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By

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EFFECTS OF DIFFERENT WATER AND NITROGEN REGIMENS ON END-USE QUALITY OF WINTER WHEAT PRODUCED IN NEBRASKA

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Wheat is the 3rd most prominent crop in the USA and approximately 50% is exported annually. Nebraska wheat production is 11th in the country, and it plays a major role in the state's agricultural economy, especially in western NE. Generally, wheat is grown under dryland conditions and the region grows much more wheat on unirrigated land than it does on irrigated. However, deficit irrigation has shown great value in producing high yielding wheat with much less water than needed for other crops. Finding new ways to leverage irrigation in wheat production may help address the need to produce food with fewer inputs. The objective of this project was to evaluate the effect of nitrogen, irrigation, and cultivar on grain yield and quality. A randomized complete block with split-split plots was used as the design for this experiment. Six cultivars were (Anton, Armour, Overland, Settler-CL, Snowmass, Wesley), five nitrogen treatments (0, 30, 60, 90, 120 lbs of N per acre) and three irrigation treatments (0, 6, 12 inches) were used. Plots were harvested when mature using small plot combines equipped with onboard weighing systems. Differences between years had a dramatic effect on yield across all treatments and all locations. However, when correcting for rainfall, location didn't have a substantial impact on yield. Irrigation events only occurred at the Scottsbluff location. Irrigation had a significant effect when compared to dryland

production, but the effect of 6 and 12-inch irrigation treatments was subtler and at times not significant. Nitrogen had little effect on yield or predicted grain protein. Variety had a significant effect on both yield and predicted grain protein, and this trend was consistent across years and locations. Test weight (TWT) was not responsive to nitrogen or irrigation, but varietal differences were significant and some trends remained constant from year to year. However, TWT trends did not align between locations in either year. Gluten response was very similar to protein, but the response was much less dramatic.

Dedication

Dedicated to my wife, Mary, and our five children:

Sariah, Séamus, Freya, Daphne, and Nora.

Acknowledgments

Many people have graciously given help and support throughout the process of attaining my degree and writing this thesis. My advisor Dr. Dipak Santra and have been patient and allowed me to learn how to be a researcher. Dr. Alex Pavlista, Dr. Gary Hergert, Dr. Bejish Maharjan, and Dr. Teshome Regassa for helping with planning and problem-solving. They have helped to prepare me for my career, and I am grateful for their time and sacrifice on my behalf.

My wife, Mary, who has been my motivation throughout this entire process. She has been more patient than anyone while have worked on this degree. She has worked and sacrificed, often caring for our five children while I was on the road or working late. Her love and understanding gave me the motivation to finish. I am also very grateful for my mother; she sacrificed a great deal to help me as I got through university, I couldn't have done it without her help.

Dr. Cody Creech and Strahinja Stepanovic, we shared an office while graduate students and they were always willing to help me. Also Allison Rickey, and Les Campbell, Vernon Florke at the Panhandle Extension center for always being willing to help me with my research. And many others, which I will always be grateful for their help.

Joseph Davis

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Chapter 1 – Introduction

Wheat Production

It is projected that the world population will grow to 9 billion people by 2050. During that time the amount of cultivatable land will decrease, the demand for food will increase, and the effects of climate change will become greater. Water is a limited natural resource, and agriculture accounts for nearly 70% of humanity's total water usage. Fossil fuels are a finite natural resource as well, and synthetic nitrogen fertilizer is derived from fossil fuels via the Haber process. Therefore, there will be a growing need to manage natural resources such as water and fertilizer more sustainably. Ultimately, the world must produce more food with less land and with fewer inputs. Wheat is a vital crop in this effort: Wheat is grown on more land area than any other crop, and regarding production, it is second to maize. Wheat is highly adaptable; it can grow in a wide range of elevations, temperatures, soil conditions, and with dramatically different levels of precipitation. Winter wheat is grown between latitudes 30-60N and 27-40S (Curtis, 2002).

Wheat has held a prominent role in western agriculture, from the early agrarians until now. Wheat is a significant crop because of an assortment of traits that, when combined, increase its utility to farmers, food producers, and consumers. Wheat has a wide adaptability and stability across various geographies. It is scalable, capable of being planted and harvested by hand; also, able to be part of large-scale commercial production. In larger farms, wheat can be produced with little labor and a reduction in production costs. Wheat can easily and rapidly be planted and harvested through mechanical means. It has a very consistent seed size for planting, a very uniform height, threshes easily, and semi-dwarf varieties have a low volume of straw to process during harvest. The harvested product is typically clean and requires almost no post-processing before it enters food markets. Modern combines can harvest swaths in upwards of 60', and the ground speeds are consistently increasing as designs improve. Harvested wheat can be shipped and stored with less effort than is required for many other crops. Wheat also has a relatively long storage life. Other small grains, such as rice do not store well without processing because of the lipid content of whole rice. However, once milled whole wheat flour has a very short storage life. If wheat is left intact, then it can easily be stored in large quantities without a measurable loss in protein or utility (Doblado-Maldonado et al., 2012). Because wheat is capable of being directly utilized in food production, there should always be markets available. (Ahmad et al., 1991; Bishop and Bugbee, 1998; Battenfield et al., 2013).

Wheat, through a complicated chain of events, evolved in a large and diverse region known as the Fertile Crescent sometime between 7,000-10,000 years ago (Fig. 1.1) (Brown et al., 2009; Fort, 2012). Agricultural practices began at this time, but the evolution of wheat likely came from naturally occurring events. This region is regarded as the place where humans transitioned from nomads to agrarian neoliths. Wild grasses such as Einkorn wheat, Barley, and Emmer Wheat were all found in the region, but they were adapted to slightly different geographies in the region. There is evidence that people were using these wild grains for food. But at some point, a series of natural crosses from some of these wild ancestors led to modern wheat growing wild, and people began to cultivate it. During this same time, people started raising animals and staying a location for multiple years, they no longer had to move with the seasons. Because people were able to stay in a location they could more easily select for the most desirable plants.

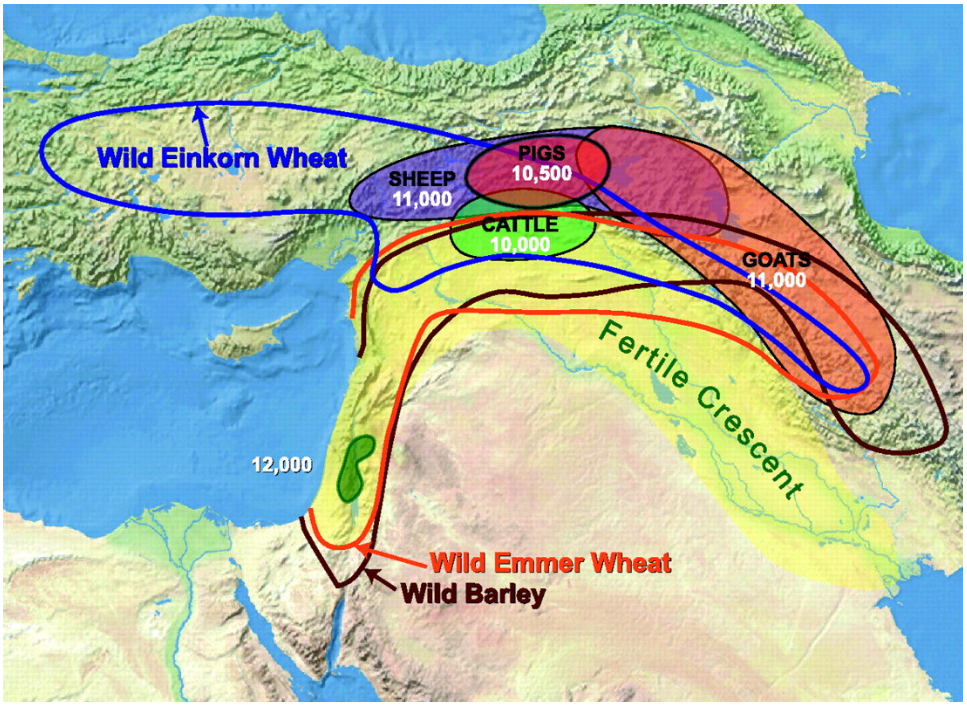


Figure 1-1 Map of the Fertile Crescent. The people of the region were largely nomadic, traveling with animals. These people began domesticating animals and small grains as their agricultural practices developed. Emmer and Einkorn share a common ancestry with Bread Wheat. This figure shows the small geography where agricultural practices were initially developed. (Driscoll et al., 2009)

