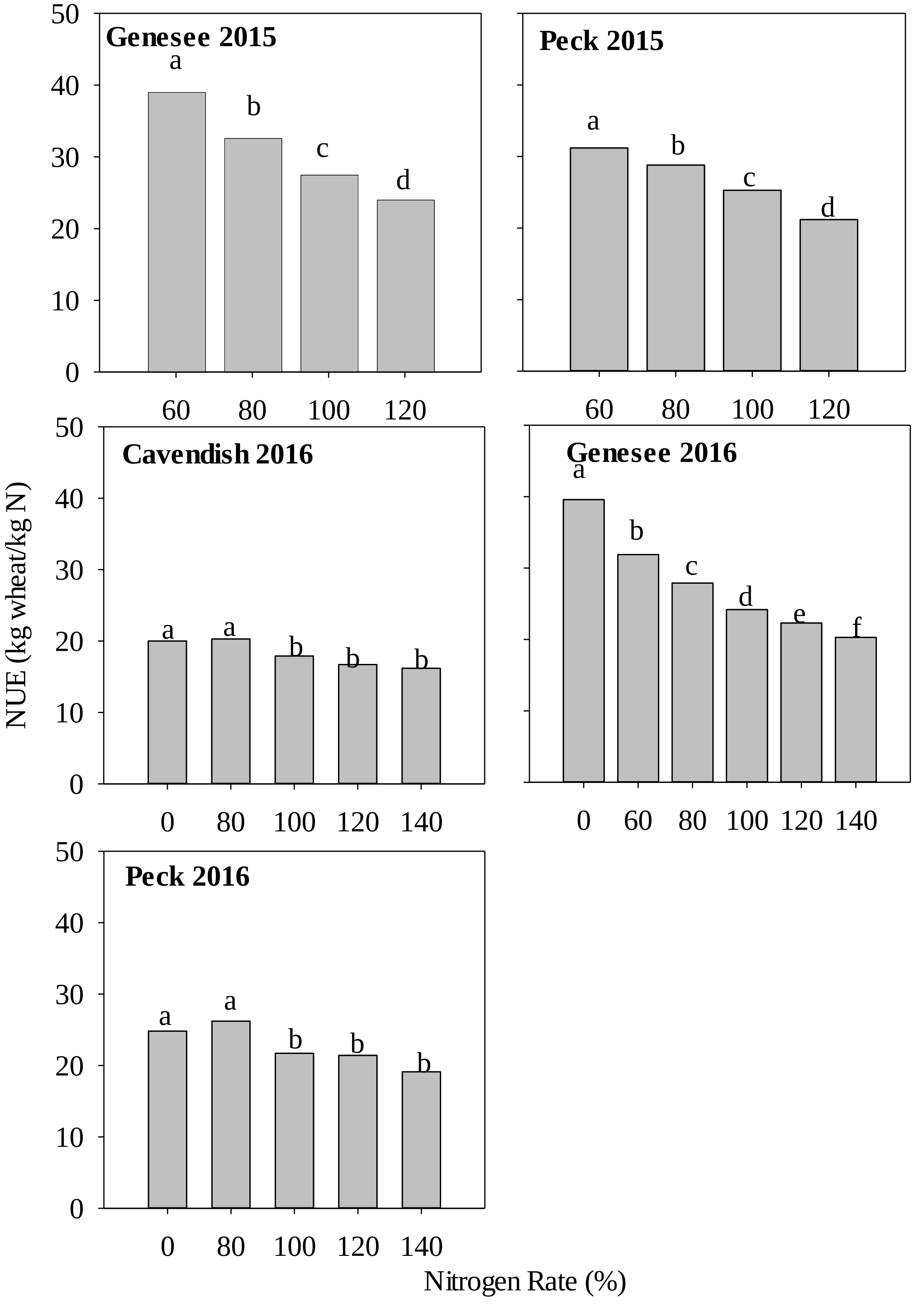

Figure 2.4. Impact of nitrogen rate on NUE (nitrogen use efficiency) of soft white winter wheat in northern Idaho. Bars with the same letter are not significantly different using Fishers' LSD ($P<0.05$). Nitrogen average of 100% is based on 0.042 kg N kg wheat^{-1}. NUE is calculated using grain weight divided by total nitrogen in soil (added nitrogen + mineralizable N + NO_3/NH_4).

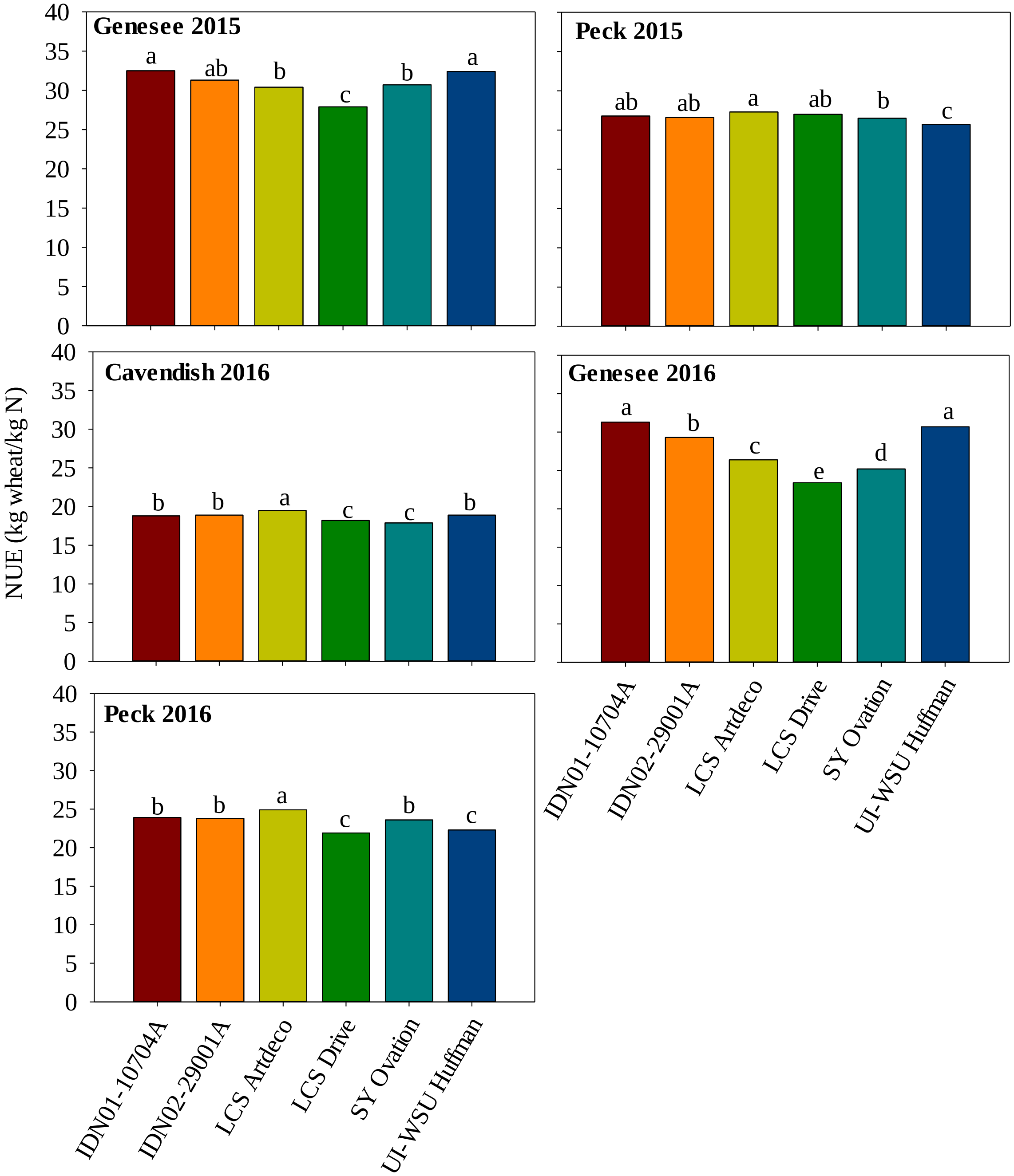

Figure 2.5. Impact of cultivar on NUE (nitrogen use efficiency) of soft white winter wheat in northern Idaho. Bars with the same letter are not significantly different using Fishers' LSD ($P<0.05$). NUE is calculated using Grain weight divided by total nitrogen in soil (added nitrogen + mineralizable N + NO_3/NH_4).

Test weight varied by year with lower grain weights in 2015 due to drought stress conditions during grain fill. Test weight was significantly influenced by nitrogen rates at Genesee 2015 and Peck 2015 (Table 2.19). At Genesee 2015 and Peck 2015, increasing nitrogen rates significantly decreased test weight. The lowest nitrogen rate (60%) resulted in test weights of 76.3 and 74.1 kg hL^{-1} at Genesee 2015 and Peck 2015, respectively. The highest nitrogen rate (120%) produced the lowest test weight at each site. Test weights were very similar between nitrogen rates at Cavendish 2016, Genesee 2016 and Peck 2016. Regardless of the nitrogen rates, all test weights were above the USDA Grade 1 for test weight of 75.0 kg hL^{-1}.

Test weight was influenced by seeding rates from all 2016 sites (Table 2.20). At each of these locations the higher seeding rates resulted in significantly heavier test weights than the lowest seeding rate which was 0.2 to 0.3 kg hL^{-1} lower than the top two rates. Seeding rate did not influence test weight at either location in 2015.

Cultivars have fundamental differences in test weights due to genetic ability (Table 2.21). LCS Artdeco and LCS Drive tended to have lower test weights while IDN 02-29001A and SY Ovation typically had the heaviest test weight. Peck 2015 test weights were lower than all the other sites with an average of 71.6 kg hL^{-1}. All 2016 trials produced test weights higher than the 75.0 kg hL^{-1} standard except LCS Artdeco and LCS Drive at Genesee.

Regarding test weight, a significant cultivar by nitrogen rate interaction was present in Peck 2015 and Genesee 2016 in addition to a significant cultivar by seeding rate interaction at Peck 2016. Despite these significant interactions, there were no obvious trends in the data.

Protein was influenced by drought stress in 2015. Protein content was higher at the Genesee and Peck locations in 2015 than the same sites in 2016. At Genesee and Peck in both years of the study, there was an increase in protein in parallel with increasing nitrogen rates. The highest nitrogen rates produced the highest protein of 11.3, 10.9, 10.1 and 7.9% at Genesee 2015, Peck 2015, Genesee 2016 and Peck 2016, respectively. The results at Cavendish 2016 differed with increasing nitrogen rates decreasing protein. The highest protein of 7.8% was at the 0% nitrogen rate, while the lowest protein of 7.4% was at 120 and 140% nitrogen rate (Table 2.22). The desired protein for soft white winter wheat should be lower than 10.5%.

Seeding rate had little influence on protein. However, at Peck 2015 and Cavendish 2016 there was a significant difference between seeding rates (Table 2.23). At Peck 2015, the lowest seeding rate had the highest protein of 9.4%. Protein decreased as the seeding rate increased with the highest seeding rate producing the lowest protein (9.1%). Cavendish 2016 had an opposite response with 247 and 198 seeds m^{-2} rates producing protein of 7.5 and 7.6%, respectively. The 148 seeds m^{-2} rate had significantly lower protein of 7.4%.

There were cultivar differences in protein that were relatively consistent across locations (Table 2.24). LCS Drive produced the highest protein at Genesee 2015, Cavendish 2016, Genesee 2016 and Peck 2016. IDN 01-10704A tends to have lower protein compared to other cultivars. These trends in protein also correlate with yield for these cultivars, with higher yielding cultivars accumulating lower grain protein. Each cultivar response to protein is dependent on the environment.

There was a significant influence on protein between cultivar and nitrogen rate for Peck 2015 and Genesee 2016. Peck 2016 had a significant cultivar by seeding rate interaction with protein accumulation in the wheat.

Table 2.19. Impact of nitrogen rate on test weight of soft white winter wheat in northern Idaho.

Nitrogen Rate	Genesee 2015	Peck 2015	Cavendish 2016	Genesee 2016	Peck 2016
- % -	------------------------------------- kg hL^{-1} -----------------------------------				
0	-	-	76.4	76.0	76.6
60	76.3 [a]	74.1 [a]	-	76.1	-
80	76.2 [a]	72.7 [b]	76.3	76.0	76.6
100	75.5 [b]	71.1 [c]	76.3	76.1	76.4
120	75.5 [b]	69.1 [d]	76.2	76.0	76.7
140	-	-	76.3	76.0	76.7

Means followed by the same letter within one column is not significantly different using Fishers' LSD (P<0.05).

Table 2.20. Impact of seeding rate on test weight of soft white winter wheat in northern Idaho.

Seeding Rate (seeds/m^2)	Genesee 2015	Peck 2015	Cavendish 2016	Genesee 2016	Peck 2016
- seeds m^{-2} -	------------------------------------ kg hL^{-1} -----------------------------------				
247	75.7	71.9	76.3 [a]	76.3 [a]	76.7 [a]
198	76.1	71.7	76.3 [a]	76.0 [b]	76.6 [a]
148	76.0	71.7	76.1 [b]	76.0 [b]	76.5 [b]

Means followed by the same letter within a column is not significantly different using Fishers' LSD (P<0.05).

Table 2.21. Impact of cultivar on test weight of soft white winter wheat in northern Idaho.

Cultivar	Genesee 2015	Peck 2015	Cavendish 2016	Genesee 2016	Peck 2016
	-----------------------------	----------- kg hL^{-1}	-----------	-----------	---------------------------
IDN 01-10704A	76.0 ^{b}	71.2 ^{c}	76.5 ^{b}	76.1 ^{c}	76.9 ^{b}
IDN 02-29001A	78.0 ^{a}	73.7 ^{a}	77.4 ^{a}	78.0 ^{a}	77.9 ^{a}
LCS Artdeco	75.2 ^{c}	70.7 ^{c}	75.5 ^{c}	74.2 ^{e}	75.7 ^{d}
LCS Drive	73.0 ^{d}	69.9 ^{d}	76.4 ^{b}	74.5 ^{d}	76.6 ^{c}
SY Ovation	77.4 ^{a}	73.7 ^{a}	76.4 ^{b}	76.6 ^{b}	76.5 ^{c}
UI-WSU Huffman	75.8 ^{bc}	72.0 ^{b}	75.5 ^{c}	76.6 ^{b}	75.6 ^{d}

Means followed by the same letter within a column is not significantly different using Fishers' LSD ($P<0.05$).

Table 2.22. Impact of nitrogen rate on protein of soft white winter wheat in northern Idaho.

Nitrogen Rate (%)	Genesee 2015	Peck 2015	Cavendish 2016	Genesee 2016	Peck 2016
- % -	-----------------------	-----------------------	----------- %	-----------------------	-----------------------
0	-	-	7.8 ^{a}	9.4 ^{cd}	7.7 ^{b}
60	10.0 ^{d}	8.0 ^{d}	-	9.5 ^{bc}	-
80	10.5 ^{c}	8.5 ^{c}	7.7 ^{a}	9.2 ^{d}	7.8 ^{ab}
100	10.9 ^{b}	9.7 ^{b}	7.5 ^{b}	9.6 ^{bc}	7.6 ^{b}
120	11.3 ^{a}	10.9 ^{a}	7.4 ^{b}	9.7 ^{b}	7.8 ^{ab}
140	-	-	7.4 ^{b}	10.1 ^{a}	7.9 ^{a}

Means followed by the same letter within one column is not significantly the same using Fishers' LSD ($P<0.05$).

Table 2.23. Impact of seeding rate on protein of soft white winter wheat in northern Idaho.

Seeding Rate	Genesee 2015	Peck 2015	Cavendish 2016	Genesee 2016	Peck 2016
- seeds m^{-2} -	-----------------------	-----------------------	----------- %	-----------------------	-----------------------
247	10.6	9.1 ^{b}	7.6 ^{ab}	9.7	7.8
198	10.6	9.3 ^{a}	7.6 ^{a}	9.5	7.8
148	10.6	9.4 ^{a}	7.5 ^{b}	9.6	7.8

Means followed by the same letter within one column is not significantly different using Fishers' LSD ($P<0.05$).

Table 2.24. Impact of cultivar on protein of soft white winter wheat in northern Idaho.

Cultivar	Genesee 2015	Peck 2015	Cavendish 2016	Genesee 2016	Peck 2016
	------------------------------- % ----------------------------				
IDN 01-10704A	10.1 ^{c}	9.0 ^{bc}	7.4 ^{c}	8.7 ^{e}	7.5 ^{d}
IDN 02-29001A	10.7 ^{b}	9.5 ^{a}	7.5 ^{c}	9.4 ^{d}	7.8 ^{cb}
LCS Artdeco	10.2 ^{c}	9.2 ^{b}	7.6 ^{b}	10.1 ^{b}	7.9 ^{b}
LCS Drive	11.0 ^{a}	8.9 ^{c}	7.9 ^{a}	10.5 ^{a}	8.2 ^{a}
SY Ovation	10.6 ^{b}	9.1 ^{bc}	7.6 ^{b}	9.7 ^{c}	7.7 ^{c}
UI-WSU Huffman	10.7 ^{b}	9.2 ^{b}	7.3 ^{d}	8.9 ^{e}	7.5 ^{d}

Means followed by the same letter within one column is not significantly different using Fishers' LSD ($P<0.05$).

Thousand seed weights were only recorded in 2016. The nitrogen rates influenced the outcome of 1000 seed weight and seeds per spike (Tables 2.25 and 2.28). At each site, increasing nitrogen rate resulted in a decrease in the weight of the seed. Cavendish weights ranged from 47.0 g at 0% to 45.8 g at 140% nitrogen rate. At Genesee, the 1000 seed weight at 0% nitrogen was 47.4 g while the 140% nitrogen rate was 44.0 g. At Peck the heaviest weight of 47.0 g was produced with 0% nitrogen rate while the lightest weight was produced at 140% rate with 44.8 g. The same trend was observed for the number of seeds per spike, with counts decreasing with increasing nitrogen rate.

Seeding rate did not influence the 1000 seed weight (Table 2.26). There was no significant difference or trend related to seeding rate. However, seeding rate significantly influenced the number of seeds per spike at Genesee (Table 2.29). The highest seeding rate produced the least number of seeds at 27.3, 29.4 and 34.7 seeds per spike at Cavendish, Genesee and Peck, respectively.

Cultivars each expressed differences in 1000 seed weight and seeds per spike (Tables 2.27 and 2.30). SY Ovation produced the heaviest seed across all three sites with an average of 50.7g per 1000 seeds, but also significantly fewer seeds per spike compared to most of the other cultivars. IDN 01-10704A and UI-WSU Huffman produces the lightest seed, but also produces the greatest number of seeds per spike at all sites. Thousand seed weight was similar between each site. However, Peck had the greatest number of seeds per spike followed by Genesee and finally Cavendish.

Table 2.25. Impact of nitrogen rate on 1000 seed weight of soft white winter wheat in northern Idaho.

Nitrogen Rate	Cavendish 2016	Genesee 2016	Peck 2016
- % -	--------------------	g 1000 seeds^{-1}	---------------
0	47.0 ^{a}	47.4 ^{a}	47.0 ^{a}
60	-	47.4 ^{a}	-
80	46.8 ^{ab}	46.2 ^{b}	46.8 ^{a}
100	46.3 ^{bc}	45.4 ^{c}	46.4 ^{ab}
120	46.2 ^{cd}	44.9 ^{c}	45.7 ^{b}
140	45.8 ^{d}	44.0 ^{d}	44.8 ^{c}

Means followed by the same letter within one column is not significantly different using Fishers' LSD (P<0.05).

Table 2.26. Impact of seeding rate on 1000 seed weight of soft white winter wheat in northern Idaho.

Seeding Rate (seeds/m^{2}	Cavendish 2016	Genesee 2016	Peck 2016
- seeds m^{-1} -	-------------------	g 1000 seeds^{-1}	-------------
247	46.4	46.1	46.0
198	46.5	45.9	46.2
148	46.5	45.7	46.2

Means followed by the same letter within a column are not significantly different using Fishers' LSD (P<0.05)

Table 2.27. Impact of cultivar on 1000 seed weight of soft white winter wheat in northern Idaho.

Cultivar	Cavendish 2016	Genesee 2016	Peck 2016
	---------------- g 1000 seeds^{-1}		-----------
IDN 01-10704A	45.0 ^{d}	43.0 ^{e}	45.0 ^{d}
IDN 02-29001A	47.3 ^{b}	46.7 ^{c}	46.2 ^{c}
LCS Artdeco	46.6 ^{c}	47.4 ^{b}	46.9 ^{b}
LCS Drive	46.3 ^{c}	46.0 ^{d}	46.5 ^{bc}
SY Ovation	50.9 ^{a}	51.4 ^{a}	50.0 ^{a}
UI-WSU Huffman	42.6 ^{e}	40.9 ^{f}	42.6 ^{e}

Means followed by the same letter within a column are not significantly different using Fishers' LSD ($P<0.05$).

Table 2.28. Impact of nitrogen rate on seeds per spike of soft white winter wheat in northern Idaho.

Nitrogen Rate	Cavendish 2016	Genesee 2016	Peck 2016
- % -	------------------- seeds spike^{-1}		---------------
0	26.0 ^{d}	28.4 ^{d}	33.8 ^{b}
60	-	29.3 ^{cd}	-
80	27.6 ^{cd}	29.8 ^{bc}	34.0 ^{b}
100	28.0 ^{bc}	30.0 ^{bc}	35.5 ^{ab}
120	29.2 ^{ab}	30.9 ^{b}	37.5 ^{a}
140	30.7 ^{a}	32.5 ^{a}	37.3 ^{a}

Means followed by the same letter within one column are not significantly different using Fishers' LSD ($P<0.05$).

Table 2.29. Impact of seeding rate on seeds per spike of soft white winter wheat in northern Idaho.

Seeding Rate	Cavendish 2016	Genesee 2016	Peck 2016
- seeds m^{-2} -	----------------- seeds spike^{-1}		----------------
247	27.5 b	29.4 b	34.9 b
198	28.4 ab	30.0 ab	35.7 ab
148	29.0 a	31.0 a	36.4 a

Means followed by the same letter within a column are not significantly different using Fishers' LSD ($P>0.05$).

Table 2.30. Impact of cultivar on seeds per spike of soft white winter wheat in northern Idaho.

Cultivar	Cavendish 2016	Genesee 2016	Peck 2016
	------------------	seeds spike^{-1}	---------------
IDN 01-10704A	30.3 a	35.7 a	39.1 a
IDN 02-29001A	29.1 ab	33.4 b	39.0 a
LCS Artdeco	28.8 ab	27.0 c	35.6 b
LCS Drive	27.8 b	25.2 d	31.8 c
SY Ovation	23.9 c	24.2 d	31.4 c
UI-WSU Huffman	30.1 a	35.2 a	37.0 b

Means followed by the same letter within a column are not significantly different using Fishers' LSD ($P<0.05$).

2.3.2 Economic Return of all Sites and Years.

The mean square form the analysis of variance of each of the traits analyzed are presented in Appendix A, Tables A.6 and A.7. The economic return based on nitrogen rate, seeding rate or cultivar varied by location. The Genesee 2015 location generated the highest overall return compared to all other site years (Table 2.31). Likewise, Genesee had the highest return in 2016 as well. Due to environmental characteristics, Genesee has a higher yield potential than Cavendish or Peck. The three highest nitrogen rates at Genesee 2015 (80, 100, and 120%) showed very little difference in economic return. The 60% nitrogen rate resulted in the lowest return of \$1249 ha^{-1} (Table 2.31). At Peck 2015 the highest return was observed with the average nitrogen rate of 100%, although the 80% was not significantly lower. The Cavendish 2016 site produced the lowest economic return of all site years for the study. At Cavendish, the lowest two nitrogen rates 0 and 80% (0% is equivalent to 60% of the recommended rate) produced the highest returns of \$351 and \$348 ha^{-1}, respectively. The average rate (100%) produced a significantly lower return of \$311/ha. At Genesee 2016, the highest returns were observed at 120 and 140% nitrogen rates with values of \$926 and

\$905 ha^{-1}, respectively. The 0% nitrogen rate produced the lowest return (\$633 ha^{-1}). At Peck 2016 the 80% nitrogen rate had the highest return at \$561 ha^{-1}, although the 60, 100 and 120% nitrogen rates were not significantly lower. The lowest return was generated at a nitrogen rate of 140%.

There was a significant response to seeding rate at Genesee 2015, Genesee 2016 and Peck 2016. At Genesee 2015, the highest seeding rate had a significantly higher return (\$1411 ha^{-1}) than either of the lower seeding rates (Table 2.32). At Genesee 2016, the highest and lowest seeding rates were significantly higher than the 198 seeds m^{-2} rate. At Peck 2016 the highest two seeding rates had a significantly higher return than the lowest seeding rate. There was not a substantial difference in the economic return among the different seeding rates at Peck 2015 and Cavendish 2016 although the lowest seeding rate produced the lowest return.

Cultivars differed by location with respect to economic return. All cultivars were among the top for economic return except for SY Ovation (Table 2.33). At Genesee in both years of the study, IDN 01-10704A and UI-WSU Huffman had significantly higher returns compared to the other cultivars. LCS Artdeco, LCS Drive and IDN 01-10704A had the highest returns at Peck 2015. Likewise, LCS Artdeco had a significantly greater economic return than other cultivars at Cavendish 2016. LCS Artdeco along with IDN 01-10704A and IDN02-29001A had statistically higher returns that the other cultivars at Peck 2016. IDN01-10704A was among the most economical cultivars at four of the five locations.

The optimal nitrogen rate was identified by examining the economic return by each cultivar and site year. Table 2.34 shows the optimal return using a polynomial regression. At Genesee 2015 all cultivars showed better return at near normal nitrogen rates. At Peck

2015 optimal returns were all above the 100% rate, with the Idaho cultivars optima being slightly lower than the other three cultivars. Cavendish 2016 had the lowest nitrogen rate optima of 88 % or lower. At Genesee 2016 the majority of the cultivars had an optimum nitrogen rate in excess of 120% with the exception of LCS Artdeco and LCS Drive. For the Peck 2016 site, all cultivars had an optimum below 84% and four of the cultivars were at 60%. Examining cultivars across all locations, LCS Drive and SY-Ovation have the highest optimal nitrogen rate to achieve the maximum economic return of 111 and 116% respectively. LCS Artdeco uses the lowest nitrogen rate to generate optimal return. The cultivars developed in Idaho had an optimum nitrogen rate around 100%.

Table 2.31. Impact of nitrogen rate on economic return of soft white winter wheat in northern Idaho.

Nitrogen Rate	Genesee 2015^{x}	Peck 2015^{x}	Cavendish 2016^{y}	Genesee 2016^{y}	Peck 2016^{y}
- % -			$ ha^{-1}		
0	-	-	351 ^{a}	633 ^{c}	517 ^{a}
60	1,250 ^{b}	639 ^{c}	-	681 ^{c}	-
80	1,357 ^{a}	805 ^{ab}	349 ^{a}	791 ^{b}	561 ^{a}
100	1,385 ^{a}	845 ^{a}	311 ^{b}	826 ^{b}	492 ^{ab}
120	1,385 ^{a}	785 ^{b}	278 ^{c}	905 ^{a}	535 ^{ab}
140	-	-	274 ^{c}	926 ^{a}	446 ^{b}

Means followed the same letter are not significantly different (LSD ≤ 0.05).

^{x}Economic return 2015 year: N = \$1.45 kg^{-1}, P = \$1.21 kg^{-1}, S = \$0.66 kg^{-1}, Seed price = \$0.52 kg^{-1}, Soft White Wheat market price = \$250.27 metric ton^{-1}, Protein Premium = \$0.10 for each 0.1% below 10.5% protein down to 8.6% protein, machinery/labor/pesticide/fuel = \$292.52 ha^{-1}.

^{y}Economic return 2016 year: N = \$1.26 kg^{-1}, P = \$1.21 kg^{-1}, S = \$0.62 kg^{-1}, Seed price = \$0.52 kg^{-1}, Soft White Wheat market price = \$202.49 metric ton^{-1}, machinery/labor/pesticide/fuel = \$292.52 ha^{-1}.

Table 2.32. Impact of seeding rate on economic return of soft white winter wheat in northern Idaho.

Seeding Rate	Genesee 2015[y]	Peck 2015[y]	Cavendish 2016[z]	Genesee 2016[z]	Peck 2016[z]
- seeds m^{-2} -	--------------------------------- \$ ha^{-1} -------------------------------				
247	1411 ^{a}	773	313	808	529
198	1300 ^{b}	773	314	768	521
148	1320 ^{b}	758	309	806	495

Means followed by the same letter within one column are not significantly different (LSD ≤ 0.05).

[x] Economic return 2015 year: N = \$1.45 kg^{-1}, P = \$1.21 kg^{-1}, S = \$0.66 kg^{-1}, Seed price = \$0.52 kg^{-1}, Soft White Wheat market price = \$250.27 metric ton^{-1}, Protein Premium = \$0.10 for each 0.1% below 10.5% protein down to 8.6% protein, machinery/labor/pesticide/fuel = \$292.52 ha^{-1}.

[y] Economic return 2016 year: N = \$1.26 kg^{-1}, P = \$1.21 kg^{-1}, S = \$0.62 kg^{-1}, Seed price = \$0.52 kg^{-1}, Soft White Wheat market price = \$202.49 metric ton^{-1}, machinery/labor/pesticide/fuel = \$292.52 ha^{-1}.

Table 2.33. Impact of cultivar on economic return of soft white winter wheat in northern Idaho.

Cultivar	Genesee 2015[y]	Peck 2015[y]	Cavendish 2016[z]	Genesee 2016[z]	Peck 2016[z]
	--------------------------------- \$ ha^{-1} -------------------------------				
IDN 01-10704A	1,447 ^{a}	773 ^{ab}	318 ^{b}	974 ^{a}	527 ^{ab}
IDN 02-29001A	1,367 ^{bc}	758 ^{b}	319 ^{b}	868 ^{b}	536 ^{ab}
LCS Artdeco	1,312 ^{c}	807 ^{a}	354 ^{a}	738 ^{c}	562 ^{a}
LCS Drive	1,159 ^{d}	783 ^{ab}	289 ^{cd}	581 ^{e}	452 ^{c}
SY-Ovation	1,353 ^{bc}	768 ^{b}	282 ^{d}	676 ^{d}	522 ^{b}
UI-WSU Huffman	1,425 ^{ab}	719 ^{c}	312 ^{bc}	926 ^{a}	461 ^{c}

Means followed by the same letter within one column are not significantly differet (LSD ≤ 0.05).

[x] Economic return 2015 year: N = \$1.45 kg^{-1}, P = \$1.21 kg^{-1}, S = \$0.66 kg^{-1}, Seed price = \$0.52 kg^{-1}, Soft White Wheat market price = \$250.27 metric ton^{-1}, Protein Premium = \$0.10 for each 0.1% below 10.5% protein down to 8.6% protein, machinery/labor/pesticide/fuel = \$292.52 ha^{-1}.

[y] Economic return 2016 year: N = \$1.26 kg^{-1}, P = \$1.21 kg^{-1}, S = \$0.62 kg^{-1}, Seed price = \$0.52 kg^{-1}, Soft White Wheat market price = \$202.49 metric ton^{-1}, machinery/labor/pesticide/fuel = \$292.52 ha^{-1}.

Table 2.34. Optimal nitrogen rate for cultivar on economic return for soft white winter wheat in northern Idaho.

Cultivar	Genesee 2015[y]	Peck 2015[y]	Cavendish 2016[z]	Genesee 2016[z]	Peck 2016[z]	Average
	%					
IDN 01-10704A	108	108	88	140	60	101
IDN 02-29001A	108	116	88	140	60	104
LCS Artdeco	84	120	68	88	60	78
LCS Drive	120	120	68	92	60	111
SY Ovation	120	120	68	140	84	116
UI-WSU Huffman	84	116	76	120	82	96

[x] Optimal nitrogen rates were determined using polynomial regression of $y = a + b_1x + b_2x^2$ for each cultivar and site year.
Nitrogen rate percentage based on average rate of 100% = 0.042 kg N kg grain^{-1}.
[y] Economic return 2015 year: N = \$1.45 kg^{-1}, P = \$1.21 kg^{-1}, S = \$0.66 kg^{-1}, Seed price = \$0.52 kg^{-1}, Soft White Wheat market price = \$250.27 metric ton^{-1}, Protein Premium = \$0.10 for each 0.1% below 10.5% protein down to 8.6% protein, machinery/labor/pesticide/fuel = \$292.52 ha^{-1}.
[z] Economic return 2016 year: N = \$1.26 kg^{-1}, P = \$1.21 kg^{-1}, S = \$0.62 kg^{-1}, Seed price = \$0.52 kg^{-1}, Soft White Wheat market price = \$202.49 metric ton^{-1}, machinery/labor/pesticide/fuel = \$292.52 ha^{-1}.