Common bread wheat (*T. aestivum*) is an allohexaploid (*2n=6x=42, AABBDD*), and has a relatively complex genome when compared to other major crops. Modern bread wheat has evolved through naturally occurring hybridization between its progenitors (Fig. 1.2). Two diploid wild relatives: *T. uratu (2n=2x=14,AA) and Ae. Speltoides*

(2n=2x=14,BB), leading to *T. turgidum*(2n=4x=AABB) which crossed with *T. tauschii* (DD) resulting in *T. spelta*(AABBDD). Modern bread wheat (*T. aestivum*) was derived from *T. spelta* through natural evolution. *T. turgidum* is then divided into subspecies via selection pressure. Durum (*T. turgidum subsp. durum* or *T. durum*) and Emmer (*T. turgidum subsp. dicoccum* or *T. dicoccum*). All the progenitors of modern wheat came from the same region and are still in production, but on a much smaller scale than modern wheat. Einkorn is a diploid species, and it was one of the earliest domesticated forms of wheat. Wild Einkorn has a head that drops seeds easily whereas the domesticated head holds seeds until being threshed. Einkorn has poor yield characteristics but is hardier in marginal environments. Einkorn is not free-threshing meaning that the seed coat doesn't easily separate from the seed (Stallknecht et al.,; Zohary et al., 2000). Emmer is also a diploid species, it shares many characteristics with Einkorn. Both of these early kinds of wheat were naturally seen in the region and they were both domesticated and cultivated at near the same time. Wild Emmer shatters and drops seeds, domesticated Emmer has a head that holds seeds until being threshed. Emmer is not free-threshing (Stallknecht et al.,). Tauschii is a wild goat grass, it isn't really a food item and it was found in the eastern reaches of the fertile crescent. It is also a diploid, and the final component of the modern hexaploid wheat. it has a very tight head that has very small grains. Wild goat grass is a very hardy plant, capable of growing in very poor soil conditions ("Taxonomy - GRIN-Global Web v 1.10.3.6,"). Bread wheat has more seeds per plant and is easier to harvest than other types of wheat; giving it greater yield, value, and utility in modern agriculture. Over time, people have developed tailored uses for each type of wheat, and these types are frequently distributed based on social boundaries rather than on natural boundaries. Durum is widely used for making pasta and is considered better for the task than other types of wheat. Durum pasta dough is strong but flexible, able to be formed into thin sheets. However, the dough is not elastic like other wheat doughs; These qualities are what make durum useful in making pasta. Emmer wheat is used to make bread, however, it does not see widespread use because of relatively poor agronomic characteristics. (Fifield et al., 1945; Kimber and Sears, 1987; Wishart, 2004).

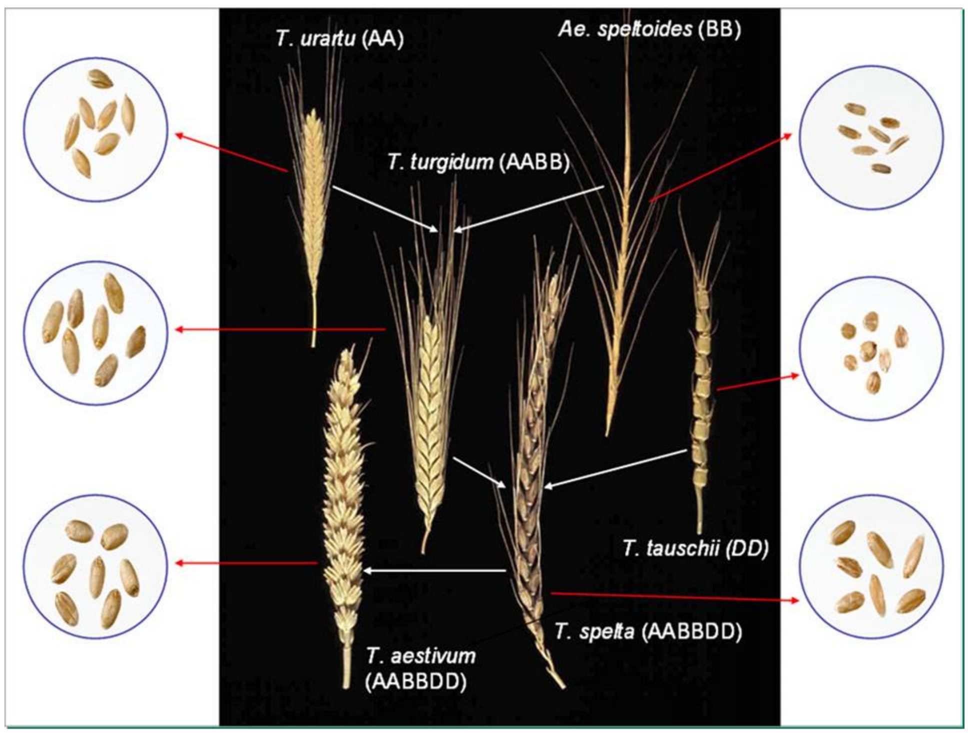


Figure 1-2 Evolution of modern wheat. (Shewry, 2009)

Production and Distribution:

Wheat spread throughout the Mediterranean and then Europe because of its utility as a food source for early agrarians. Wheat became a staple food throughout Europe, Russia, and North America.

Worldwide, wheat ranks first based on total production area but ranks second with respect to tons of grain produced. Globally wheat production area is 551 million acres, which produces 834 million short tons of wheat. Rice production area is 400 million acres, and production is 541 million short tons. Maize global production area is 480 million acres, and production is 1237 million short tons.

Comparison of Top 10 US Wheat Producing States in 2018				
	Million Acres	**% of US**	**Million Tons**	**% of US**
North Dakota	7.74	16	10.91	19
Kansas	7.70	16	8.32	15
Montana	5.39	11	5.93	11
Texas	4.50	9	1.68	3
Oklahoma	4.40	9	2.10	4
Colorado	2.26	5	2.12	4
Washington	2.22	5	4.60	8
South Dakota	1.88	4	2.17	4
Minnesota	1.62	3	2.79	5
Idaho	1.19	2	3.13	6
Nebraska	1.10	2	1.48	3
US Totals	47.82		56.55	

Table 1-1 This data is based on total planted acres. Worldwide production statistics references all wheat classes, this data also shows all wheat classes and production methods.

Top 5 Nebraska counties by total acres planted to wheat in 2018		
Region	**County**	**Acres**
Northwest	Kimball	95,000
Northwest	Box Butte	89,700
Southwest	Perkins	75,100
Northwest	Deuel	53,320
Southwest	Hitchcock	52,500

Table 1-2 The top five counties according to total acres planted in wheat, this is dryland and irrigated.

Top 5 Nebraska counties by irrigated acres harvest in wheat in 2017		
Region	**County**	**Acres**
Northwest	Box Butte	18,263
Southwest	Chase	8,306
Northwest	Cheyenne	6,417
Southwest	Dundy	4,828
Northwest	Morrill	4,732

Table 1-3 The top 5 wheat-producing Nebraska counties by acres planted, that were also irrigated.

Classes of Wheat

Modern wheat is subdivided further, into different classes based on appearances and end-use production. These classes are: growth habit, kernel color, and kernel hardness. Growth habit is the most significant classification for wheat and is based on the need for a vernalization period, a period of uninterrupted cold after germination. Winter wheat requires vernalization; spring wheat does not require Vernalization is determined by the *Vrn* genes, which are heritable and allow for growth at various latitudes based on the combination of the alleles. Typically, winter wheat will need between 180 and 250 days to reach harvest; this is long compared to many crops, but this includes the fall growing period. Color and Hardness are also heritable but are not as complex as growth habit. Based on color, wheat can either be Red or White. The hardness of the grain dictates how much force is required to mill the grain into flour. Based on these different factors, wheat can be classified as follows: hard red winter (HRW), hard red spring (HRS), soft red winter (SRW), and so on (Fifield et al., 1945).