2.3.3 Milling and Baking Quality

Baking and milling quality of Genesee 2015, Peck 2015, Genesee 2016, and Peck 2016 mean squares from the analysis of variance are in Appendix A, Tables A.8 to A.11. Nitrogen rates impacted flour protein at all site-years, with the highest nitrogen rate having the highest protein (Table 2.35, 2.36, 2.37, and 2.38). At Genesee 2015 the lowest two nitrogen rates produced similar flour protein of 9.2 and 9.4%, with the higher two nitrogen rates (100 and 120%) reaching 10.2%. Peck 2015 has the largest range in flour protein with 60% nitrogen rate having 7.2% protein, increasing to 9.9% flour protein at the 120% nitrogen rate. Genesee 2016 had an overall trend of increasing flour protein with increasing nitrogen rate. The lowest protein was at 60% nitrogen rate with 8.6% protein while the highest protein was at 140% nitrogen rate with 9.5%. Peck 2016 had the lowest change in flour protein with increasing nitrogen rates. The 140% nitrogen rate flour protein was 7.6%, while the remaining nitrogen rates (0 to 120%) had a flour protein between 7.1 to 7.2%. Table 2.43 shows the target quality that is desired for flour protein, indicating that flour protein should below 8.71%.

There was a significant difference between cultivars with respect to flour yield at all site-years (Table 2.39, 2.40, 2.41 and 2.42). Flour protein did not differ substantially at Genesee 2015, although IDN01-10704A had the lowest flour protein (9.4%) and SY Ovation had the highest flour protein (10.0%). At Peck 2015, the flour protein for IDN 01-10704A, IDN 02-29001A, LCS Artdeco and SY Ovation were not statistically different. LCS Drive had the lowest flour protein at Peck 2015 of 7.9%. The flour protein at Genesee 2016 was lower than Genesee 2015. LCS Artdeco and LCS Drive had the highest flour protein of 9.8 and 9.5%, respectively. The lowest flour protein was with IDN 01-10704A at 7.6%. The results for Peck 2016 differed from those observed at Peck 2015. UI-WSU Huffman and IDN 01-10704A had the lowest flour protein of 6.9 and 6.6%, respectively. LCS Artdeco and LCS Drive had the highest flour protein at 7.7% each.

Peck 2015 and Genesee 2016 were the only location to have nitrogen rate impact flour yield (Table 2.37 and 2.40). At Peck 2015 nitrogen rates of 60 to 100% had the same flour yield of 66.4% while 120% significantly lower at 64.7%. Genesee 2016 flour yield does not have a very clear trend. The highest flour yield was at 120% with a 65.2% flour yield. The lowest flour yield was at 60% nitrogen rate with a 63.5% flour yield. Overall flour yield was lower at Genesee 2016 compared to Peck 2015.

Cultivar impacted flour yield at all site-years (Table 2.36, 2.38, 2.40 and 2.42). The cultivar IDN02-29001A flour yield was highest with 67.8, 68.7, 66.8 and 68.5% at Genesee

2015, Peck 2015, Genesee 2016 and Peck 2016, respectively. The lowest flour yield was observed for LCS Artdeco and LCS Drive at all sites. Flour yield above 68.2 is desired for optimal baking (Table 2.43). IDN02-29001A at Peck 2015 and Peck 2016 was the only cultivar to meet the desired flour yield.

Nitrogen rate impacted flour ash content and was significant at all site-years (Table 2.35, 2.36, 2.37 and 2.38). Genesee 2015, Peck 2015 and Genesee 2016 had similar response of increasing nitrogen rate increasing flour ash percentage. The effect between nitrogen rates was very small with only a difference of only 0.01 to 0.02%. The 120% (both 2015 sites) and 140% (Genesee 2016) produced the highest flour ash of 0.35%. At Peck 2016, the flour ash appeared to have the reverse trend with the 100 and 140% nitrogen rates having a slightly lower ash content than the other rates. At all site-years flour ash was below the desired quality target (0.38%) for baking and milling (Table 2.43).

Like nitrogen rate, cultivar impacted flour ash content at all site-years (Table 2.39, 2.40, 2.41, and 2.42). The highest flour ash at Genesee 2015 was 0.35% with LCS Artdeco, LCS Drive and IDN 02-29001A. The lowest observed ash was 0.33% with IDN 01-10704A. At Peck 2015, LCS Artdeco flour ash was the highest at 0.35%, while SY Ovation produced the lowest flour ash of 0.32%. At Genesee 2016 IDN01-10704A had the lowest with 0.33% while LCS Artdeco, LCS Drive and SY Ovation had the highest of 0.35%. At Peck 2016, like the previous sites, LCS Artdeco had the highest flour ash of 0.34%. The lowest ash was with IDN 01-10704A at 0.31%.

Break flour yield tended to be higher at Peck in both years of the study. Break flour yield was only impacted by nitrogen rate at Peck 2015 and Genesee 2016 (Table 2.36 and 2.38). At Peck 2015 there was a trend of decreasing break flour yield with increasing nitrogen rate. The lowest three nitrogen rates (60 to 100%) had significantly higher break flour yield than the 120% nitrogen rate. The nitrogen rates at Genesee 2016 did not have a clear trend. The highest break flour yield was 38.1% at the 120% nitrogen rate, while the lowest break flour yield was 37.2% at 60% nitrogen rate. The remaining break flour yields varied between the 60 and 120% nitrogen rates.

Cultivars showed a high level of significance with break flour yield for all site-years (Table 2.38, 2.39, 2.40 and 2.41). IDN02-29001A had the top break flour yield of 40.3, 46.9, 41.4 and 43.5% at Genesee 2015, Peck 2015, Genesee 2016 and Peck 2016, respectively. SY Ovation was the lowest at Peck 2015 and Genesee 2016 with values of 41.8 and 34.8%, respectively. At Genesee 2015 and Peck 2016 UI-WSU Huffman at the lowest break flour yield of 36.3 and 39.2%, respectively. IDN02-29001A break flour yield at Peck 2015 was the only cultivar from all site years to be above the 46.8% desired quantity of break flour yield (Table 2.43)

Kernel hardness was impacted by nitrogen rate at Peck 2015, Genesee 2016 and Peck 2016 (Table 2.36, 2.37, and 2.38), although the trends are not very clear. At Peck 2015 nitrogen rates of 60 to 100% had the same statistical value while the 120% rate produced a higher kernel harness of 26.8. At Genesee 2016 the hardest kernel was seen at the highest nitrogen rate (140%), while the softest kernel (15.3) was at 80% nitrogen rate. The lowest nitrogen rate (0%) at Peck 2016 produced the hardest kernel with a value of 17.9. Nitrogen rates 80 and 100% produced statistically lower kernel hardness of 16.0 and 15.3, respectively.

Cultivar greatly impacted kernel hardness at all site years (Table 2.39, 2.40, 2.41 and 2.42). IDN01-10704A was the hardest cultivar at all sites with values of 29.0, 24.8, 18.6 and

22.4 for Genesee 2015, Peck 2015, Genesee 2016 and Peck 2016, respectively. LCS Artdeco had the softest kernel for all site years with values of 22.6, 19.9, 11.2 and 9.3 for Genesee 2015, Peck 2015, Genesee 2016 and Peck 2016, respectively. All other cultivars have kernel hardness values between IDN01-10704A and LCS Artdeco. All kernel hardness was well below the standard classification for soft white wheat of 45 (Table 2.43).

Table 2.35. Impact of nitrogen rate on flour protein, flour yield, flour ash, break flour yield, cookie diameter, and kernel hardness at Genesee 2015.

Nitrogen Rate	Flour Protein	Flour Yield	Flour Ash	Break Flour Yield	Kernel Hardness
- % -	- % -	- % -	- % mb -	- % -	- SKCS -
60	9.2 ^{b}	65.6	0.34 ^{b}	38.2	25.8
80	9.4 ^{b}	65.7	0.34 ^{b}	37.9	25.7
100	10.2 ^{a}	65.3	0.35 ^{ab}	38.1	24.8
120	10.2 ^{a}	65.6	0.35 ^{a}	38.1	26.5

Letters followed by the same letter within one column are not significantly different using Fishers' LSD (P<0.05)

Table 2.36. Impact of nitrogen rate on flour protein, flour yield, flour ash, break flour yield, and kernel hardness at Peck 2015.

Nitrogen Rate	Flour Protein	Flour Yield	Flour Ash	Break Flour Yield	Kernel Hardness
- % -	- % -	- % -	- % -	- % -	- SKCS -
60	7.2 ^{c}	66.4 ^{a}	0.33 ^{b}	44.6 ^{a}	22.3 ^{b}
80	7.5 ^{c}	66.4 ^{a}	0.33 ^{b}	44.3 ^{a}	20.3 ^{b}
100	8.5 ^{b}	66.4 ^{a}	0.33 ^{b}	43.7 ^{a}	21.3 ^{b}
120	9.9 ^{a}	64.7 ^{b}	0.35 ^{a}	42.6 ^{b}	26.8 ^{a}

Means followed by the same letter within one column are not significantly different using Fishers' LSD (P<0.05)

Table 2.37. Impact of seeding rate on flour protein, flour yield, flour ash, break flour yield, and kernel hardness at Genesee 2016

Nitrogen Rate	Flour Protein	Flour Yield	Flour Ash	Break Flour Yield	Kernel Hardness
- % -	- % -	- % -	- % -	- % -	- SKCS -
0	8.8 ^{bc}	64.0 ^{cd}	0.34 ^{b}	37.6 ^{abc}	16.6 ^{ab}
60	8.6 ^{c}	63.5 ^{d}	0.34 ^{b}	37.2 ^{c}	16.5 ^{ab}
80	8.6 ^{c}	64.8 ^{abc}	0.34 ^{b}	38.0 ^{ab}	15.3 ^{b}
100	8.9 ^{bc}	64.3 ^{bcd}	0.34 ^{b}	37.4 ^{bc}	15.9 ^{ab}
120	9.1 ^{b}	65.2 ^{a}	0.34 ^{b}	38.1 ^{a}	15.6 ^{ab}
140	9.5 ^{a}	64.9 ^{ab}	0.35 ^{a}	37.9 ^{ab}	16.9 ^{a}

Means followed by the same letter within one column are not significantly different using Fishers' LSD (P<0.05)

Table 2.38. Impact of seeding rate on flour protein, flour yield, flour ash, break flour yield, and kernel hardness at Peck 2016

Nitrogen Rate	Flour Protein	Flour Yield	Flour Ash	Break Flour Yield	Kernel Hardness
- % -	- % -	- % -	- % -	- % -	- SKCS -
0	7.1 ^{b}	66.0	0.33 ^{ab}	41.3	17.9 ^{a}
60	-	-	-	-	-
80	7.2 ^{b}	65.9	0.33 ^{ab}	41.5	16.0 ^{b}
100	7.2 ^{b}	66.0	0.32 ^{b}	41.6	15.3 ^{b}
120	7.2 ^{b}	66.1	0.33 ^{a}	41.1	17.3 ^{ab}
140	7.6 ^{a}	66.4	0.32 ^{ab}	41.3	16.7 ^{ab}

Means followed by the same letter within one column are not significantly different using Fishers' LSD (P<0.05)

Table 2.39. Impact of cultivar on flour protein, flour yield, flour moisture, flour ash, break flour yield and kernel hardness at Genesee 2015.

Cultivar	Flour Protein	Flour Yield	Flour Ash	Break Flour Yield	Kernel Hardness
	- % -	- % -	- % -	- % -	- SKCS -
IDN 01-10704A	9.4 ^{b}	66.3 ^{b}	0.33 ^{d}	38.7 ^{b}	29.0 ^{a}
IDN 02-29001A	9.7 ^{ab}	67.8 ^{a}	0.35 ^{ab}	40.3 ^{a}	27.0 ^{ab}
LCS Artdeco	9.7 ^{ab}	64.5 ^{d}	0.35 ^{a}	38.1 ^{c}	22.6 ^{c}
LCS Drive	9.9 ^{a}	63.1 ^{e}	0.35 ^{ab}	37.6 ^{dc}	23.3 ^{c}
SY Ovation	10.0 ^{a}	66.0 ^{bc}	0.34 ^{c}	37.3 ^{d}	26.3 ^{ab}
UI-WSU Huffman	9.8 ^{a}	65.7 ^{c}	0.34 ^{bc}	36.3 ^{e}	26.1 ^{b}

Means followed by the same letter within one column are not significantly different using Fishers' LSD (P<0.05)

Table 2.40. Impact of cultivar on flour protein, flour yield, flour ash, break flour yield, and kernel hardness at Peck 2015.

Cultivar	Flour Protein	Flour Yield	Flour Ash	Break Flour Yield	Kernel Hardness
	- % -	- % -	- % -	- % -	- SKCS -
IDN 01-10704A	8.3 ^{ab}	66.2 ^{b}	0.33 ^{c}	46.2 ^{b}	24.8 ^{a}
IDN 02-29001A	8.6 ^{a}	68.7 ^{a}	0.34 ^{c}	46.9 ^{a}	22.4 ^{bc}
LCS Artdeco	8.4 ^{ab}	64.3 ^{c}	0.35 $_{a}$	42.1 ^{de}	19.9 ^{d}
LCS Drive	7.9 ^{c}	64.5 ^{c}	0.34 ^{b}	43.5 ^{c}	20.8 ^{dc}
SY Ovation	8.3 ^{abc}	66.0 ^{b}	0.32 ^{d}	41.8 ^{e}	24.1 ^{ab}
UI-WSU Huffman	8.1 ^{bc}	66.2 ^{b}	0.33 ^{dc}	42.7 ^{d}	24.1 ^{ab}

Means followed by the same letter within one column are not significantly different using Fishers LSD (P<0.05)

Table 2.41. Impact of cultivar on flour protein, flour yield, flour ash, break flour yield, and kernel hardness at Genesee 2016.

Cultivar	Flour Protein	Flour Yield	Flour Ash	Break Flour Yield	Kernel Hardness
	- % -	- % -	- % -	- % -	- SKCS -
IDN 01-10704A	7.6 ^{e}	66.8 ^{a}	0.33 ^{d}	41.4 ^{a}	18.6 ^{a}
IDN 02-29001A	8.9 ^{c}	67.0 ^{a}	0.34 ^{c}	40.0 ^{b}	17.4 ^{ab}
LCS Artdeco	9.8 ^{a}	62.3 ^{d}	0.35 ^{a}	36.2 ^{d}	11.2 ^{d}
LCS Drive	9.5 ^{ab}	62.0 ^{d}	0.35 ^{b}	36.9 ^{c}	14.7 ^{c}
SY Ovation	9.3 ^{b}	63.6 ^{c}	0.35 ^{b}	34.8 ^{e}	18.6 ^{a}
UI-WSU Huffman	8.4 ^{d}	65.1 ^{b}	0.34 ^{c}	37.0 ^{c}	16.5 ^{b}

Means followed by the same letter within one column are not significantly different using Fishers' LSD (0.05)

Table 2.42. Impact of cultivar on flour protein, flour yield, flour ash, break flour yield, and kernel hardness at Peck 2016.

Cultivar	Flour Protein	Flour Yield	Flour Ash	Break Flour Yield	Kernel Hardness
	- % -	- % -	- % -	- % -	- SKCS -
IDN 01-10704A	6.6 ^{d}	67.4 ^{b}	0.31 ^{e}	43.2 ^{a}	22.4 ^{a}
IDN 02-29001A	7.5 ^{b}	68.5 ^{a}	0.33 ^{c}	43.5 ^{a}	18.0 ^{b}
LCS Artdeco	7.7 ^{a}	64.7 ^{d}	0.34 ^{a}	41.0 ^{b}	9.3 ^{d}
LCS Drive	7.7 ^{a}	64.8 ^{d}	0.33 ^{b}	41.4 ^{b}	16.0 ^{c}
SY Ovation	7.1 ^{c}	65.7 ^{c}	0.32 ^{d}	40.1 ^{c}	16.0 ^{c}
UI-WSU Huffman	6.9 ^{cd}	65.5 ^{c}	0.33 ^{bc}	39.2 ^{d}	18.0 ^{b}

Means followed by the same letter are not significantly different using Fishers' LSD (0.05)

Table 2.43. Quality targets for soft white wheat.

Grain Quality Parameter	
Kernel Hardness (SKCS)	≤45
Protein (%, 12% mb)	10.5
Flour Quality Parameter	
Protein (%, 14% mb)	<8.71
Ash (%, 14% mb) at 67% extraction	<0.38
Flour Yield (%)	>68.15
Break Flour Yield (%)	>46.75
Sugar-Snap Cookie Diameter (cm) at 8.7% protein	9.3

Generated at Quality Targets Steering Committee: January 25, 2005
Obtained from PNW Wheat Quality Conference 2016 Crop Year

2.4 Discussion

2.4.1 Agronomy Trial

The primary objective of this project was to determine whether cultivars differ in their response to nitrogen rate and seeding rate. Based on results of five field trials conducted over two years and three locations, nitrogen rate has the largest impact on yield and economic return where seeding rate plays a lesser role. Despite cultivar differences, the seasonal variability and local environment played a significant role in cultivar response to these inputs.

Precipitation and temperature also played a major role in influencing yield, protein and test weight of both locations in 2015. In Genesee, the overall precipitation was 550 mm during the 2014-2015 growing season which is 80 mm below the 30-year annual average precipitation for this location. From June to August of 2015 there was less rain than the average or the corresponding period in 2016 (Figure 2.6). In addition, the average temperature in June of 2015 was about 4°C higher than the 30-year average (Figure 2.7).

Both factors introduced plant stress that was exacerbated by increasing nitrogen rates. Peck 2015 precipitation did not show any major reduction in accumulation compared to the 30-year average. In general, both 2015 and 2016 growing years had greater precipitation than the 30-year average at Peck (Figure 2.6). The combination of lower precipitation and/or higher temperature in 2015 led to lower yields, lower test weights, higher protein and poor end-use quality at both locations. The 2015-2016 season for all three sites (Cavendish, Genesee and Peck) provided near average precipitation resulting in higher yields as well as test weights and protein contents that are more normal for the region.

Seeding rate influenced plant density at all sites and years. Yield increased with increasing seeding rate only during the 2015 year and at Peck in 2016. A study by Briggs (1975) showed that increasing seeding rates from 30 to 90 kg ha^{-1} in spring wheat will increase yield, but the 90 to 180 kg ha^{-1} did not increase yield. Blue et al (1990) had similar results with highest seeding rate (101 kg ha) producing the highest yields. The sites in the agronomy trial that had significant difference in yield (Genesee 2015, Peck 2015 and Peck 2016) all show the highest seeding rate (247 seeds m^{-2}) to produce the highest yield.

Test weight was impacted by seeding rate for only 2016 sites. The change in test weight was very small with the largest change being only 0.3 kg hL^{-1} between the lowest and highest seeding rate. There have been studies showing seeding rate impacting grain quality like test weight in Europe. Contrary to their findings, increasing seeding rate in winter wheat was found to decrease test weight (Bavec et al, 2002). Bavec et al. (2002) saw a decrease in test weight with increasing seeding rate in two out of seven years with no change in the other years. Though Genesee 2015 seeding rates did not significantly impact test weight, the highest seeding rate (247 seeds m^{-2}) had the lowest test weight. Pendleton and Dungan (1960) saw similar trends with seeding rate not affecting test weight in winter wheat. The difference of seeding rate impacting grain quality like test weight may point to the role of environment in influencing the outcome from year to year (Zecevic et al, 2014).

Protein content was recorded to be impacted with seeding rate. There were only two sites (Peck 2015 and Cavendish 2016) showing any differences among seeding rate. The general trend was Peck 2015 had decreasing protein with increasing seeding rate, while the opposite occurred at Cavendish 2016. While the differences in protein were subtle, it does demonstrate that seeding rate can influence protein. Bavec et al (2002) showed that winter wheat will respond to increasing seeding rate with decreasing protein.

Nitrogen rate was highly significant with all evaluations for the 2014-2015 season at Genesee and Peck locations. This is expected due to high temperatures and low precipitation when wheat was maturing. Peck 2015 was the only site that showed the highest nitrogen rate (120%) producing lower yields than the other nitrogen rates. This can be attributed to higher temperatures affecting the yield during wheat maturing. In the PNW, a part of a study showed that increases in precipitation increased yield regardless of nitrogen added for winter wheat production (Camara et al 1996). Looking at Figure 2.1, the 2014-2015 season at Peck showed April having significantly less precipitation than average, thus putting the crop in stress during stem elongation.

Genesee 2015, Cavendish 2016, Genesee 2016 and Peck 2016 all responded to increasing nitrogen rate with increased yields. Delogu et al (1998) found that increasing nitrogen rate increased yield without achieving a peak yield in winter wheat. Another study looking at nitrogen rates in winter wheat found that increasing nitrogen rates to have increasing yield to the highest nitrogen rate (Brennan et al, 2014). Both Delogu et al (1998) and Brennan et al (2014) both concluded the reason for increasing nitrogen rates to have increasing yield is dependent on the weather and environment. Under dryland systems, weather is the main factor to determining the yield response to nitrogen rates when looking at one cultivar of wheat.

With 2015 being warmer and having less precipitation, protein and test weight was influenced dramatically by nitrogen rates. The lowest nitrogen rates showed lower protein while the higher rates produced higher protein. Under stress conditions (low precipitation and high temperature) you may see nitrogen rates increase protein accumulation with increasing nitrogen rates (Chen et al, 2008; Halvorson et al, 2004). However, Chen et al (2008) and Halvorson et al (2004) found that nitrogen rates impacted wheat protein content varied from year to year due to differences in precipitation. Likewise, test weights were affected with increasing nitrogen rates reducing test weights. Saint Pierre et al (2008) found that water stress under irrigation can dramatically reduce yield, test weight and kernel weight. Test weight was not affected by nitrogen rates for all sites during the 2016 growing season.

Only during the 2016 season was tiller count, spike count, seed weight and seeds per spike recorded. With increasing nitrogen rate tiller, spike and seeds per spike increased. Increased tillers relate to an increase in spikes and the number of seeds per spike when adequate precipitation is present in wheat (Allard et al 2012; Pandey et al 2000; Sinclair and Jamieson, 2006). This is part of the reason that there is an increase in yield with increasing nitrogen rate. Contrary to the other measurements, seed weight decreased with increasing nitrogen rates. This has been studied before under irrigation environments of hard white winter wheat (Saint Pierre et al, 2008). It was found that higher nitrogen rates lowered seed weight due to extended growth of the crop (under irrigation) causing more stress when higher temperature was present.

Nitrogen use efficiency was highly significant for nitrogen rate and cultivar. All nitrogen rates showed decreasing NUE with increasing nitrogen rate. This trend has been observed in many NUE studies comparing nitrogen rate (Hirel et al. 2007; Zhu et al, 2011). The overall goal of NUE is to improve it by applying less nitrogen or having realistic yield goals (Dawson et al. 2008).

Cultivars each showed different response to NUE. NUE trends follow the yield trends where high yield means the NUE is likely going to be higher. Studies show that environment has an effect on cultivar interaction with NUE. Gauer et al (1992) saw that moderate moisture (drought stress later in the growing season) had no effect on NUE even though the cultivars studied had differences in yield. Under high moisture (adequate rain during growing seasons), Gauer et al (1992) saw that the cultivars interacted significant with NUE. Sowers et al (1994) saw differences in NUE between split application and all fall applied nitrogen between sites and years. In one year, there was not any changes in NUE, while in the second there was a change. The cultivars in the current study did show different NUE for all site-years. What is evident is an environmental interaction. Genesee 2015 and 2016 had the largest change in NUE between cultivars. While the remaining sites had minimal changes in NUE between cultivars. A study by Ortiz-Monasterio et al (1997) observed a similar trend in that under higher nitrogen inputs there was greater variability in NUE. Cultivars tended to have different NUE with each nitrogen rate. Thought the overall trend shows increasing nitrogen rate lowers NUE. Genesee has higher yield potential, which requires 56 kg ha more nitrogen than Peck and Cavendish at the 100% rate. This may be the reason for Genesee having a larger response of NUE.

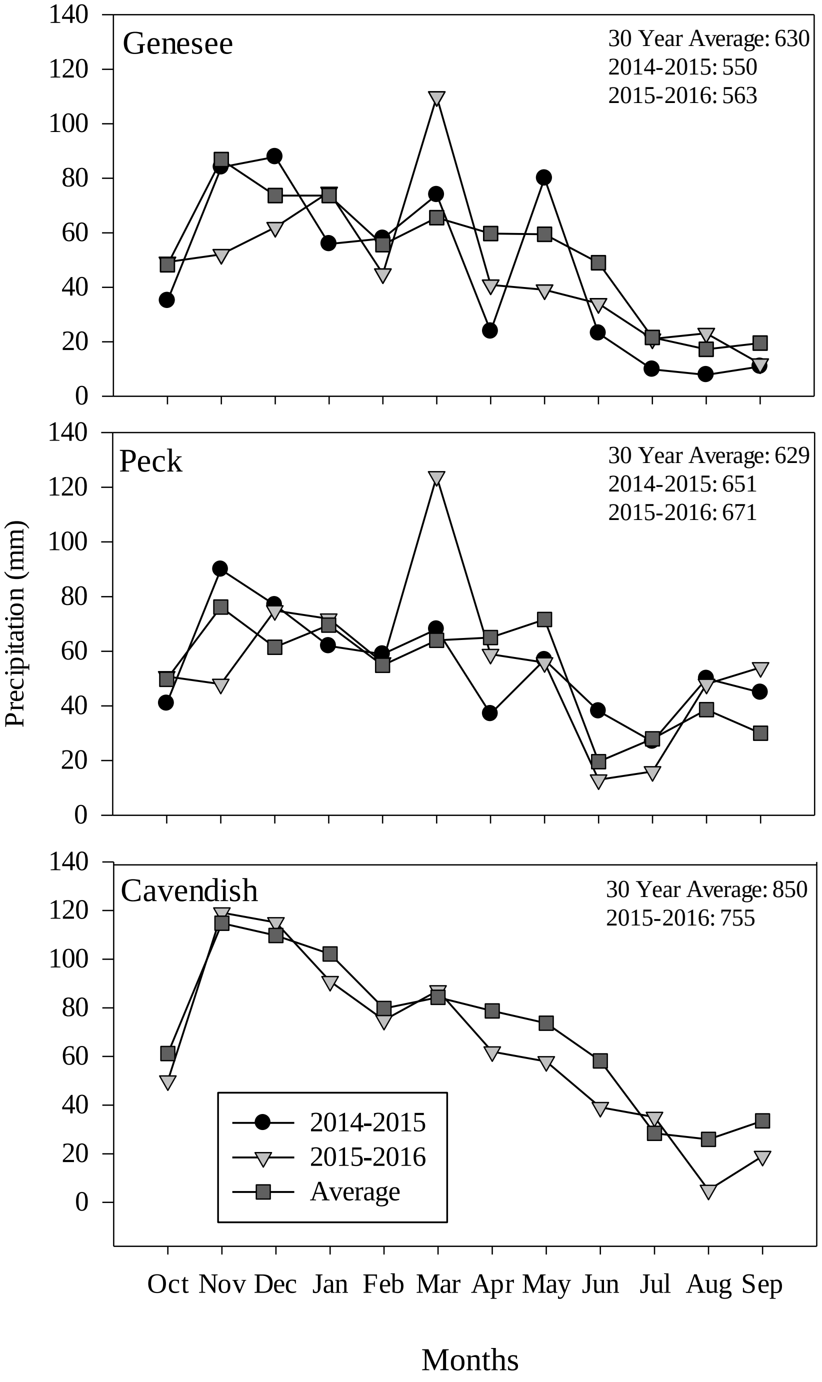

Figure 2.6. Genesee, Peck and Cavendish precipitation for the 2015 and 2016 growing seasons along with the 30-year average.

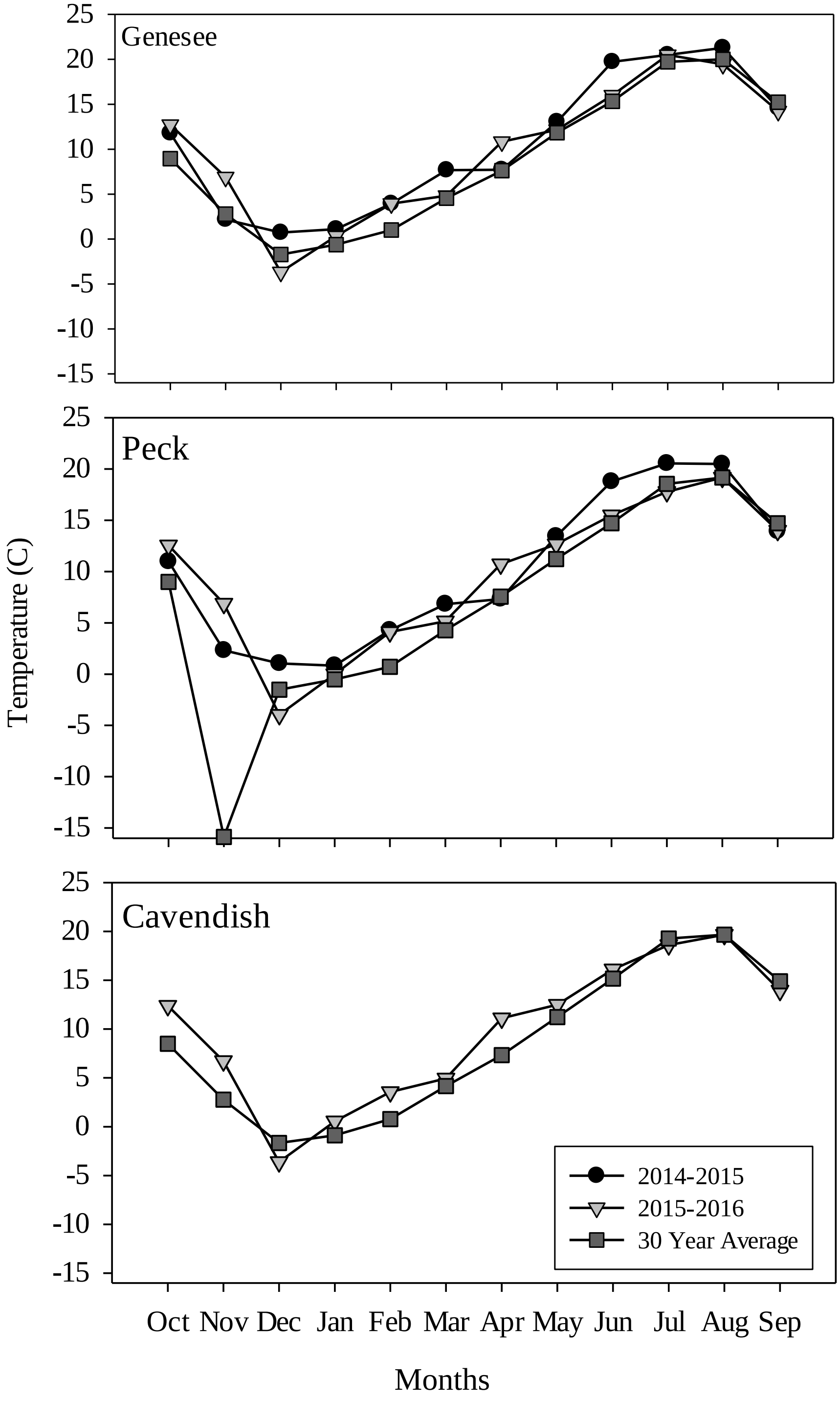

Figure 2.7. Genesee, Peck and Cavendish temperature for the 2015 and 2016 growing seasons along with the 30-year average.

Each cultivar has its own unique genetic background than can influence how they grow and respond to different environments and inputs. LCS Artdeco was the highest yielding cultivar for Peck 2015 and 2016, and Cavendish 2016. IDN 01-10704A was the highest yielding for Genesee 2015 and 2016, and was the second highest yielding cultivar at Peck in both years as well as at Cavendish.

IDN 01-10704A produced a lower protein content for all sites and years compared to the rest of the cultivars. LCS Drive produced the highest protein content for all years and sites except Peck 2015. Genesee and Peck sites in 2015 produced higher protein content than any sites from 2016. This is due to higher temperature and lower precipitation resulting in stressed crops. One study in Spain showed three years' worth of data looking at wheat protein and nitrogen rates (Lopez-Bellido et al, 1998). In two out of the three years, there was a significant reduction in precipitation that resulted higher nitrogen rates increasing protein (Lopez-Bellido et al, 1998). The 2016 sites had adequate precipitation resulting in smaller changes in protein with increasing nitrogen rate. Rao et al. (1993) saw similar trends with observing protein content in soft white winter wheat in the PNW. The authors found that precipitation and soil moisture are the limiting factors that influence protein in wheat. When adequate precipitation and soil moisture is available, protein content has less severe changes with increasing nitrogen rates.

Each individual cultivar has different potential for producing test weight. LCS Artdeco tends to show lower test weights compared to other cultivars. In general, LCS Drive and LCS Artdeco were on the lower end of test weight for all sites and years. IDN 02-29001A produced the heaviest test weight for all years and sites. The ideal test weight needs to be over 75 kg hL^{-1} to meet Grade 1 from the UDSA standard for test weight (USDA Test Weight).

Optimal nitrogen rates for each cultivar was determined using polynomial regression equation at each site and year. As seen before the overall trend is that the highest nitrogen rate (120% for 2015 and 140% for 2016) generated the highest yield. In some situations, cultivars can use lower nitrogen rates and achieve higher yields. In 2015, IDN01-10704A had 104% while UI-WSU Huffman had 110% for both sites (Genesee and Peck). LCS Artdeco had optimal rates lower than the highest nitrogen rate for three site years (Peck 2015, Genesee 2016 and Peck 2016) out of five total. Cultivars tend to have certain qualities that are unique compared to other cultivars. SY Ovation and LCS Drive both tend to show that increasing nitrogen rates will increase yields for those cultivars.