Wheat as a Calorie Source

When comparing the grains as calorie sources worldwide, wheat and rice are tied and have been for many years. Both wheat and rice directly provide close to 20% of the world's calories each. Maize, however, directly supplies approximately 5% of the world's caloric needs. Maize undoubtedly supplies many calories as a secondary source because it is often used as an animal feed source. Whereas, rice and wheat are almost entirely used as a food source for people. Grains supply nearly half of the calories eaten by all people. Wheat has higher protein level relative to rice and maize. Wheat has the highest ratio of protein to calorie content among these top three cereals. Rice has the highest caloric density, followed by wheat, and then maize. However, it is important to remember that none of these grains contain all necessary amino acids for human nutrition, and as such, a single one cannot be a sole source of nutrition (Dhuyvetter, 2016; "FAOSTAT," 2017).

Wheat is most commonly milled into flour; typically this involves separating the bran from the endosperm, yielding white flour. The milled endosperm produces a flour that has outstanding dough qualities and is very palatable to most cultures. Whole grain flour, containing both the bran and the endosperm, is gaining popularity for both health and culinary reasons. With whole grain flour, the entire grain is milled and retained for baking. The white flour stores longer than the whole wheat flour, but even still, white flour spoils quickly. (Pena, 2002).Typically, hard red winter (HRW) wheat is the best wheat for making bread, cereal, and general-purpose flour. White wheat is typically used in confectionaries and pasta. However, HWW is beginning to be used more often as a leavened bread flour source. There is a growing effort to utilize hard white wheat in whole bread products, thus improving the nutritional value. Many consumers have a negative perception of whole wheat bread as it relates to palatability, but this seems to be mostly connected to the color of the flour. Whole wheat flour milled from HWW yields a much lighter color that many people find to be more palatable. Bread wheat has a very high level of gluten which allows for a very light bread that can rise substantially in the preparation and baking process. Gluten creates strong and highly elastic bonds that trap gases in the rising process, enhancing the appeal of the bread.

Management Practices for High Wheat Yield

There are many factors which affect wheat yield. The important agronomic inputs with major effect are cultivars, water and nitrogen availability in soil during growing season. Other factors with relatively less effect on yield are soil type, seeding rate, row spacing, date of planting. Management practices have been shown to have a significant impact on yield and quality. Planting density will have one of the largest impacts on yield (Kiesselbach and Sprague, 1926). However, planting population should not be so high that it inhibits tillering in individual plants, as tillering significantly improves yield (Gardner et al., 1985). Harvest Index is linearly and negatively related to plant height; management practices should focus on grain yield and quality rather than aggressive vegetative growth (Miralles and Slafer, 1995). Varieties vary widely in their response to heat and drought stress (Stone and Nicolas, 1994). Varieties also vary in their performance when grown in different regions from where they were initially developed, or if they are managed differently from what is common in the home region (Souza et al., 2004). Varietal differences lead to significant differences among all significant economic traits (Stone and Nicolas, 1994). Therefore, planting correct varieties that are well suited to their environment is important. The dissertation focuses on cultivars, soil water and nitrogen and therefore, these three inputs are discussed in detail.

Cultivars

Genetics of the cultivar is very important for high wheat yield. Genetically improved cultivars should have high yield potential under any given production environment when compared to wild types. This genetic improvement should be seen under optimal or sub-optimal soil water and nitrogen availabilities. Wheat is a genetically complex plant, an example of this is plant height. Plant height can be affected by more than 20 genes located across 17 of the 21 chromosomes found in the wheat genome. These genes that affect plant height are collectively referred to as *Rht* genes. Currently there have been two groups of *Rht* genes defined. The first group is gibberellic acid sensitive genes that either do not produce gibberellic acid or produced a modified form that doesn't function correctly in the plant. Plants with only these genes affecting plant height will grow to normal heights if external gibberellic acid is applied. The second group are less-sensitive to external gibberellins, these plants will only respond to GA under very high doses. (Korzun et al., 1998; Worland et al., 1998; Zanke et al., 2014)

Modern commercial wheat appears different from its wild ancestors. The wheat produced today is shorter than older lines because of selection for the *Rht* gene. These varieties are known as semi-dwarfs. Semi-dwarf plants are less prone to lodging, especially when they receive large amounts of nitrogen fertilizer. Many of these semi-dwarf lines were also capable of higher yields relative to the tall lines. This yield increase is not without issue though; the shorter growth affects the plant at all stages, and with the semi-dwarf plant even the coleoptiles are shorter and can make it difficult to plant the wheat into moisture while still allowing for uniform germination. ("Semidwarf Wheat Varieties," 1968; Ahmad et al., 1991; Sial et al., 2010)

Genetic improvement of wheat has consistently risen over the last century, as the understanding of wheat genetics has evolved (Austin et al., 1980, 1982). Wheat productivity is dependent upon several yield components and traits, such as plant height, straw strength, tillers per plant, spikes per acre, grains per spike, grain weight. Modern breeding programs have focused on these components, as well as responsiveness to irrigation and fertilization. Many modern varieties are also very resilient to disease and poor environmental conditions (Kiesselbach and Sprague, 1926; Thomas, 2014).

Soil Water

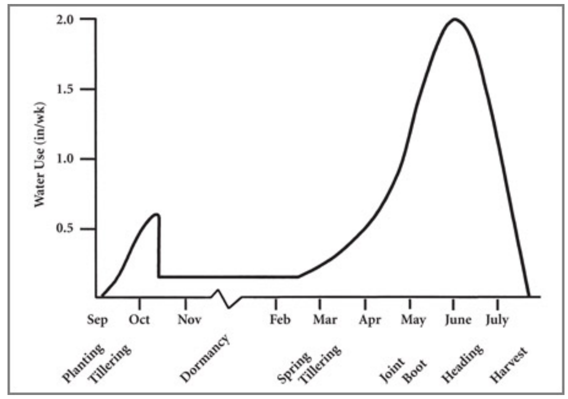


Figure 1-3: Seasonal water consumption in winter wheat.

Water is essential for all physical functions within a plant. Water use varies dramatically throughout the life cycle of the crop. Water use is dependent upon the growth stage of the crop; water usage increases dramatically during the reprodu Water demands and responsiveness to water stress is different between varieties (Lopes et al., 2012).

Water use in field crops is measured by tracking all irrigation and rainfall then account for the movement of that water. An equation represents this water movement, where W is the total amount of water the crop receives in a growing season, R is runoff, D is soil drainage, E_c & E_s is the water lost through evaporation from the crop and soil, T_w & T_c is the transpiration from weeds and crops:

$$W = R + D + E_c + E_s + T_w + T_c$$

Equation 1-1: Crop Water Use.

Water Use Efficiency (WUE) goes further by comparing productivity or yield (P) against seasonal water availability (W). Improvements in WUE translate into reductions in water application and increases in profitability and yield.

$$WUE = P/W$$

Equation 1-2: Water Use Efficiency.

Improving WUE is not accomplished only by reducing the total applied water, but by improving the synchrony of water applications to match the demands of the crop. Ultimately the most significant gains in WUE are realized when all applied water is utilized by the crop, and the crop's entire water demand is met through the growing season. Deficit irrigation (DI) is an irrigation management that focuses on matching water application to crop needs to significantly improves WUE (Xue et al., 2006). Deficit Irrigation seeks to reduce drought stress during heading, flowering, and grain fill. The duration of grain fill is mostly based on environment and can be prolonged by well-timed irrigation (Yang et al., 2001). Well-Managed stress after anthesis can result in more pronounced remobilization of stored assimilates (Gallagher et al., 1976). Improved grain yields are correlated with an extended grain fill period (Gallagher et al., 1976).