2.4.2 Economic Return.

Seeding rate had the least significant impact on economic return. Genesee 2015 was the only site to have seeding rate influence return with the highest seeding rate (247 seeds m^{-2}) being significantly higher than the other two seeding rates. However, nitrogen rates did impact the economic return for all sites and years. Due to year by year variation in price, the 2015 nitrogen prices were higher than 2016. Despite the higher nitrogen prices, higher economic returns were observed in 2015 due to a protein premium and a higher commodity price for wheat. In both years at Genesee, higher nitrogen rates resulted in the greatest returns. At the other two locations, a moderate nitrogen rate provided the higher economic returns. In fact, the highest returns at Cavendish 2016 were with the 0% rate which effectively included 60% of the nitrogen in the profile prior to planting and the 80% rate. The annual precipitation at Cavendish is higher than the other locations with 657 mm of precipitation falling from October to May, making this site more prone to leaching of nitrogen. The yield potential for this site is higher than the yield observed in the 2016 growing season. This location would likely benefit from a split application of nitrogen between the fall and spring to increase yield and economic return at higher nitrogen rates.

Economic return from cultivars reflect the yield. IDN 01-10704A was one of the top yielding cultivars across locations and tended to have the best overall return for all site and years. LCS Artdeco was better under lower yielding and nitrogen input sites (Cavendish and Peck). LCS Artdeco is the only cultivar to have an average optimal nitrogen rate around 80%, excluding Peck 2015. All other cultivars have higher average rates. The three cultivars from Idaho (IDN 01-10704A, IDN 02-29001A and UI-WSU Huffman) each have an average optimal economic return when about 100% (0.042 kg N kg grain^{-1}) or a standard nitrogen rate is used. LCS Drive has the second highest optimal nitrogen rate of 111%. SY Ovation had a similar optimal rate of 116% when averaged across all sites. In conversation with representatives from Syngenta, they suggest that this cultivar responds to higher rates of nitrogen than similar cultivars in the region and this work supports that idea. Despite having a high optimal nitrogen rate to achieve maximum economic return, SY Ovation was never the most economical cultivar due in part to lower productivity or NUE than other cultivars.

2.4.3 Milling and Baking Quality.

During the 2015 growing season in the PNW, May and June rainfall was well below normal and heat stress in late June and July created significant stress conditions, resulting in high protein accumulation in soft white winter wheat. Thus, wheat buyers were offering a premium for low protein (<10.5%) SWWW. The following year, 2016, growers in the PWN were faced with another debacle of late maturity alpha amylase (LMA) which resulted in widespread problems with low falling numbers (falling number below 300 not accepted). Excess alpha amylase is undesirable for end users and will causes quality issues with baking (Mares and Mrva, 2014).

Some of the milling and baking qualities did not meet the desired specifications millers and bakers are looking for and included flour yield and break flour yield. Despite these shortcomings, there are interesting observations that can be drawn from this data. The most consistent impacts of increasing nitrogen rate were an increase in flour protein and increased flour ash. However, cultivar was observed to have a greater impact on flour characteristics than nitrogen rate. Otteson et al. (2008) found that in hard red spring wheat, genotype plays a major role in baking and milling quality. With each genotype evaluated in their study, there was a different response for the evaluations. The same was seen in this current study. Each cultivar has a different genetic make-up and yield potential that influences the baking and milling properties. Fowler and De La Roche (1975) looked at 15 site-years of winter and spring wheat across Canada. They found that cultivars can influence quality across many environments. Peterson et al (1998) studied thirty hard red winter wheat cultivars grown in 17 different locations across Nebraska. Due to the number of environments, Peterson summarized that both genetics and environments influence end-use quality.

Johnson et al (1984) studied the milling and baking quality of soft red wheat, these authors saw an increase in flour protein with increasing nitrogen rate. In hard white winter wheat and hard red spring wheat, a similar response was seen with increasing nitrogen rates causing an increase in flour protein (Saint Pierre et al, 2008, Ayoub et al, 1994). Pushman and Bingham (1976) observed increasing protein with increasing nitrogen rates in winter wheat used for bread baking.

Flour yield was decreased at the highest nitrogen rate at Peck 2015, although it was unaffected at the other locations. Interestingly Johnson et al (1984) observed a decrease of flour yield with split applied nitrogen, but no change in yield when nitrogen was all fall applied. In the current study at Genesee 2015 and Peck 2016 there was no response of flour yield to nitrogen rates, while at the other two sites (Peck 2015 and Genesee 2016) there was a response. Genesee and Peck 2015 had a split application for the 80, 100 and 120% rates in which 44.8 kg ha^{-1} of nitrogen was added to each of these plots in the spring. This may be evidence of seasonal variability influencing the outcome of the baking and milling quality. As nitrogen rate increases, there is a potential to negatively impact milling and baking properties of soft white winter wheat, particularly flour protein and flour ash.

Nitrogen rates do influence many of the milling and baking qualities evaluated. However, environment also influences baking and milling properties of wheat. Rao et al (1993) reported that there was large variation in most baking and milling qualities between environments. The trial showed that Peck 2015 had more flour characteristics impacted by nitrogen rate where Genesee 2015 had few. The following year (2016) had the opposite trend with nitrogen rate having a greater influence on flour evaluations at Genesee compared to Peck.

2.5 Conclusion

The agronomy trial results show many interactions with nitrogen rates, cultivar and seeding rates. In most cases seeding rate was not significant with the measurements studied. The biggest influences came from nitrogen rates and cultivars. Individual cultivars show response to nitrogen rates and yield resulting in most cultivars having the highest nitrogen rate with the highest yield, although this is not necessarily the most economical. While there were some differences between cultivars with regard to nitrogen rate, environmental factors influenced the response.

When evaluating the economic return of each cultivar and identifying the optimal nitrogen rate based on return, the impact of nitrogen rate on yield and cultivar became clearer. For example, SY Ovation produced the greatest yield at the highest nitrogen rate, but based on the economic analysis a 116% nitrogen rate was determined to be optimal. LCS Drive responded similar to SY Ovation having an optimal yield and economic return at 111% of the standard nitrogen rate. The second Limagrain Cereal Seed cultivar Artdeco was quite different when examining the economic optima with a nitrogen rate of 78%. Based on this observation, LCS Artdeco may be well suited for low input farming systems due to a lower nitrogen requirement to achieve an optimal economic return. The three University of Idaho lines seem to generate optimal returns near the 100% (96 to 104%) nitrogen rate which is equivalent to 0.042 kg N kg grain^{-1}. This is interesting because the agronomy trial was based off the *North Idaho Fertility Guide for Winter Wheat* (Mahler, 2015), suggesting that the standard recommendation for north Idaho is still valid for winter wheat cultivars developed at Idaho.

Baking and milling qualities for all site-years evaluated showed many interesting trends. The overall influence shows that decreasing the nitrogen rate will result in lower protein and flour ash as well as possibly improving flour yield. Despite using higher than normal nitrogen rates, four characteristics are not dramatically impacted. However, the highest rate is not the best and based on this study, the economic optima is the most meaningful way to express differences between cultivars in response to nitrogen rates.

Table 2.44 – Average seed yield over years, sites and N levels, and slope (N rate response) and intercept from regression of seed yield onto N available.

Cultivar	Mean Yield	Rank	Slope	Intercept
	- kg ha^{-1} -			
IDN 01-10704A	5,849	1	37.7102	1,534
IDN 02-29001A	5,670	2	31.3302	2,023
UI-WSU Huffman	5,647	3	29.1324	2,184
LCS Artdeco	5,555	4	28.2172	2,272
LCS Drive	5,093	6	26.5562	1,899
SY Ovation	5,357	5	27.9752	1,996

Although there is statistical limitation to analyses of the nitrogen response over years and sites, it is interesting to consider all the data collectively (Table 2.44). Over years and sites and N levels cultivar IDN 01-10704A produced highest seed yield, while LCS Drive was lowest yielding. In general, the three cultivars developed from the University of Idaho breeding program, were higher yielding compared to the other commercial cultivars. Highest yield was always associated with greatest nitrogen rate response (slope). Indeed 66% (r = 0.8107) of the variability in seed yield was attributed to N rate response. For example, IDN 01-10704A produced 37.7 kg of grain for each kg of N available, while LCS Drive produced only 26.6 kg of grain for each kg of N available. For the locations selected in northern Idaho, growing cultivars that have high yield potential with using less inputs can generate the best economic return.

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Chapter 3: On Farm Testing of Variable Rate Seeding of Soft White Winter Wheat in the PNW

3.1 Introduction

With the introduction of GPS guidance in tractors during the 1980's (Johnson et al, 1983), the technology eventually gave rise to precisely monitoring yields in combines. With the use of monitoring yields came the application of mapping fields based on yield performance (Sawyer, 1994; Shearer et al, 1999). The deregulation of satellite signals in late 2000 opened the door to even greater precision and an increase in the use of VRT (Schimmelpfennig and Ebel, 2015). VRT involves the use of GPS guidance systems to apply specific recommendations for variable rate seeding, fertilizer application and herbicide application (Bullock et al, 2009). The use of VRT in agriculture can lead to reduced inputs and improved yields (Bullock et al, 1998; LaRuffa et al, 2001).

3.1.1 Variable Rate Fertilizer

Although fertilizers are typically applied uniformly across a field, fertilizer can be applied at different rates. For fertilizer applications, VRT is primarily used with nitrogen. Variable rate nitrogen (VRN) has been shown to successfully reduce cost and sustain yield in corn and other cereals (Koch et al, 2004). Applying VRN across a field that is set up in zones can work with the use of yield monitors (Bongiovanni et al, 2007). This method requires generating information such as mapping out a field based on yield and then determining the yield potential for zones within the field and applying varying rates of nitrogen accordingly (Koch et al, 2004; Khosla et al, 2001; Bongiovanni et al, 2007; Fleming et al, 2000). Studies have shown that site-specific fertilization can save upward of

12% on cost without hindering yield for cereal crops in the United States (Ehlert et al, 2004; Isik and Khanna, 2002; Raun et al, 2002).

3.1.2 Variable Rate Seeding

Variable rate seeding (VRS) involves being able to change seeding rates while in motion during planting. This technology uses GPS mapping based on yield and programs to change the seeding rates when necessary. Geleta et al (2002) looked at finding optimal seeding rate and genotype effects of 20 wheat cultivars. What was observed is that seeding rate may not play a huge role in yield and end-use quality (such as protein and flour yield), whereas the environment is a major factor influencing the outcome of wheat. This study indicates that seeding rate may only influence performance based on local environment. Bullock et al (1998) studied an economical theory of VRS in corn in the U.S. Corn Belt between 1987 and 1996. 42,000 experiential units were evaluated within the region looking at seeding rate ranging from 44 to 104 seeds m^{-2}. In conclusion, it was found that savings in cost was more influential than yield in corn. Few have explored VRS in wheat, though there are studies looking at optimizing seeding rate. The general theory is to look at different cultivars of wheat and determine if optimal seeding rates can be achieved outside of average seeding rate of any region. Beavers et al (2008) studied spring wheat in an organic system evaluating seeding rate performance in Saskatchewan, Canada. Four seeding rate ranging from optimal up to two times the average was used (1, 1.25, 1.50 and 2 x rate). Though the highest seeding rate provided the highest yield, it was found plant density and spike count was hindered at the highest seeding rate. Using a seeding rate of 1.25 higher than average provided high yields while optimizing tillers and spike production in organic. One problem that seems to be occurring is the variability of environment within a Mediterranean type region. In Spain, a two-year study looked at four spring wheat cultivars grown under six seeding rates ranging from 150 to 500 seeds m^{-2} at two sites (Lloveras et al, 2002). It was found that the highest seeding rates had the highest yields but not with all the cultivars studied. There was an environmental interaction between sites and years with only one site-year showing reduced yields at the highest seeding rate. It was determined that the highest seeding rates are better for weed competition due to more plants to cover the field.

3.1.3 Objectives

To address the theory of applying variable seeding rate to fields in the PNW, the objectives for the study included examining variable seeding rates across several fertility zones on a farm-scale plot on the Camas Prairie of northern Idaho. Specifically, to determine whether different seeding rates will influence yield, test weight and protein.

3.2 Material and Methods

3.2.1 Locations and Fertility

3.2.1.1 Winona 2014-2015

This site is in Idaho County, Idaho approximately 46 km north of Grangeville, Idaho. The trial was placed in a field off Thorn Spring Road at 46.1733º, -116.1463º. The average annual precipitation for Winona is 582 mm (WRCC, WWDT). During the 2014-2015 growing season from October of 2014 to September 2015, this location received 467 mm of precipitation (WRCC, WWDT).

The previous crop was spring canola. The growers have previously mapped out the field based on yield potential with SMS AgLeader™ technology. This enables the growers to fertilize the field using variable nitrogen applications. Variable rate fertilizer was applied using a chisel plow outfitted with anhydrous ammonia and liquid fertilizer capabilities.

Fertility zones were determined based on previous year yield maps and the prescription for nitrogen application in the current year of the study based on soil fertility tests. The fertility zones were labeled ‘Low’, ‘Medium’ and ‘High’ based on yield potential. For each zone, there were three different nitrogen rates of anhydrous ammonia applied. The ‘Low’ zone: 67.3 kg ha^{-1}, ‘Medium’ zone: 78.5 kg ha^{-1} and ‘High’ zone: 95.3 kg ha^{-1}. To all acres of the field, 65.5 L ha^{-1} of ammonium phosphate (10-34-0-0, nitrogen: 0.14 kg L^{-1} and phosphorus: 0.21 kg L^{-1}) and 28.1 L ha^{-1} of Thio-Sul® (nitrogen: 0.16 kg L^{-1} and sulfur: 0.34 kg L^{-1}) were applied. At planting, banded below the seed all acres were fertilized with 28.1 L ha^{-1} of ammonium phosphate (10-34-0-0) and 56.1 L ha^{-1} of Solution 32 (nitrogen: 0.42 kg L^{-1}).

3.2.1.2 Nezperce 2015-2016

The second-year trial was located 11 km southwest of Nezperce, Idaho in Lewis County. The trial was on Jacobs Road with at 46.1933º, -116.3244º. The average annual precipitation is 530 mm with the 2015-2016 year accumulating 566 mm (WRCC, WWDT).

Previous crop was chickpea, this combined with drought stress conditions during the previous growing season, resulted in high residual nitrogen in the soil and the cooperator chose to use only two nitrogen rates. There were still three zones, these zones are based on yield potential not fertility. The zones were fertilized with the following rates, the ‘Low’ and ‘Medium’ zones had 62.8 kg ha^{-1} of anhydrous ammonia applied, while the ‘High’ zone had 80.7 kg ha^{-1} applied. All acres received 46.8 L ha^{-1} of ammonium phosphate (10-34-0-0, nitrogen: 0.14 kg L^{-1} and phosphorus: 0.21 kg L^{-1}) and 28.1 L ha^{-1} of Thio-Sul® (nitrogen: 0.16 kg L^{-1} and sulfur: 0.34 kg L^{-1}). At planting, additional fertilizer was banded below the seed and included 28.1 L ha^{-1} of ammonium phosphate and 37.4 L ha^{-1} of Solution 32 (nitrogen: 0.42 kg L^{-1}).

3.2.2 Dimensions and Experimental Design

A Great Plains™ 4010HD no-till drill equipped with double disked openers and a turbo culture. The drill had a width of 12.1 m and 25.4 cm row spacing with variable seeding rate technology was used to plant the study. The first year at Winona the seeding rates included 247, 185, 124, and 62 seeds m^{-2}. In the second year, the lowest seeding rate was dropped due to grower concerns and weed competition issues. The resulting seeding rates for at Nezperce (second year) included 247, 206, 165, and 124 seeds m^{-2}. The strips ran the length of the fields for Winona (about 1.6 km) and Nezperce (1 km) in a north to south direction using four seeding rates and planting across three fertility zones. The seeding rates were placed in a randomized complete block (RCB) with four replications. The cultivar used in both years was a soft white winter wheat SY Ovation (Syngenta®). Within each seeding rate by fertility zone combination, two points (plots) were selected for detailed measurements throughout the growing season, for a total of 96 sample points.