Water applications must be optimized to match the crop needs during the reproductive phase to improve productivity, reduce water usage, and maintain high protein levels (Yang and Zhang, 2006). Yield reduction due to water stress under hot, drought conditions depends on at what stage of growth and development the stress occurred. Reduced irrigation levels and mild drought stress during vegetative growth (Feekes 4-9) do not have a significant effect on grain yield (Kang et al., 2002; Zhang et al., 2004). Yield components are reduced by heat and drought stress during early reproductive stages (Feekes 10, 11) (Kobata et al., 1992; Guttieri et al., 2000; Altenbach et al., 2003). Drought occurring at or near anthesis can reduce total number of grains per spike, accelerate senescence, and reduce the overall grain-fill period (Kobata et al., 1992; Palta et al., 1994; Gibson and Paulsen, 1999).

Harvest Index (HI) is a similar measure that is related to efficiency and productivity in cropping systems. HI is the ratio between the economic yield and the biological yield (Gardner et al., 1985). Crops with low HI produce large amounts of vegetative growth relative to the economic yield of the crop. Harvest Index relates to WUE because they are both measures of productivity. Irrigating early in the season encourages wasteful straw growth at the expense of grain and input costs. Water can be significantly reduced early in the year with no significant effect on yield (Yang et al., 2001; Yonts et al., 2009).

$$harvestindex = \frac{economicyield}{biologicalyield} * 100$$

Equation 1-3: Harvest Index.

Water availability is the most significant management input when producing small grains (Zhang et al., 2004; Ali et al., 2007). Grain yields in wheat will be highest under full irrigation, but as water input increases beyond necessary levels, WUE will decrease (Ali et al., 2007). Like any plant, wheat has a point of diminishing returns when applying irrigation water. Wheat has a nearly linear response to applied water (Zhang et al., 2004). Vegetative biomass production increases with early-season irrigation (Xue et al., 2006). There is a practical limit when irrigating wheat; any water applied after that point will have significant diminishing returns (Clark et al., 2001). The grain protein content is established at early grain fill; however, grain starch production is dependent on the length of grain fill period. The relative protein content is higher under post-flowering water stress (Gooding et al., 2003).

Nitrogen

Nitrogen (N) availability in modern wheat production is almost as important as soil water availability. Without adequate N supply, all stages of growth will be severely hindered. (Cassman et al., 2002). Nitrogen uptake and utilization are dependent upon soil water availability. In semi-arid regions (like western Nebraska) nitrogen uptake increases with irrigation (Ercoli et al., 2008). An overabundance of nitrogen under optimal soil water level can delay reproductive growth and lead to lodging as plant height is unnecessarily increased (Guarda et al., 2004). Moreover, there is significant variability among cultivars their responsiveness to nitrogen applications (Austin et al., 1977).

Nitrogen availability influences both yield components and quality. The benefits of nitrogen fertilizer on yield and quality is dependent upon rate and timing of the application (Borghi et al.,; Spiertz and Vos, 1983). Increased N level before spike development can increase kernels per spike (Guarda et al., 2004). Increasing levels of nitrogen has a positive effect on the number of spikes/m^2 (Abedi et al., 2011). Early season N applications increase dry-matter growth and plant height (KSU Extension, 1997). Heading date in wheat is delayed with higher levels of applied nitrogen (Guarda et al., 2004). Nitrogen uptake during grain fill in wheat is strongly correlated with the amount of applied N (Delogu et al., 1998). Nitrogen applications do not have a substantial effect on the duration of grain fill (Halse et al., 1969).

Quality is directly affected by nitrogen applications; however, the timing of the application has a significant impact on the utility of the application (Mahler et al., 1994). Applying liquid, foliar fertilizer near heading has a positive effect on grain protein

(Garrido-Lestache et al., 2004). Applications after flowering will not affect yield or protein (Abad et al., 2004).

Nitrogen Use Efficiency (NUE) is the relationship between applied nitrogen and what the plant uses. Wheat can utilize a large amount of nitrogen, with much of that nitrogen going to the straw (Abril et al., 2007). Large improvements can be made to NUE by matching applications to the growth stage of the plant and reducing wasteful vegetative growth (Mahler et al., 1994). Protein content is set early in the grain fill process; however, starch continue to accumulate throughout grain fill. Protein is negatively correlated to yield because the starch continue to accumulate thereby reducing the relative protein content (Rao et al., 1993).

Justification and Objectives

Nebraska has varying geography, and crop production practices change depending on geography and climate. The most prominent production practice that defines wheat production in the region is irrigation. Wheat can either be dryland (rainfed) or irrigated. This project is significant because it helps to address the challenges of wheat production in Nebraska.

Dryland production is characterized by minimal inputs and minimal capital costs on the farm. Often the rotation is summer fallow, where wheat is planted in alternating years and in the off years the ground is not disturbed and weeds are managed via chemical weed control. In dryland settings there is no infrastructure to provide irrigation, farmers must manage all of their on-farm operations based entirely on weather. There is an additional concern about managing soil to prevent wind erosion, so reside and tillage must be utilized properly in-order to address these challenges. Dryland production limitations are predominately characterized by negotiating a delicate balancing act; drylands farmers can lose substantial amounts of money if they apply fertilizer that is never utilized by the plant or if they apply weed control at the wrong time. Because dryland wheat has a low yield potential, all inputs must be timed perfectly to ensure maximum return on investment.

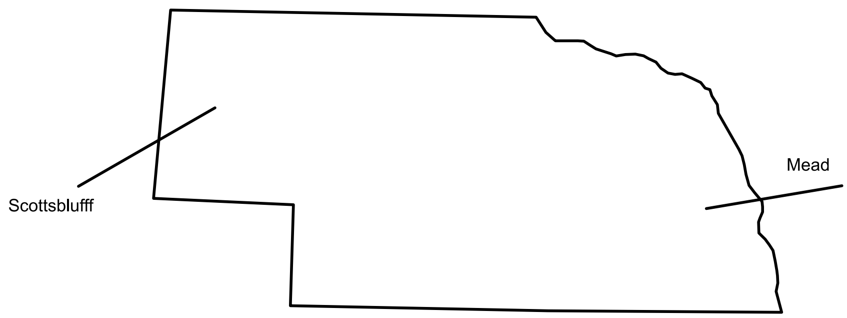
Irrigated wheat is typically managed more intensely in-order to maximize yield. Capital and input costs are often much higher because there is greater yield potential with these farms. This higher yield potential helps to justify utilizing more inputs that help push yield even higher. Production concerns and limitations are somewhat different with irrigated wheat versus dryland. Irrigated wheat fields can often be heavily tilled, requiring entirely different management strategies than in dryland fields that may not be tilled at all. Nitrogen and water allocations have to be timed to maximize output but not push the crops to the point of damage. Further there is an additional concern not to waste resources. In Western Nebraska, water is a scarce resource that is functionally non-renewable (Basso et al., 2013). The primary irrigation source is water derived from the High Plains Aquifer, the rate of recharge is less each year than the rate of discharge which makes this a limited and non-renewable natural resource (Sophocleous, 2005).

Therefore, it is imperative for growers to find a balance wherein they achieve the highest yield potential while not wasting water. Most of information currently available for what production is dated. There is a clear need to improve our understanding of dryland and irrigated wheat production. Further, the study and understand surround the interactions of irrigation, fertility, and variety selection are extremely complicated. The objective of this project is to add to the body of data surrounding problem of how to best manage water in wheat production when water is in limited supply. Secondly, how to most efficiently use nitrogen in these limited irrigation scenarios. And third, to confirm that this information is consistent across various cultivars that are representative to the region.

Chapter 2 Materials and Methods

Trial Locations

Figure 2-1: Research locations in the state of Nebraska. Two locations were used for the experiment, Scottsbluff in the west and Mead in the east.



Scottsbluff was chosen to represent semi-arid High Plains of Nebraska Panhandle, the major wheat producing region of the state. Whereas, Mead was selected to represent eastern Nebraska site with contrasting environment and climate of high rainfall and low elevation. The western field trials were planted at Panhandle Research and Extension Center (PREC) in Scottsbluff, NE (Tripp very fine sandy loam, i.e., Coarse-silty, mixed, superactive, mesic Aridic Haplustolls) (N41°.89″, W-103°.68″) with an elevation of 3,891ft (1186m). The eastern field trials were planted at the Agricultural Research and Development Center near Mead, NE (Tomek silt loam, i.e., fine, smectitic, mesic Pachic Argiudolls) (N41°.16″, W-96°.41″) with an elevation of approx. 1211ft (369m). Growing conditions at these two sites provide contrasting experimental field conditions because of their significantly different climates. Scottsbluff has less precipitation and fewer accumulated Growing Degree Days (GDD). Scottsbluff has approximately 140 frost-free days, and Mead has approximately 150 frost-free days. (Table 2.1)

Monthly Precipitation (inches)													
	Scottsbluff												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Sum
2012	0.16	0.69	0	0.98	0.35	1.74	0.93	0	0.79	0.87	0.29	0.19	6.99
2013	0.26	0.28	0.21	2.43	1.46	1.54	0.88	0.79	2.37	1.67	0.85	0.63	13.37
2014	0.46	1.14	0.85	0.62	4.08	1.73	1.5	1.66	4.26	0.59	0.91	1.47	19.27
30 Yr. Avg.	0.39	0.65	0.94	1.85	2.46	2.68	1.64	1.22	1.31	1.2	0.62	0.53	15.49
	Mead												
2012	0.16	1.84	0.62	2.81	3.8	4.24	0.26	0.91	1.18	1.36	0.25	1.06	18.49
2013	0.44	0.42	1.31	3.62	6.42	4.68	0.62	1.8	3.79	3.86	1.27	0.15	28.38
2014	0.07	0.46	0.21	3.22	6.48	8.33	0.55	6.97	3.12	3.3	0.22	1.51	34.44
30 Yr. Avg.	0.54	0.71	1.56	2.99	4.33	4.68	3.33	3.5	3	2.15	1.31	0.94	29.04

Table 2-1: Annual Precipitation (inches) at Scottsbluff and Mead

Monthly Growing Degree Days (GDD 50)													
	Scottsbluff												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Sum
2012	0	0	103	142	349	764	929	754	462	87	7	0	3597
2013	0	0	13	49	326	624	780	791	523	41	0	0	3147
2014	0	1	12	88	277	492	740	698	431	144	1	0	2884
30 Yr. Avg.	0	1	15	70	268	540	765	697	380	91	6	0	2833
	Mead												
2012	3	0	228	185	508	681	974	727	439	114	11	0	3870
2013	0	0	1	67	343	604	738	764	587	158	5	0	3267
2014	0	0	18	130	384	616	653	702	416	175	6	2	3102
30 Yr. Avg.	0	1	34	129	361	644	786	732	451	171	21	0	3330

Table 2-2: Monthly Growing Degree Days for Scottsbluff and Mead

The growing season for wheat begins in September, at planting and continues through to the following August. At Scottsbluff, total precipitation during the growing season in 2013 was 8 inches. Of this precip., 3.18 inches was rainfall after spring green-up and before harvest (Table 2-1). Total precipitation during the growing season in 2014 was 14 inches. Of this total precip., 6.78 inches was rainfall after spring green-up and before harvest (Table 2-1). Which means 2014 had 6" more annual precip., than 2013. Of which 3.6" was additional rainfall during the spring and summer in 2014 than that of 2013. That means 2014 had 3.6" more rainfall during the active growing season and 2.4" more rain and snow between Sept., '13 to March '14. Thus, 2014 was a wetter year than in 2013. Compared to the 30-year average, precipitation in 2013 was below average while in 2014 it was slightly higher than average.

At Mead, both years provided above adequate moisture for winter wheat production. Compared to the 30-year average, precipitation was near average in 2013 and above average in 2014.

Design & Treatments

The experiment was a randomized complete block design with a split-split-plot configuration. Design was based on three main factors: irrigation, nitrogen, and cultivar. Irrigation treatments were applied at three rates (0”, 6”, 12”). Nitrogen fertilizer treatments were applied at five rates (0, 30, 60, 90, 120 lbs/acre). Variety was the final treatment and six unique cultivars were used four hard red winter (HRW) and two hard white winter (HWW). The experiment was replicated three times at each location. The irrigation treatments were main plots and were applied as blocks. Nitrogen treatments were applied in strips, as subplots within each irrigation treatment. Cultivars were randomized within each nitrogen treatment. Buffer strips were incorporated on all sides of the field with 30 feet buffers between each irrigation treatment.

Figure 2-2 Field design from year two of the study. Demonstrating experimental design and facilitating the simplicity required to irrigate with lateral irrigation system. It is important to note that because of a significant stand issue related to seed purity, we decided to drop Overland from the analysis because we were not certain that it was representative of the variety.

REP 1	0	120	Anton	Snowmass	Armour	Overland	Wesley	Settler-CL
		60	Snowmass	Armour	Settler-CL	Wesley	Anton	Overland
		30	Armour	Overland	Anton	Settler-CL	Wesley	Snowmass
		90	Settler-CL	Wesley	Overland	Anton	Snowmass	Armour
		0	Overland	Settler-CL	Wesley	Snowmass	Armour	Anton
	6	0	Snowmass	Overland	Anton	Wesley	Armour	Settler-CL
		90	Overland	Settler-CL	Armour	Snowmass	Wesley	Anton
		60	Wesley	Anton	Snowmass	Settler-CL	Overland	Armour
		30	Anton	Snowmass	Wesley	Armour	Settler-CL	Overland
		120	Armour	Wesley	Settler-CL	Overland	Anton	Snowmass
	12	120	Anton	Overland	Snowmass	Wesley	Armour	Settler-CL
		0	Wesley	Settler-CL	Armour	Overland	Anton	Snowmass
		90	Overland	Armour	Settler-CL	Snowmass	Wesley	Anton
		30	Armour	Snowmass	Overland	Anton	Settler-CL	Wesley
		60	Settler-CL	Wesley	Anton	Armour	Snowmass	Overland
REP 2	12	120	Anton	Wesley	Snowmass	Settler-CL	Overland	Armour
		30	Settler-CL	Overland	Anton	Armour	Snowmass	Wesley
		90	Snowmass	Armour	Wesley	Overland	Anton	Settler-CL
		60	Wesley	Settler-CL	Overland	Snowmass	Armour	Anton
		0	Overland	Anton	Armour	Wesley	Settler-CL	Snowmass
	0	90	Settler-CL	Wesley	Anton	Snowmass	Armour	Overland
		0	Wesley	Overland	Armour	Anton	Settler-CL	Snowmass
		30	Overland	Settler-CL	Snowmass	Armour	Anton	Wesley
		120	Armour	Anton	Overland	Wesley	Snowmass	Settler-CL
		60	Anton	Snowmass	Settler-CL	Overland	Wesley	Armour
	6	120	Snowmass	Armour	Wesley	Anton	Overland	Settler-CL
		60	Wesley	Settler-CL	Anton	Overland	Armour	Snowmass
		0	Armour	Overland	Snowmass	Wesley	Settler-CL	Anton
		90	Anton	Wesley	Armour	Settler-CL	Snowmass	Overland
		30	Settler-CL	Anton	Overland	Snowmass	Wesley	Armour
REP 3	6	120	Wesley	Snowmass	Overland	Armour	Settler-CL	Anton
		30	Anton	Overland	Settler-CL	Wesley	Armour	Snowmass
		0	Overland	Settler-CL	Wesley	Snowmass	Anton	Armour
		60	Settler-CL	Armour	Snowmass	Anton	Overland	Wesley
		90	Snowmass	Anton	Armour	Settler-CL	Wesley	Overland
	12	90	Wesley	Anton	Armour	Settler-CL	Overland	Snowmass
		120	Overland	Wesley	Settler-CL	Snowmass	Anton	Armour
		0	Settler-CL	Overland	Wesley	Armour	Snowmass	Anton
		60	Snowmass	Armour	Overland	Anton	Settler-CL	Wesley
		30	Anton	Settler-CL	Snowmass	Wesley	Armour	Overland
	0	0	Settler-CL	Wesley	Snowmass	Armour	Overland	Anton
		90	Anton	Armour	Settler-CL	Wesley	Snowmass	Overland
		120	Snowmass	Wesley	Overland	Settler-CL	Anton	Armour
		30	Overland	Anton	Armour	Snowmass	Wesley	Settler-CL
		60	Wesley	Settler-CL	Overland	Anton	Armour	Snowmass

Irrigation Levels and Methods

The experiment included three irrigation levels, which were applied in addition to rainfall and all allocated water would be applied so long as it did not damage the crop. The allocations were: 0, 6, 12 inches of irrigation water. In reality, the total amount of irrigation water might not be utilized because of adequate rainfall. The goal of this treatment style is to mimic the methods of irrigation management used by regional farmers. Evapotranspiration (ET), rainfall, and irrigation were all tracked throughout the season in a checkbook method. Crop growth stage was also tracked so that ET could be matched to variable crop needs.