3.2.3 Data Recorded

Measurements taken throughout the growing season included stand counts, tiller counts, and spike counts. Stand count was recorded in February by counting the number of plants in 0.5 m of row at three random spots within each plot. Tiller counts were recorded after boot in late May. Ten plants were removed from the soil and the number of tillers was recorded from each of the ten plants. Spike counts were recorded after emergence of head by counting the number of spikes in 0.5 m of row at three random spots at each point. After harvest, above ground biomass weight, yield, harvest index, 1000 seed weight, and number of seeds per spike were recorded. For above ground biomass, plant material was collected from a 2.032 m^2 (2 m x 1.016 m) area at Winona. Due to high biomass accumulation, a smaller plot was harvested in the second year at Nezperce the size was 1.524 m^2 (2 m x 0.762 m). Biomass of each plot was weighed then threshed using a Wintersteiger Nurserymaster Elite™ (Wintersteiger, Inc.; Salt Lake City, UT) combine as a stationary thresher. Yield was calculated using weight of seed from each plot. Test weight was calculated using a Cox funnel (Seedburo Equipment Company, Des Plaines, IL) and measuring the weight of grain collected in a one-pint cup. Harvest index was formulated using total yield of the plot/biomass weight. Protein analysis was done at University of Idaho Wheat Quality Lab in Aberdeen, Idaho. Thousand seed weights were recording using an Old Mill Seed Counter® and the number of seeds per head was derived from the seed weight, plot yield and spike count.

3.2.4 Data Analysis

Data were analyzed using an analysis of variance. Mean comparison was performed using Fisher's least significant difference ($P = 0.05$). All data were analyzed using SAS version 9.4 (SAS Institute Inc., Cary, NC)

3.3 Results

Mean squares from the analysis of variance of each of the traits analyzed are presented in Appendix B (Tables B.1 - B.4). Seeding rate was highly significant with stand count, total biomass, yield, test weight and 1000 seed weight at Winona. Nezperce only had stand count and yield show significant interaction with seeding rate.

Fertility zone was significant with stand count, tiller count, biomass, yield, harvest index, test weight, protein, 1000 seed weight and seeds per spike. Nezperce had stand, tiller and spike counts significant with fertility zone. The same post-harvest evaluations were significant by fertility zone with the addition of spike counts at Nezperce. The only two-way interaction that was significant was test weight and 1000 seed weight at Winona.

Seeding rate by stand count and fertility zone by stand count was significant at Winona and Nezperce. At Winona, the stand ranged from 34.6 to 77.9 plants m^{-2}, with the highest two seeding rates resulting in the same final population (Table 3.1). The populations were lower than expected due to a severe freeze event that occurred in November of 2014. Likewise, at the Nezperce location in year 2, the plant density ranged from 111.0 to 141.7 plants m^{-2} (Table 3.2). The number of emerged plants correlated with the seeding rates with the lower two seeding rates having significantly fewer plants than the higher seeding rates. At Winona, the 'High' and 'Medium' fertility zones had significantly fewer plants (55.9 and 57.5 plants m^{-2}, respectively) than the 'Low' fertility zone (68.5 m^{-2}) (Table 3.3). However, in year 2 at Nezperce the 'Medium' fertility zone had the greatest plant density at 146.5 plants m^{-2}, while the 'High' and 'Low' zone produced 123.6 and 114.2 plants m^{-2}, respectively (Table 3.4).

Seeding rate did not influence the number of tillers per plant at either Winona or Nezperce (Tables 3.1 and 3.2). However, at Winona the number of tillers per plant was significantly higher in the 'High' fertility zone with 2.9 per plant versus in the 'Medium' and 'Low' fertility zones with 2.4 and 2.3 tillers per plant respectively (Table 3.3). Similar results were observed the second year in Nezperce where the 'High' fertility zone produced the most tillers at 5.1 tillers per plant. The 'Medium' and 'Low' zones were significantly lower at 4.0 and 4.4 tillers per plant, respectively (Table 3.4).

Total biomass weight at Winona was influenced by seeding rate with the highest three seeding rates (124 to 247 seeds m^{-2}) producing significantly greater biomass (925 –

993 g m^{-2}) than the lowest seeding rate (815 g m^{-2}) (Table 3.1). There was no difference in biomass between seeding rates at Nezperce. Fertility rate significantly impacted biomass in both years of the study. At Winona, the 'Medium' and 'High' fertility zones did not differ from each other, but biomass in both zones was significantly higher than in the 'Low' fertility zone (Table 3.3). At Nezperce, the biomass was significantly affected by fertility zone (Table 3.4). The 'High' fertility zone had the greatest biomass of 1,843 g m^{-2} while the 'Low' fertility zone that the lowest biomass of 1,144 g m^{-2}.

The lowest seeding rate at Winona resulted in a yield of 2474 kg ha^{-1} while the 124, 185 and 247 seeds m^{-2} rates produced significantly higher yields of 2783 to 3015 kg ha^{-1} (Table 3.1). A different trend in yield was observed at Nezperce with the lowest seeding rate producing the highest yield of 7266 kg ha^{-1} while the highest seeding rate produced the lowest yield of 6570 kg ha^{-1} (Table 3.2). The intermediate seeding rates of 165 and 206 seeds m^{-2} had yields of 6725 and 7189 kg ha^{-1}, respectively and were not significantly different from the highest yielding seeding rate (Table 3.2). In both years of the study, there was a significant difference in yield for every fertility zone. The 'Low' fertility zone consistently had the lowest yield at Winona and Nezperce with a yield of 4715 and 2350 kg ha^{-1}, respectively (Tables 3.3 and 3.4). The highest yielding fertility zones were the 'Medium' fertility zone at Winona and the 'High' fertility zone at Nezperce.

Harvest index (HI) was formulated by dividing the measure yield (kg) by biomass weight (kg). There were no differences between seed treatments at either Winona or Nezperce. At Winona, the average HI was 0.31 and a higher HI of 0.43 was observed at Nezperce in 2015-2016 (Tables 3.1 and 3.2). The 'Medium' fertility zone at Winona produced the highest HI of 0.34. 'High' and 'Low' zone produced significantly lower HI of

0.29 and 0.28, respectively (Table 3.3). At Nezperce, there was a linear response to fertility zone with HI increasing from 0.39 in the 'Low' fertility zone to 0.46 in the 'High' fertility zone (Table 3.4).

In both years of the study, the test weight was greatest at the highest seeding density (247 seeds m^{-2}) and decreased with lower seeding rates (Tables 3.5 and 3.6). At Winona, the 247 seeds m^{-2} rate was significantly higher than the 62 seeds m^{-2} rate. There also were significant differences between fertility rates, with similar trends. At both locations, the 'High' fertility zone produced one of the lower test weights for both sites. At Winona, the 'Medium' fertility rate resulted in the highest test weight and was significantly greater than the test weight for the 'Low' and 'High' fertility rates. The 'Medium' and 'Low' fertility rates at Nezperce were significantly higher than the 'High' fertility rate, although the difference was small. Nezperce was the only site to produce all test weights above 75.0 kg hL^{-1} Grade 1 standard (Table 3.7 and 3.8), while all test weights at Winona were below the USDA grade standard for wheat.

Protein was not affected by seeding rate for Winona and Nezperece (Table 3.5 and 3.6). However, the nitrogen rates influenced protein. Substantially higher protein quantities were produced at Winona compared to Nezperce (Table 3.7 and 3.8). At Winona, the 'Medium' fertility zone produced the highest protein of 14.5 % while 'High' and 'Low' fertility zones had protein content of 13.5% (Table 3.7). The results at Nezperce differed with the 'High' fertility zone producing the lowest protein of 9.5%. Increasing protein quantities were observed with the 'Medium' and 'Low' fertility zones with 10.5 and 11.9%, respectively.

Seeding rate did not influence the number of spikes m^{-2} nor did the fertility zone at Winona although there was a trend of decreasing number of spikes with the lower fertility zones. However, at Nezperece there was a significant difference between each of the fertility zones with respect to spike counts with the 'High' fertility zone producing 521.3 spikes m^{-2} and the 'Low' fertility zone producing only 389.0 spikes m^{-2} (Table 3.8).

Seeding rate slightly influenced 1000 seed weight. The 247 seeds m^{-2} seeding rate was the heaviest at 33.7 g 1000 seeds^{-1}. The middle two seeding rates (185 and 124 seeds m^{-2}) were not statistically different with 33.1 and 32.6 g 1000 seeds^{-1}, respectively. The lowest seeding rate produced the lightest seed of 31.9 g 1000 seeds^{-1} (Table 3.5). There were no trends in 1000 seed weight at Nezperce, although the higher two seeding rates had a slightly greater 1000 seed weight than the lower two seeding rates. The 1000 seed weight was influenced by fertility zone at both locations. In Winona, the 'Medium' fertility zone produced significantly heavier seed at 34.0 g 1000 seeds^{-1} than the 'Low' or 'High' fertility rates (Table 3.7). At Nezperce, the 'Medium' and 'Low' fertility zones produced statistically similar 1000 seed weights of 49.1 g and 48.5 g, respectively (Table 3.8). However, the 'High' fertility zone resulted in a significantly higher 1000 seed weight of 51.8 g.

Number of seeds/head corresponds with plot yield, 1000 seed weight and spike count. There were no differences between the seeding rates with respect to number of seeds per spike at either location. However, fertility zone did impact the number of seeds per spike at both locations. The 'High' and 'Medium' fertility zones produced significantly more seeds per spike than the 'Low' fertility zone at both Winona and Nezperce (Tables 3.7 and 3.8). At Winona, the number of seeds per spike was 28.1 and 30.3 for the 'High' and

‘Medium’ fertility zones, respectively. The number of seeds per spike was higher at Nezperce with the ‘High’ and ‘Medium’ fertility zones producing 31.9 and 32.5 seeds per spike, respectively.

Table 3.9 shows seeding rates impact on yield at each fertility zone for Winona and Nezperce. The ‘Medium’ zone had the over highest yield for Winona. In the ‘High’ fertility zone at Winona, the top three seeding rates produced significantly higher yields than the 62 seeds m^{-2} rate. However, the highest yield in the ‘High’ fertility zone was at 185 seeds m^{-2} with 6623 kg ha^{-1}. In the ‘Medium’ fertility zone, the 247 seeds m^{-2} rate had the highest yield of 7405 kg ha^{-1} although not statistically higher than the 124 and 185 seeds m^{-2} rates. There was no significant difference in yield among the seeding rates in the ‘Low’ fertility zone, but it is important to note that the highest yield was 5042 kg ha^{-1} at the 185 seeds m^{-2} rate. In all fertility zones, the lowest seeding rate (62 seeds/m^{2}) had the lowest yield. At Nezperce, the ‘High’ and ‘Medium’ zones did not have any significant differences in yields between seeding rates. The lowest seeding rate of 124 seeds m^{-2} had the highest yields of 8747 and 8119 kg ha^{-1} for the ‘High’ and ‘Medium’ zones, respectively. The second highest yields of 8513 (‘High’ fertility) and 7552 (‘Low’ fertility) kg ha^{-1} came from the same seeding rate of 206 seeds/m^{2}. In the ‘Low’ zone, the highest yield of 5414 kg ha^{-1} came from the 206 seeds m^{-2} followed by the 124 seeds m^{-2} with a yield of 4965 kg ha^{-1}. Both of these seeding rates produced yields that were significantly higher than the 247 and 165 seeds m^{-2} rates.

Table 3.1. Impact of seeding rate on stand count, tillers, total plant biomass, yield and harvest index at Winona 2014-2015.

Seed Rate	Plant Density	Tillers	Total Biomass	Yield	Harvest Index
- seeds m^{-2} -	- plants m^{-2} -	- # $plant^{-1}$ -	- g m^{-2} -	- kg ha^{-1} -	- yield $biomass^{-1}$ -
247	77.9 ^{a}	2.4	979 ^{a}	3,015 ^{a}	0.31
185	77.9 ^{a}	2.8	993 ^{a}	3,015 ^{a}	0.31
124	52.8 ^{b}	2.7	925 ^{a}	2,783 ^{a}	0.31
62	34.6 ^{c}	2.5	815 ^{b}	2,474 ^{b}	0.29

Means followed by the same letter within one column are not significantly different using Fisher's LSD ($P<0.05$).

Table 3.2. Impact of seeding rate on stand count, tiller, total plant biomass, yield and harvest index at Nezperce 2015-2016.

Seeding Rate	Plant Density	Tiller	Total Biomass	Yield	Harvest Index
- seeds m^{-2} -	- plants m^{-2} -	- # $plant^{-1}$ -	- g m^{-2} -	- kg ha^{-1} -	- yield $biomass^{-1}$ -
247	142 ^{a}	4.5	1,505	6,570 ^{b}	0.42
206	137 ^{ab}	4.3	1,612	7,189 ^{a}	0.43
165	123 ^{bc}	4.4	1,517	6,725 ^{ab}	0.43
124	111 ^{c}	4.7	1,611	7,266 ^{a}	0.44

Means followed by the same letter within one column are not significantly different using Fisher's LSD ($P<0.05$).

Table 3.3. Impact of fertility zone on stand count, tillers, total plant biomass, yield, and harvest index at Winona 2014-2015.

Fertility Zone	Plant Density	Tillers	Total Biomass	Yield	Harvest Index
	- plants m^{-2} -	- # $plant^{-1}$ -	- g m^{-2} -	- kg ha^{-1} -	- yield $biomass^{-1}$ -
High	220 ^{b}	2.9 ^{a}	975 ^{a}	2,876 ^{b}	0.29 ^{b}
Medium	226 ^{b}	2.4 ^{b}	1,000 ^{a}	3,393 ^{a}	0.34 ^{a}
Low	270 ^{a}	2.3 ^{b}	810 ^{b}	2,350 ^{c}	0.28 ^{b}

Means followed by the same letter within one column are not significantly different using Fisher's LSD ($P<0.05$).

Table 3.4. Impact of fertility zone on stand count, tiller biomass weight, yield and test weight at Nezperce 2015-2016.

Fertility Zone	Plant Density	Tiller	Total Biomass	Yield	Harvest Index
	- plants m^{-2} -	- # plant^{-1} -	- g m^{-2} -	- kg ha^{-1} -	- yield biomass^{-1} -
High	124 ^{b}	5.1 ^{a}	1,843 ^{a}	8,426 ^{a}	0.46 ^{a}
Medium	147 ^{a}	4.0 ^{b}	1,698 ^{b}	7,575 ^{b}	0.44 ^{a}
Low	114 ^{b}	4.4 ^{b}	1,144 ^{c}	4,715 ^{c}	0.39 ^{b}

Means followed by the same letter within one column are not significantly different using Fisher's LSD ($P<0.05$).

Table 3.5. Impact of seeding rate on test weight, protein, spike count, 1000 seed weight, and seeds per spike at Winona 2014-2015.

Seed Rate	Test Weight	Protein	Spike Count	1000 Seed Weight	Seeds Per Spike
- seeds m^{-2} -	- kg hL^{-1} -	- % -	-# m^{-2} -	- g -	
247	63.1 ^{a}	14.2	333	33.7 ^{a}	27.7
185	61.8 ^{ab}	13.7	308	33.1 ^{ab}	29.1
124	61.5 ^{ab}	13.7	325	32.6 ^{ab}	26.8
62	60.1 ^{b}	13.6	301	31.9 ^{b}	26.0

Means followed by the same letter are not significantly different using Fisher's LSD ($P<0.05$).

Table 3.6. Impact of seeding rate on test weight, protein, spike count, 1000 seed weight and seeds per spike at Nezperce 2015-2016.

Seeding Rate	Test Weight	Protein	Spike Count	1000 Seed Weight	Seeds Per Spike
- seeds m^{2} -	- kg ha^{-1} -	- % -	- # m^{-2} -	- g -	
247	76.2	10.8	472	49.8	27.4
206	76.1	10.4	455	50.0	31.2
165	75.8	10.4	461	49.6	28.6
124	75.8	10.9	466	49.7	30.9

Means followed by the same letter within one column are not significantly different using Fisher's LSD ($P<0.05$)

Table 3.7. Impact of fertility zone on test weight, protein, spike count, 1000 seed weight and seeds per spike at Winona 2014-2015.

Fertility Zone	Test Weight	Protein	Spike Count	1000 Seed Weight	Seeds Per Spike
	- kg hL^{-1} -	- % -	- # m^{-2} -	- g -	
High	61.1 ^{b}	13.5 ^{b}	321	32.6 ^{b}	28.1 ^{a}
Medium	62.9 ^{a}	14.5 ^{a}	318	34.0 ^{a}	30.3 ^{a}
Low	60.6 ^{b}	13.5 ^{b}	314	31.8 ^{b}	23.9 ^{b}

Means followed by the same letter within one column are not significantly different using Fisher's LSD (P<0.05).

Table 3.8. Impact of fertility zone on harvest index, spike count, 1000 seed weight, seeds per head and protein at Nezperce 2015-2016.

Fertility Zone	Test Weight	Protein	Spike Count	1000 Seed Weight	Seeds Per Spike
	- kg hL^{-1} -	- % -	- # m^{-2} -	- g -	
High	75.5 ^{b}	9.5 ^{c}	521 ^{a}	51.8 ^{a}	31.9 ^{a}
Medium	76.0 ^{a}	10.5 ^{b}	480 ^{b}	49.1 ^{b}	32.5 ^{a}
Low	76.2 ^{a}	11.9 ^{a}	389 ^{c}	48.5 ^{b}	24.1 ^{b}

Means followed by the same letter within one column are not significantly different using Fisher's LSD (P<0.05).