The dry-land treatment (0") was a negative control. There was a significant drought across the region in 2012 and the early part of 2013. In the absence of fall rains, 0.5" irrigation was required to incorporate the nitrogen fertilizer to prevent volatilization and loss of the experiment. An additional 0.25" was applied across all treatments in the spring to ensure uniform stand as the crop ending dormancy. Whereas in the 2013-'14 season, no irrigation was applied in the fall and 0.25" was applied to all treatments in the spring. Both the 6- and 12-inch irrigation was distributed throughout the season wisely in such a way to minimize water stress during critical growth stages, flowering and grain-fill stages (Figure 2.3 & 2.4).

Figure 2-3 2012-2013 Irrigation Schedule. Irrigation management prioritized avoiding stress during flowering, followed by avoiding stress during grain fill.

2012-2013 Irrigation Log									
Period	**Week**		**Phenology**	**Weekly Use**	**Cumltv Use**	**0"**	**6"**	**12"**	**Rain**
						Actual	Actual	Actual	
1	Start of Week	End of Week		0.25	0.25	0.5	0.5	0.5	0
2	22-Apr-13	28-Apr-13	Leaf Elong	0.3	0.55	0	0	0	0
3	29-Apr-13	5-May-13	Leaf Elong	0.5	1.05	0	0	0	0
4	6-May-13	12-May-13	Jointing	0.85	1.9	0	0	0	0
5	13-May-13	19-May-13	Jointing	1	2.9	0	0.5	0.5	1.15
6	20-May-13	26-May-13	Pre-Boot	1.25	4.15	0	0.5	0.5	0.09
7	27-May-13	2-Jun-13	Boot-head	1.25	5.65	0	0.75	1.5	0.27
8	3-Jun-13	9-Jun-13	Head-Flowr	1.5	7.55	0	0.75	1.5	0.13
9	10-Jun-13	16-Jun-13	Flowr-Fill	1.9	9.55	0	0.5	1.75	0
10	17-Jun-13	23-Jun-13	Grain milk	2	11.55	0	0.5	1	1.54
11	24-Jun-13	30-Jun-13	Grain Fill	2	13.45	0	1.68	1.68	0
12	1-Jul-13	7-Jul-13	Soft dough	1.9	15.25	0	0	2	0
13	8-Jul-13	14-Jul-13	stiff dough	1.8	16.75	0	0	1	0
14	15-Jul-13	21-Jul-13	Ripening	1.5	17.75	0	0	0	0
15	22-Jul-13	28-Jul-13		1	18.25	0	0	0	0
16	29-Jul-13	4-Aug-13		0.5	18.5	0	0	0	0
17	5-Aug-13	11-Aug-13	Mature	0.25	18.75	0	0	0	0
	TOTAL			19.75		0.5	5.68	11.93	3.18
					Remaining	-0.5	0.32	0.07	

Figure 2-4 2013-2014 Irrigation Schedule. Irrigation management prioritized avoiding stress during flowering, followed by avoiding stress during grain fill.

2013-2014 Irrigation Log

Period	Week		Etr	Phenology	Weekly Etc	Dry Actual	6 Inch Actual	12 Inch Actual	Rain Inch
1	Start of Week	End of Week				0	0	0	0
2	21-Apr	27-Apr	2.08	Leaf Elong	1.9	0	0	0	0.66
3	28-Apr	4-May	1.63	Leaf Elong	1.5	0	0	0	0
4	5-May	11-May	0.86	Jointing	0.9	0.5	0.5	0.5	2.67
5	12-May	18-May	1.12	Jointing	1.2	0	0	0	0.14
6	19-May	25-May	0.98	Boot	1.1	0	0	0	0.16
7	26-May	1-Jun	1.44	Heading	1.6	0	1	1.75	0.68
8	2-Jun	8-Jun	1.40	Flowering	1.5	0	0.68	1.75	0.14
9	9-Jun	15-Jun	1.40	Grain Fill	1.5	0	0.75	1.75	0
10	16-Jun	22-Jun	1.40	Grain Fill	1.5	0	1	1	1.44
11	23-Jun	29-Jun	1.40	Grain Fill	1.5	0	1	2	0
12	30-Jun	6-Jul	1.54	Soft Dough	1.5	0	1.25	2	0
13	7-Jul	13-Jul	1.40	Ripening	0.7	0	0	0.75	0.53
14	14-Jul	20-Jul	2.00	Ripening	1.0	0	0	0	0.25
15	21-Jul	27-Jul	1.60	Ripening	0.8	0	0	0	0.11
	USED					0.5	6.18	11.5	6.78
	REMAINING					-0.5	-0.18	0.5	

The irrigation management scheme was derived from well-documented methods collectively known as deficit irrigation. Deficit irrigation is the deliberate under-irrigation of the crop, where less water is applied that is required to match seasonal ET. During vegetative growth, available water is below total ET and above wilting point. However, as the plant transitions into reproductive growth stages, irrigation must match crop ET to ensure the highest possible yield.(English, 1990)

Farmers in the region commonly use some form of the checkbook method (Melvin and Yonts, 2009) to track rainfall, irrigation events, and crop water usage. To schedule irrigation in this way a grower must accurately track rainfall and irrigation as well as evapotranspiration (ET). Using crop specific ET data from the University, growers can accurately predict water consumption of the crop and available soil moisture ("Table of Wheat Water Use by Growth Stage.pdf,"). Irrigation treatments and rainfall were carefully recorded whereby, the crop could be stressed without significantly reducing the yield. Crop growth stage was monitored closely to aid in predicting ET. ("High Plains Regional Climate Center,")

Gravimetric soil analysis is the process of weighing soil, drying it, and weighing it again to determine the soil water content. This analysis was performed before the first irrigation of the season to establish a baseline of stored soil water to begin the process of irrigation scheduling. The formula has multiple components:

$$\theta_d = \frac{(wt\ of\ wet\ soil) - (wt\ of\ dry\ soil)}{(wt\ of\ dry\ soil)}$$

$$\theta_{vd} = \theta_d * \frac{soil\ bulk\ density}{water\ density}$$

Figure 2-5: Volumetric water content in soil

Where θ_d is the water content of soil on a dry basis, θ_{vd} is the volumetric water content of the soil and, θ_{vd} is the value that was used to represent the water content of the soil.

Empty reference bag weights were recorded prior to drying, and these bags were dried and reweighed at the end of the process to account for bag weights throughout the process. Soil samples were placed in their empty bags, and the bag with soil was weighed before being placed in the drying oven. The samples were placed in an oven at a temperature of 110°C and remained there until the weights of the samples were stable across 24 hours (Klocke et al., 2004). Data from this process determined when irrigation would begin. This process was completed before the stem elongation stage ended (Feekes 4-5). Irrigation planning and application followed the methods described in Nebraska Extension Guide EC731 (Melvin and Yonts, 2009).