Table 3.9. Impact of seeding rate on yield of each fertility zone at Winona 2014-2015 and Nezperce 2015-2016.

	High Zone	Medium Zone	Low Zone
- seeds m^{-2} -	-------------------------------- kg ha^{-1} -----------------------------		
Winona			
247	6,426 ^{a}	7,405 ^{a}	4,944
185	6,623 ^{a}	7,243 ^{ab}	5,042
124	5,743 ^{a}	6,567 ^{ab}	4,875
62	4,560 ^{b}	6,331 ^{c}	4,164
Nezperce			
247	8,122	7,327	4,323 ^{b}
206	8,513	7,552	5,414 ^{a}
165	8,469	7,504	4,224 ^{b}
124	8,747	8,119	4,965 ^{ab}

Means followed by the same letter within one column and by location are not significantly different using Fishers' LSD (P<0.05).

3.4 Discussion

A variable rate seeding rate trial was conducted over two years at Winona and Nezperce, Idaho. The objective was to determine if variable seeding rate is possible across distinctive fertility zones in the Camas Prairie region of northern Idaho. In Winona, higher seeding rates were favored over lower seeding rates in the ‘High’ and ‘Medium’ fertility zones. The ‘Low’ fertility zone did not have any significant differences between seeding rates, but the highest yield was with the 185 and 247 seeds m^{-2} seeding rates. Due to seasonal weather differences, Nezperce trends differed from those observed at Winona. While there were no significant differences between seeding rates within the ‘High’ and ‘Medium’ fertility zones, the highest yield was obtained at the lowest seeding rate of 124 seeds m^{-2}. The highest yield in the ‘Low’ fertility zone at Nezperce was obtained at the 206 seeds m^{-2} rate. This shows evidence of variable seeding rate may be feasible under different fertility zones, but weather patterns and local environment may strongly influence the outcome.

The plant stand was lower in Winona than Nezperce. November 2014 had a significant weather even resulting in dramatic drop in temperature. On the 10th of November, the daytime high was 9.4ºC with a low of 0ºC. The following day the temperature dropped a low of -9.4ºC. The next 7 days resulted in a daytime high average of -5ºC with an average low of -10ºC (Western Regional Climate Center). With no snow cover, emergence was reduced and winter injury was present. In addition to lower plant density at Winona, yield and test weight were reduced because of reduced precipitation and heat stress during late spring and early summer. During optimal grain filling (June to July) the temperature was 5ºC higher than average (Figure 3.1). In combination with the temperature, from March to August in 2015 there was only 189 mm of precipitation accumulated. A 30-year average for precipitation from March to August is 310 mm (Figure 3.2). The lower precipitation and high temperature put stress on the crops. This results in poor yields and reduced test weights which has been seen in other studies (Farooq et al, 2009).

In 2016 at Nezperce, adequate quantities of rainfall occurred to produce high yielding winter wheat. The 30-year average for this location is about 530 mm of annual precipitation. During 2015-2016 at Nezperce, 566 mm of precipitation was recorded, which is well above average. Especially from March to July, higher than average rainfall was produced (Figure 3.1). The timing of the excess rainfall was optimal for maximum vegetative growth and grain fill. The temperature for 2015-2016 did not depart to far from the 30-year average for the site. However, the temperature in February was warmer than normal, resulting in a shorter dormancy period in late winter. Temperatures in May through August were mild (Figure 3.2).

In Winona during the 2014-2015 growing season, the lowest seeding rate produced particularly low plant biomass and yield. This rate was lower than would ever be considered by commercial growers, but was used to examine the principle of varying seeding rate. However, due to the poor performance and greatly reduced competitiveness for weeds, the lowest rate was removed in the second growing season at the grower’s request.

Winona experienced about 400 kg ha difference in yield between the different seeding rates, while in Nezperce there was over 600 kg ha^{-1} difference in yield between the seeding rates. A study by Lloveras et al (2004) points to environment as an explanation for differences in yield. The study involved looking at different seeding rates of wheat under irrigation, with irrigation not being changed outside optimal range. One site showed the highest seeding rate producing lower yields than the middle seeding rates. The second site in the study showed increasing seeding rates increased yields. The conclusion generated from Lloveras' study was that the difference in yields by seeding rate is due to environment factors that cannot be controlled. This was observed at Winona and Nezperce. With high temperature and low precipitation in 2015 the yield potential was not as great as water became the limiting factor. Pelton (1969) looked at 8 years of seeding rate trials in spring wheat, the lowest seeding rate showed the highest yield especially in drought conditions. The lowest seeding rate at Winona also produced the lowest yield. Nezperce had adequate precipitation and normal temperatures thus creating optimal growing conditions. This resulted in the lowest seeding rate producing the highest yield. Additional studies to examine seeding rates in wheat have concluded that higher seeding rates result in higher yields. Briggs (1974) observed four spring wheat cultivars grown under three seeding rates in Canada. The results showed that the highest seeding rate had the highest yield for almost all cultivars. In Europe, winter wheat grown under different seeding rates (50 – 600 seeds m^{-2}) showed increasing seeding rate to increase yield. The second highest seeding rate (350 seeds m^{-2}) had the highest yield while 600 seeds m^{-2} had slightly lower yield (Gooding et al, 2002). Nezperce had similar results with the second highest (206 seeds m^{2}) and the lowest (124 seeds m^{-2}) produced the highest yields. Table 3.9 shows the yield at each seeding rate within each fertility zone for Winona and Nezperce. The table shows that in the 'High' and 'Medium' fertility zones show that seeding rates 124 to 185 seeds m^{-2} have yields that are almost the same as the highest seeding rate of 247 seeds m^{-2}. The 'Low' fertility zone highest yields were achieved at higher seeding rates above 185 seeds m^{-2} for both sites.

Winona response of seeding rate to test weight, biomass weight, and 1000 seed weight has been observed in other studies. Bavec et al (2002) evaluated similar responses in winter wheat planted to four seeding rates, with the test weight changing with seeding rate. Bavec reported increasing seeding rate to decrease test weight response, but it is dependent on the year. Conversely, Nezperce did not have any response of test weight, biomass weight or 1000 seed weight to seeding rates. In wheat, the lack of influence of seeding rate on test weight has been seen in dryland growing regions of the PNW (Ciha, 1983). Once again the environment plays a major role in the outcome of the evaluations due to difference in site locations (Lloveras et al, 2004). Spike counts are not affected by seeding rate but rather the number of seeds per head can be (Xue and Weiss, 2011; Pendleton and Dungan, 1960). Both years of the study showed no response of seeding rate by seeds per spike.

Protein in Winona was very high. For soft white wheat to meet quality standards for baking the protein content needs to be lower than 10.5%. Nezperce met the quality standard with the ‘High’ and ‘Medium’ fertility zones while Nezperce ‘Low’ fertility zone and all of Winona did not meet the 10.5% desired quality (Table 3.7 and 3.8). The Nezperce ‘High’ fertility zone had the highest yield, which was expected, but it also produced the lowest protein content (Table 3.7 and 3.8). Terman et al, (1969) observed that wheat with adequate amount of moisture will yield the highest and can produce low protein content.

Fertility shows more interactions than seeding rate does for both sites. That is due to variable nitrogen rates represented by each zone (Low, Medium and High). Nitrogen is responsible for more growth aspects due to plants up-taking the nutrient for plant growth and seeding production (Briskin and Bloom, 2010). Yield is reflective of standard fertility studies showing higher nitrogen rates equal higher yields (Liu et al, 2003; Halvorson et al, 2004). Fertility has the opposite effect on test weight between years. Winona low fertility produced the lowest test weight which is not normal from other research performed. Nezperce has higher test weights at the low fertility and low test weights at the high fertility, but the difference is not very dramatic. The only observation that can be made is Winona did not have test weight that met the USDA Grade No.1 for test weight, while Nezperce did. This trend has been observed in other experiments where environment and years result in different the outcomes for test weight between years (Saint Pierre et al, 2008; Nielsen and Halvorson, 1991).

Spike count, 1000 seed weight and number of seeds per spike were higher in the medium to high fertility. The low fertility for both sites produced the lowest spikes, 1000 seed weight and number of seeds per spike. Nitrogen plays a role in production of seed. With adequate amount of nitrogen and precipitation 1000 seed weight and number of seeds per spike were influenced by fertility zones for Winona and Nezperce. Fertility zone did not affect spike production at Winona, while Nezperce did. Delogu et al (1998) studied the efficiency of nitrogen in winter wheat in Italy. Under three nitrogen rates the winter wheat showed seasonal variability between years. What was discovered is nitrogen affects grain quality depending on the amount of precipitation received and nitrogen that was added. Arduini et al (2006) studied the effect of durum wheat under three seeding rates (200, 250, and 400 seeds m^{-2}) in Italy. Seeding rate had grain quality (seed weight and seeds per spike) was affected by seeding rate. Arduini site’s experienced adequate precipitation resulting in better uptake of nitrogen and longer period of photosynthesis for the wheat. Nezperce had optimal temperatures and precipitation resulting in spike counts, seed weight and seeds per spike being affected while Winona did not have spike counts being affected by fertility zone.

Winona had significantly less precipitation starting in March with higher temperatures starting in May (Figure 3.1 and 3.2), resulting in conditions that hindered grain quality under fertility zones.

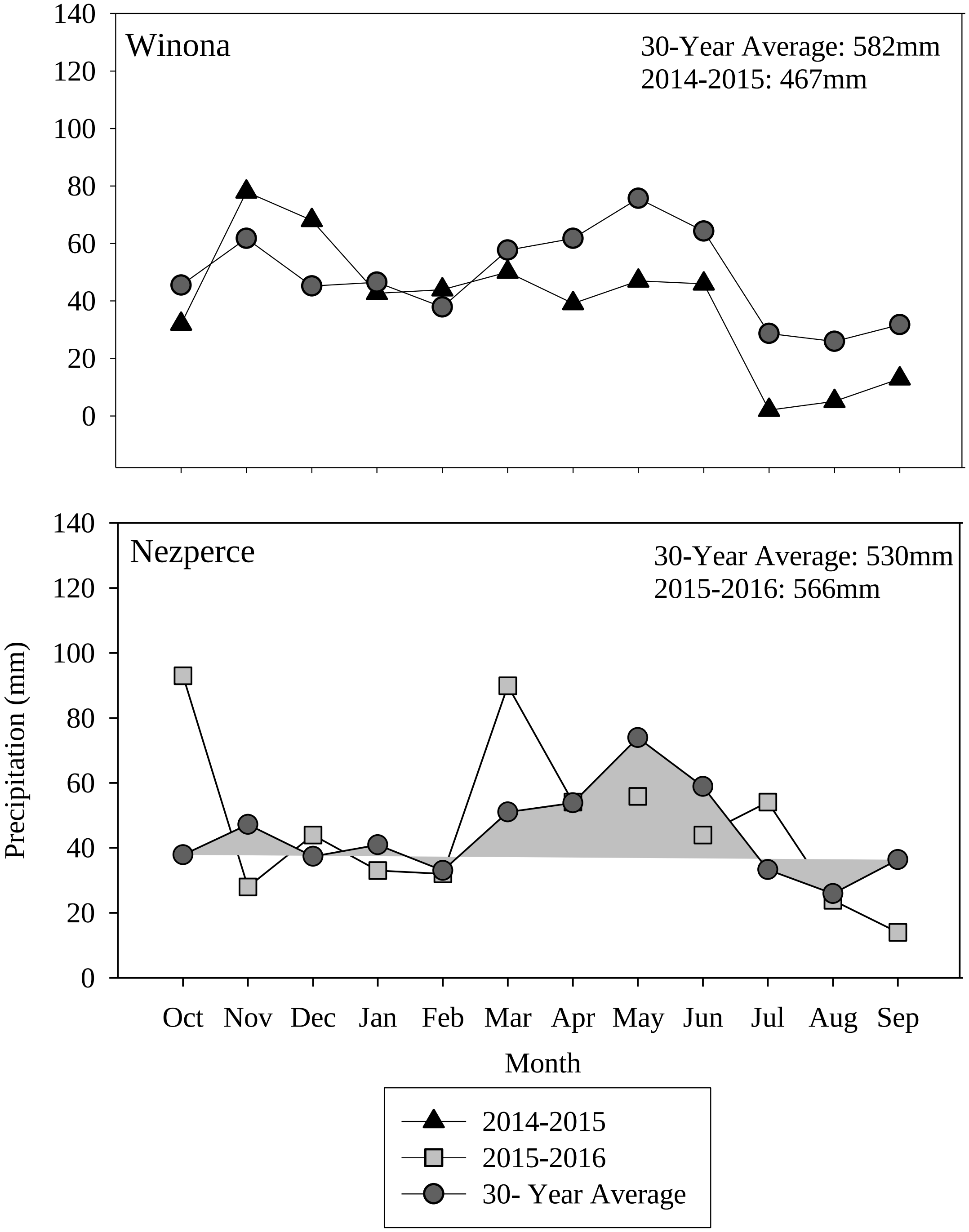

Figure 3.1. Annual precipitation by month for Winona 2015 and Nezperce 2016. Data obtained from the Western Regional Climate Center – West Wide Drought Tracker.

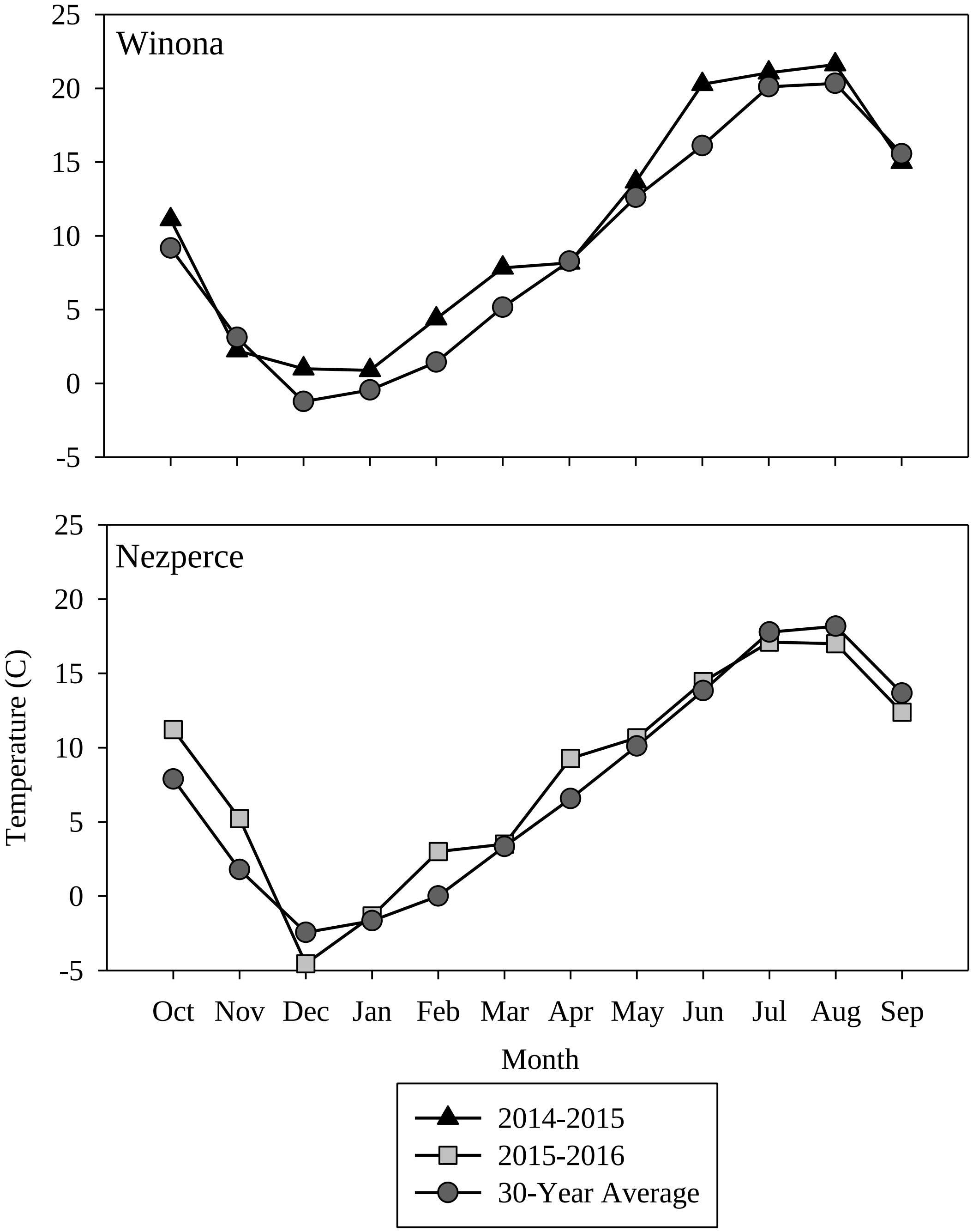

Figure 3.2. Annual temperature by month for Winona 2015 and Nezperce 2016. Data obtained from the Western Regional Climate Center – West Wide Drought Tracker.