Nitrogen fertilizer rates and application method

Fertilizer was applied at five rates: 0, 30, 60, 90, 120lbs N/acre. Granular urea (46-0-0) was the only nitrogen source. New fertilizer was purchased from Panhandle Co-Op, a local commercial agriculture retailer, each year. Fertilizer was stored in cool, dark, dry locations and remnant was disposed of after application. Nitrogen fertilization rate was not adjusted based on residual soil nitrogen, and residual soil nitrogen was minimal at both site and in both years. All fertilizer was applied near planting and before emergence. To ensure that fertilizer was incorporated into the soil, all applications were timed to coincide with rain and in the event that no rain was forecasted then 0.25" of irrigation was applied.

To improve application efficiency, fertilizer was measured volumetrically in cups. One plot's allocation of fertilizer was weighed according to the respective treatment, and plastic cups were cut to match the pre-weighed reference. At the time of application, the cups were used to scoop fertilizer, and then it was spread by hand. All five fertilizer treatments were randomized as blocks within each irrigation treatment. Each fertilizer treatment block contained all varieties, and the varieties were randomized within the fertilizer blocks. This blocking allowed for rapid and consistent application.

Varieties

Six cultivars were used, four hard red winter wheat (HRW) cultivars: ‘Armour’ (Monsanto Technology, LLC., 2014), ‘Overland’ (Baenziger P. , et al., 2006), ‘Settler-CL’ (Baenziger P. S., et al., 2011), ‘Wesley’ (Peterson, et al., 2011). Moreover, two hard white winter wheat (HWW) cultivars: ‘Anton’ (Graybosch, et al., 2011), ‘Snowmass’ (Haley, et al., 2011).

Armour is an early maturity variety that is well adapted to most regions and has moderate winter hardiness. Test weights are average and protein is slightly better than average. Armour is characterized as relatively short plant height, with moderate coleoptile length. Armour is susceptible to leaf, stem, and stripe rust. (Regassa et al., 2012)

Anton has a later maturity than other varieties and is well adapted to irrigated production in the West and West Central regions. Anton has average winter hardiness. Anton is susceptible to leaf, stripe, and stem rust. Test weights are average and grain protein is slightly better than average (University of Nebraska - Lincoln, 2016).

Settler-CL has an average maturity, with moderate winter hardiness. Settler-CL is a very short variety and was the shortest of the experimental group. It has moderate resistance to leaf and stem rust (University of Nebraska - Lincoln, 2016).

Snowmass has a moderate maturity, with moderate winter hardiness. It is well adapted to irrigated production in the West and West Central regions. Snowmass is average in height and has long coleoptiles. it is susceptible to leaf, stem, and stripe rust. Snowmass has lower than average test weight and better than average grain protein (University of Nebraska - Lincoln, 2016).

Wesley has a moderate maturity, and a moderate winter hardiness. Wesley is a short variety with short coleoptiles. Wesley is resistant to leaf rust, but is susceptible to stem and stripe rust. Wesley has low test weight and better than average grain protein (University of Nebraska - Lincoln, 2016).

These cultivars are all pertinent to Nebraska and are commonly grown by commercial growers. Moreover, they were all selected based on their strong disease resistance profiles, marketability for the farmer, and their adaptability to being produced in both the eastern and western regions of Nebraska. Further, to fulfill the intent of our experiment proposal all of these varieties were to have some ability to be utilized in whole wheat foods. And finally, some of the varieties were developed by the University of Nebraska and held added merit in that way.

Seed Preparation

Certified seed producers were used to source all six cultivars. The seed for the year was treated with Raxil® at labeled rates using a portable cement mixer (Bayer CropScience, 2010). Germination % of all seed lots was ~95% (+/-2%). All plots were drilled at the same rate of 110lbs/acre. The seeding rate was an average of recommended rates from a University of Nebraska Extension guide to planting winter wheat (Klein et al., 2011). Germination rate and seed size (TKW=Thousand Kernel Weight) was not considered while calculating seeds/packet.

Field Preparations & Planting

For both years of trials, the previous crop at Scottsbluff was silage corn, and soybean at Mead. In Scottsbluff, a disk and roller packer were used to prepare the field. In Mead, a field finisher was used as the primary tillage implement. Soil samples were taken prior to planting at both locations and in both years using the same equipment and the same methods. Samples were taken at depths of 0-12", 12-24", 24-40", 40-60"; these were then assessed for nitrogen and the surface sample was also tested for potassium and phosphorous and select micronutrients. A Giddings brand, truck-mounted soil probe was used at both sites (Ferguson et al., 1991).

Plots were 5'wide and 25' long and consisted of 8 rows with 7.5" spacing between the rows. Planting depth was approximately 0.5" to 0.75". A cone drill (Hege by

Wintersteiger) used at both locations and were calibrated to plant the plots at 25’ with 30” alleys being inclusive in the 25’ length. Planting occurred on 22-Sept-2012 and 26-Sept-2013 in Scottsbluff, and on 9-Oct-2012 and 10-Oct-2013 in Mead. These dates were after the last risk of Hessian fly damage and before the cutoff for crop insurance for regional farmers In Scottsbluff water was applied in both years after planting to incorporate nitrogen fertilizer and ensure uniform germination.

Agronomic Data

Agronomic and phenological data were collected throughout the growing season, this included: tillering, plant height, flag leaf nitrogen, grain yield, grain moisture, test weight. The data is listed in chronological order of when the notes were taken throughout the year.

Plant height was measured by placing a measuring stick at the base of the plant. The measuring stick was the held perpendicular to the ground. The plant was then held erect, parallel to the measuring stick and the tallest portion of the plant was measured, excluding the awns. Four plants within each plot randomly chosen for measurements. Measurements were never taken from plants residing in the outer rows of the plot, or from plants adjacent to alleyways. Height notes were taken before harvest to ensure that the plants were done growing for the season.

Flag Leaf N was taken during the boot stage. Four flag leaves were cut from each plot and were packaged in small paper envelopes. A critical part of the method of gathering these samples was to ensure that they did not sit idle for too long. The samples were high in moisture and were in small paper envelopes in an already humid climate.

Samples could begin to mold soon after harvest because of this the samples were quickly placed in a drying oven at 120°F; samples were dried for five days. After drying the samples were sent to Ward Laboratories of Kearney, NE for analysis. A standard test was run at the lab to assess the nitrogen content, this test typically called for the entire aboveground portion of the plant. However, for our need, the lab was able to accommodate this test.

Harvest, Yield, and Seed Quality

Harvest timing was based on the moisture of the crop and how well the plants could be threshed. The decision on when to harvest was based on average maturity between the six varieties. In both years, harvest occurred at the end of July. The combines were able to measure and record plot weight, moisture, and test weight. During harvest, a 1kg subsample was retained to be processed later in the lab; the remaining seed was discarded. Samples were collected in the cab of the combine; the samples were placed in pre-labeled paper bags.

In Scottsbluff, a Winterstieger Delta plot combine with a Harvest Master Classic Graingauge grain handling system was used to harvest all plots (Winterstieger,; "Classic GG - HarvestMaster::Juniper Systems, Inc.,"). In Mead, an Almaco plot combine was used with an Almaco SPC-40 grain handling system (Almaco,). Grain was processed on the combine during harvest through the use of on-board weighing systems. Through the use of these systems test weight (lbs/bu), total harvested weight (lbs), and percent moisture were all collected.

Limited grain quality data was collected thousand kernel weight (TKW) was determined by counting 1000 seeds via an Agiculex Inc. ESC-1 Electronic Seed Counter and then weighing the sample ("ESC-1 – Agriculex Inc.," 2018). A Perten DA 7250 NIR Analyzer, we assessed grain moisture, protein and other various quality measures such as starch and hardness(Perten Instruments, 2018). Dr. Guttieri, University of Nebraska developed the equations used to estimate flour protein and gluten from the NIR output. And these estimated values were used in our experiment. Some work was physical lab work was done to assess the quality of the flour. However, it was soon realized that the cost and time associated with this effort would outpace the ability of the research assistant and the budget of the project. Therefore, only grain protein was the only form of quality data that was collected and as such other typical quality data will not be presented here.