3.5 Conclusion

The largest influence for determining yield and test weight is environmental. The amount of precipitation and the temperature during the time wheat is maturing is important for crops especially in dryland agriculture. Variable seeding rate can be achieved; it depends on the environment. Under drought conditions, increasing the seeding rate will generate higher yields and better quality wheat. If adequate precipitation and temperatures are normal, reducing seeding rates will gain the same yields as high seeding rates. It may be feasible to incorporate variable rate seeding into fields already being managed with variable rate nitrogen.

The challenge for PNW growers is in understanding the topography of the farm fields. This topography may make it difficult to find uniform seeding rates that will work across entire fields. The diversity in terrain is what causes dramatic changes in yield potential going across a field. Using VRS, the seeding densities can be adjusted to account for changing yield potentials in a field. Under low producing areas increasing the seeding rate will produce higher yields. If an area where there is high yield potential is present one can reduce the amount of seeds being planted and generate high yields with good quality.

The differences in seeding rates between years makes confounds the ability to make a specific seeding rate recommendation but using seeding rates within 247 and 124 seeds m^{-2} can be a target range for growers in the Camas Prairie of Idaho. If a field is mapped out based on yield potential, it can be used in combination with VRS to make field specific recommendations. Due to the changing climatic zones throughout northern Idaho and the variable landscape, further research into variable rate seeding will be needed to make more definitive recommendations.

3.6 References

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Appendix A

Mean squares from the analysis of variance of each of the traits analyzed from Chapter 2 Agronomy Trial. These ANOVA show what interactions are significant with variables observed in 2015 and 2016. Tables listed include the agronomy trial, economic return and milling/baking quality.

Table A.1. Mean squares from the analysis of variance for stand count, height, yield, test weight, protein and nitrogen use efficiency at Genesee 2015.

	d.f.	Stand Count	Height	Yield	Test Weight	Protein	Nitrogen Use Efficiency
NR[1]	3	73.63***	803.56***	6926.93***	23.56***	24.310***	3766.14***
Error (1)†	12	23.51***	31.88*	119.52	3.72	0.543***	24.10
CV[2]	5	73.86***	4828.75	1476.07***	186.99***	6.799***	164.74***
CV*NR	15	10.29	531.03	190.93	4.43	0.269	27.01*
CV*SR	10	11.20	447.49	143.22	4.76	0.243	15.01
CV*SR*NR	30	9.40	972.29	225.30***	4.25	0.313	21.83
SR[3]	2	446.29***	54.44	1414.67***	3.29	0.092	178.47***
SR*NR	6	10.80	136.95	246.11	5.33	0.262	50.75***

[1]: Nitrogen Rate
[2]: Cultivar
[3]: Seed rate
†: Error (1): Nitrogen Rate x Replicates
d.f. : degrees of freedom
* Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level

Table A.2. Mean squares from the analysis of variance for stand count, height, yield, test weight, protein and nitrogen use efficiency at Peck 2015.

	d.f.	Stand Count	Height	Yield	Test Weight	Protein	Nitrogen Use Efficiency
NR[1]	3	80.67***	1639.15***	7566.36***	446.47***	143.614***	1713.88***
Error (1)†	12	36.29***	7.09	72.19***	5.87***	2.864***	15.15***
CV[2]	5	30.22*	3175.97	138.28***	144.70***	2.253***	16.56***
CV*NR	15	8.72	32.06	56.20**	2.83*	1.115***	8.64*
CV*SR	10	18.31	14.20	14.45	1.34	0.553	1.92
CV*SR*NR	30	11.89	12.85	19.52***	1.70	0.422	3.13
SR[3]	2	360.38***	7.81	75.31***	3.85	4.287***	11.45*
SR*NR	6	39.03	11.54	39.03	1.35	0.290	4.83

[1]: Nitrogen Rate
[2]: Cultivar
[3]: Seed rate
†: Error (1): Nitrogen Rate x Replicates
d.f. : degrees of freedom
* Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level

Table A.3. Mean squares from the analysis of variance for stand count, tiller count, spike count, height, yield, test weight, protein, 1000 seed weight, seeds per spike and nitrogen use efficiency at Cavendish 2016.

	d.f.	Stand Count	Tiller Count	Spike Count	Height	Yield	Test Weight	Protein	1000 Seed Weight	Seeds Per Spike	Nitrogen Use Efficiency
NR[1]	4	9.45	3.835***	2047.63***	1697.89***	4504340.00***	0.608	2.302***	20.27***	268.31***	367.07***
Error (1)†	16	34.55**	0.487	80.46**	56.21**	2087436.90***	0.462	0.164***	2.14	25.61	32.30***
CV[2]	5	280.12***	5.125***	157.58**	892.26***	1081208.80***	38.218	3.887***	565.84***	418.46***	28.91***
CV*NR	20	12.02	0.468	60.31	69.75***	168841.70	0.304	0.092	3.73	36.77*	2.44
CV*SR	10	13.12	0.455	64.77	24.75	120485.00	0.208	0.059	1.52	31.98	2.95
CV*SR*NR	40	15.69	0.185	40.19	40.82	142381.20	0.183	0.062	1.23	20.48	2.55
SR[3]	2	626.64***	1.184**	192.94**	0.53	4367.20	2.665**	0.137*	0.36	85.45*	1.86
SR*NR	8	7.36	0.340	26.25	22.36	113443.00	0.327	0.040	0.86	12.87	3.10

[1]: Nitrogen Rate
[2]: Cultivar
[3]: Seed rate
†: Error (1): Nitrogen Rate x Replicates
d.f. : degrees of freedom
* Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level

Table A.4. Mean squares from the analysis of variance for stand count, tiller count, spike count, height, yield, test weight, protein, 1000 seed weight, seeds per spike and nitrogen use efficiency at Genesee 2016.

	d.f.	Stand Count	Tiller Count	Spike Count	Height	Yield	Test Weight	Protein	1000 Seed Weight	Seeds Per Spike	Nitrogen Use Efficiency
NR[1]	5	57.00***	12.913***	9827.32***	1488.54***	22095.66***	0.079	9.093***	168.77***	180.25***	4601.84***
Error (1)†	20	21.32*	0.672	88.94	54.03	219.75*	0.384	0.455	5.24	17.73	33.96***
CV[2]	5	203.23***	3.964***	516.42***	2196.08***	8169.38***	183.673***	42.882***	1175.53***	2460.75***	929.95***
CV*NR	25	13.67	0.499	65.56	83.32*	192.79*	0.797***	0.706*	4.80	31.96*	31.73***
CV*SR	10	18.12	0.868	39.22	134.99***	140.54	0.417	0.621	6.86	37.63	20.91
CV*SR*NR	50	8.67	0.415	64.79	55.85	57.66	0.338	0.508	4.70	29.69	10.48
SR[3]	2	1557.67***	5.895***	318.70*	42.25	238.19	3.115***	1.108*	9.52	136.05***	14.20
SR*NR	10	23.63*	0.676	92.50	24.41	129.37	0.343	0.126	5.00	19.36	13.71

[1]: Nitrogen Rate
[2]: Cultivar
[3]: Seed rate
†: Error (1): Nitrogen Rate x Replicates
d.f. : degrees of freedom
* Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level

Table A.5. Mean squares from the analysis of variance for stand count, tiller count, spike count, height, yield, test weight, protein, 1000 seed weight, seeds per spike and nitrogen use efficiency at Peck 2016.

	d.f.	Stand Count	Tiller Count	Spike Count	Height	Yield	Test Weight	Protein	1000 Seed Weight	Seeds Per Spike	Nitrogen Use Efficiency
NR[1]	4	21.21	1.692***	1425.49***	1032.13***	6691.16***	1.515***	1.847***	60.75***	304.01***	823.31***
Error (1)†	16	33.86***	0.179	38.68	48.03***	381.13***	0.654***	0.559***	7.69***	52.08*	83.37***
CV[2]	5	434.99***	0.971***	376.06***	2380.69***	860.69***	59.283***	6.399***	482.08***	1083.26***	114.95***
CV*NR	20	11.84	0.200	34.64	11.52	34.56	0.257	0.104	2.49	29.97	6.41
CV*SR	10	15.63	0.180	42.49	12.56	48.83	0.712**	0.255*	2.13	7.05	8.63
CV*SR*NR	40	11.21	0.145	33.33	13.95	45.64	0.218	0.153	2.06	18.72	6.15
SR[3]	2	773.63***	0.237	451.15***	56.13*	375.90**	1.613**	0.043	6.08	56.18*	49.58**
SR*NR	8	10.49	0.268	68.07	7.66	44.05	0.112	0.142	1.66	36.56	6.47

[1]: Nitrogen Rate
[2]: Cultivar
[3]: Seed rate
†: Error (1): Nitrogen Rate x Replicates
d.f. : degrees of freedom
* Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level

Table A.6. Mean squares from the analysis of variance of Economic Return for all 2015 sites.

	Genesee 2015		Peck 2015	
	d.f.		d.f.	
NR^{1}	3	60981.01***	3	118366.30***
Error 1†	12	7095.29	12	4434.12**
CV^{2}	5	104488.70***	5	7806.72***
CV*NR	15	11796.90	15	3738.46**
CV*SR	10	8670.41	10	1032.65
CV*SR*NR	30	13457.82**	30	1205.62
SR^{3}	2	68184.99***	2	1309.89
SR*NR	6	14799.38	6	2140.51

[1]: Nitrogen Rate
[2]: Cultivar
[3]: Seed rate
†: Error (1): Nitrogen Rate x Replicates
d.f. : degrees of freedom
* Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level

Table A.7. Mean squares from the analysis of variance of economic return for all 2016 sites.

	Cavendish 2016		Genesee 2016		Peck 2016	
	d.f.		d.f.		d.f.	
NR^{1}	4	16143.16***	5	202698.40***	4	33798.85***
Error (1)	16	13411.46***	20	8544.82*	16	16635.38***
CV^{2}	5	8560.49***	5	344886.80***	5	29092.97***
CV*NR	20	996.91	25	8131.93*	20	1481.71
CV*SR	10	948.69	10	5556.32	10	1473.86
CV*SR*NR	40	853.60	50	2684.59	40	2066.36
SR^{3}	2	311.21	2	14356.60	2	7841.19
SR*NR	8	861.86	10	6049.68	8	1338.83

[1]: Nitrogen Rate
[2]: Cultivar
[3]: Seed rate
†: Error (1): Nitrogen Rate x Replicates
d.f. : degrees of freedom
* Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level

Table A.8. Mean squares from the analysis of variance of baking and milling quality for Genesee 2015.

	d.f.	Flour Protein	Flour Yield	Flour Ash	Break Flour Yield	Top Grain Score
NR[1]	3	6.471***	0.897	0.000335***	0.128	5.551***
Error (1)†	9	0.525	0.546	0.000077	0.308	3.358***
CV[2]	5	0.590	39.492***	0.000588***	27.205***	4.623***
CV* NR	15	0.280	0.279	0.000055	0.547	1.072

[1]: Nitrogen Rate
[2]: Cultivar
†: Error (1): Nitrogen Rate x Replicates
d.f. : degrees of freedom
* Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level

Table A.9. Mean squares from the analysis of variance of baking and milling quality for Peck 2015.

	d.f.	Flour Protein	Flour Yield	Flour Ash	Break Flour Yield	Top Grain Score
NR[1]	3	36.527***	17.010***	0.00172***	18.165***	33.250***
Error (1)	9	0.926**	3.185***	0.00012***	1.998**	2.593*
CV[2]	5	0.781*	40.399***	0.00093***	74.075***	1.725
CV* NR	15	0.336	1.262*	0.00009**	2.642***	1.142

[1]: Nitrogen Rate
[2]: Cultivar
†: Error (1): Nitrogen Rate x Replicates
d.f. : degrees of freedom
* Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level

Table A.10. Mean squares from the analysis of variance of baking and milling quality from Genesee 2016.

	d.f.	Flour Protein	Flour Yield	Flour Ash	Break Flour Yield	Top Grain Score
NR[1]	5	3.048^{***}	10.0111^{***}	0.000134^{***}	2.918^{**}	3.057^{**}
Error (1)	15	0.421	1.993^{***}	0.000030	1.122	2.719^{***}
CV[2]	5	15.294^{***}	115.302^{***}	0.002103^{***}	148.068^{***}	8.957^{***}
CV*NR	25	0.320	0.559	0.000026	0.838	0.474

[1]: Nitrogen Rate
[2]: Cultivar
†: Error (1): Nitrogen Rate x Replicates
d.f. : degrees of freedom
* Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level

Table A.11. Mean squares from the analysis of variance of baking and milling quality from Peck 2016.

	d.f.	Flour Protein	Flour Yield	Flour Ash	Break Flour Yield	Top Grain Score
NR[1]	4	1.035^{**}	0.921	0.000091^{*}	0.843	3.229^{**}
Error (1)	12	0.269	0.287	0.000047	1.267	1.296^{*}
CV [2]	5	4.105^{***}	51.782^{***}	0.001204^{***}	59.296^{***}	6.554^{***}
CV*NR	20	0.213	0.671	0.000031	1.234	1.184^{*}

[1]: Nitrogen Rate
[2]: Cultivar
†: Error (1): Nitrogen Rate x Replicates
d.f. : degrees of freedom
* Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level

Appendix B

Mean square from the analysis of variance of each of the traits analyzed for Chapter 3. The ANOVA tables are related to all interactions observed at Winona and Nexperce.

Table B.1. Mean squares from the analysis of variance for stand count, tiller count, total biomass weight, yield and harvest index at Winona 2015.

	d.f.	Stand Count	Tiller Count	Total Biomass	Yield	Harvest Index
Seed Rate	3	165.97***	0.185	647517.04***	331.73***	0.00091
Error (1)†	9	3.22	0.405	75078.98*	47.83	0.00126
Zone	2	23.49***	2.679**	1431484.26****	1479.15***	0.02527***
Seed Rate*Zone	6	5.13	0.568	27599.66	45.49	0.00269
Error (2)††	24	2.58	0.722	51800.76	39.09	0.00156

* Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level
d.f. = Degree of Freedom.
†Error (1) = Seed rate x replicates;
††Error (2) = Pooled Term.

Table B.2. Mean squares from the analysis of variance for test weight, protein, spike count, 1000 seed count, and seeds per spike at Winona 2015

	d.f.	Test Weight	Protein	Spike Count	1000 Seed Count	Seeds Per Spike
Seed Rate	3	35.92**	1.481	86.74	14.96*	49.06
Error (1)†	9	8.66	2.820**	66.64	6.61	69.90
Zone	2	44.69**	9.575***	8.35	41.63***	349.22***
Seed Rate*Zone	6	17.55*	0.385	74.93	9.31*	8.97
Error (2)††	24	7.89	1.311	32.66	7.75*	32.92

* Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level
d.f. = Degree of Freedom.
†Error (1) = Seed rate x replicates;
††Error (2) = Pooled Term.

Table B.3. Mean squares from the analysis of variance for stand count, tiller count, biomass weight, yield, and harvest index at Nezperce 2016.

	d.f.	Stand Count	Tiller Count	Biomass Weight	Yield	Harvest Index
Seed Rate	3	73.02*	0.629	188524.95	2614390.1*	0.000712
Error (1)†	9	8.31	0.557	126077.08	1400808.5	0.001013
Zone	2	141.95**	8.710***	10096364.91***	122666801.9***	0.036152***
Seed Rate*Zone	6	19.43	0.756	65359.06	688471.7	0.000325
Error (2)††	24	20.43	0.894	410028.30***	4989178.9***	0.002335***

* Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level
d.f. = Degree of Freedom
†Error (1) = Seed rate x replicates
††Error (2) = Pooled Term

Table B.4. Mean squares from the analysis of variance for test weight, protein, spike count, 1000 seed weight, and seeds per spike at Nezperce 2016.

	d.f.	Test Weight	Protein	Spike Count	1000 Seed Weight	Seeds Per Spike
Seed Rate	3	0.916	1.703	19.60	0.728	104.63
Error (1)†	9	0.581	1.392	53.73	1.231	41.24
Zone	2	4.650	44.357***	2343.96***	99.077***	940.01***
Seed Rate*Zone	6	0.362	1.321	59.56	1.158	18.88
Error (2)††	24	0.519	2.787	117.59**	3.945**	69.01

* Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level
d.f. = Degree of Freedom
†Error (1) = Seed rate x replicates
††Error (2) = Pooled Term