Data Analysis

In our analysis, explanatory variables were: Plant Height, Flag Leaf Nitrogen, Cultivar, Nitrogen, Irrigation, Location, and Year. Moreover, our response variables were: Yield, Test Weight, Protein, Starch, Hardness, Fiber, Plant Height, Flag Leaf Nitrogen. Some traits that would traditionally be analyzed as response variables were also assessed as explanatory variables, to see if there could be any unexpected relationships between variables, i.e., plant height and yield. In our analysis, we also evaluated the relationships between the interactions of different explanatory variables, examples of these were Nitrogen by Cultivar, Irrigation by Cultivar, Nitrogen and Irrigation by

Cultivar. All potentially meaningful relationships were analyzed to find significant relationships.

Data were analyzed using PROC GLM and PROC GLIMMIX in SAS 9.4 to detect significant differences and to evaluate complex interactions between the explanatory variables (SAS Institute, 2013). Because of the split-split-plot design of our experiment we used a nested model in PROC GLIMMIX to account for the effect of the blocks on the data. The analysis was sliced by individual cultivars and treatments to determine specific effects of each explanatory variable. Slicing allowed for the analysis to show responses on a more granular level.

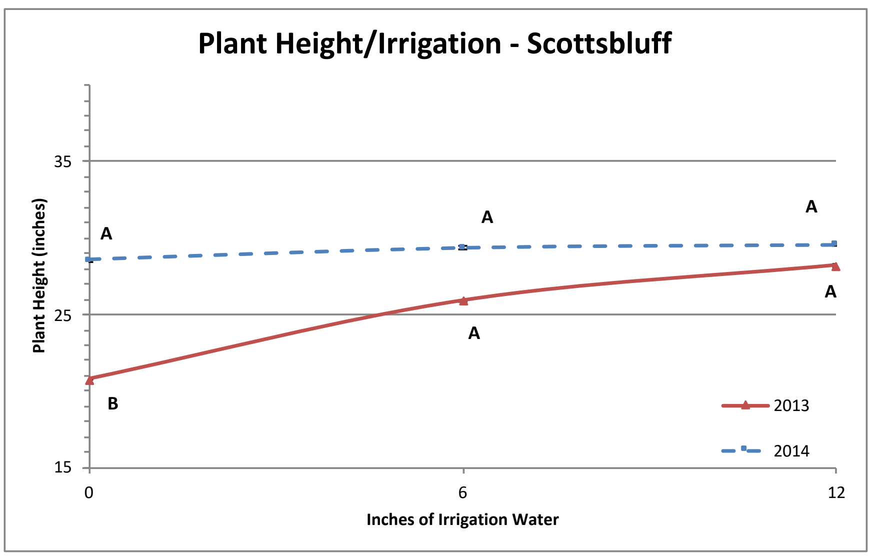
Chapter 3 Results and Discussion

PLANT HEIGHT

Plant height response to irrigation

Plant height was only recorded for Scottsbluff. In 2013 plant height was slightly responsive to irrigation treatments. The 0" treatment rate was significantly lower than the two irrigated treatments. Overall plant height was lower in 2013 than in 2014. In 2014 there were no differences between the treatments and the response curve was flat.

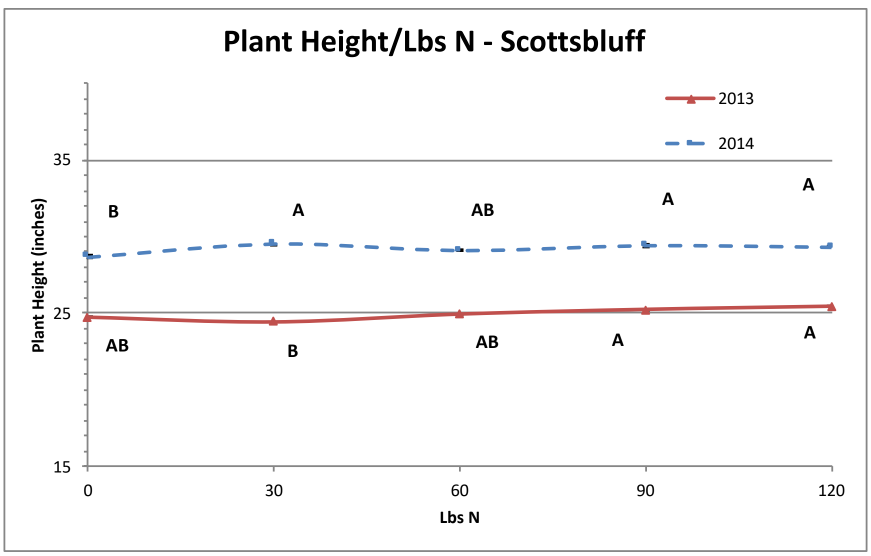
Figure 3-1: Plant height response to irrigation treatments. Plant height across all varieties and nitrogen treatments was averaged. Different letters denote statistically different groups at p=0.05.



Plant height response to nitrogen

Plant height was lower in 2013 than in 2014. Differences among treatments were subtle but there were significant differences in both years that correlated with increasing nitrogen treatment rates. There was a five-inch height difference between all treatments from 2013 to 2014.

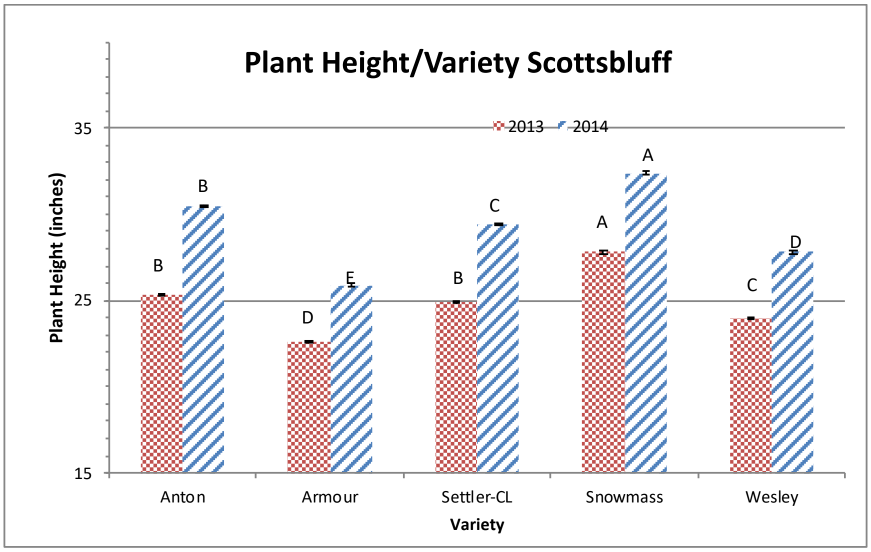
Figure 3-2: Plant height response to nitrogen. Plant height across all varieties and irrigation treatments averaged. Different letters denote statistically different groups at p=0.05.



Plant height response to variety

Plant height was significantly different between varieties in both years. In 2013 all varieties had lower plant heights than in 2014. In 2013 and 2014 Snowmass was the tallest variety and Armour was the shortest. Variety. In most cases there was about a five inch height difference between 2013 and 2014 data for each variety.

Figure 3-3: Plant height response to variety. Plant height across all nitrogen and irrigation treatments was averaged. Different letters denote statistically different groups at p=0.05.



YIELD

Yield response to irrigation:

There was no irrigation treatments at the Mead location because rainfall was higher than crop water needs. Therefore, the results presented here are based on two years of trial data at the Scottsbluff location only.

During 2013 there was a 20-bushel/acre yield difference between each irrigation treatment (Fig.3-1). Further, in 2013 a linear response from the application of irrigation treatments was observed and the yield difference was significantly different between each treatment. Whereas, in 2014 there were no significant differences between the 6” and 12” treatments (Fig.3-1). However, the yield response between 0” and 6” treatments was similar to that of 2013. This differences in yield is likely in response to the higher levels of rainfall during the growing season (see Table 2-1). As seen in Figure 3-1, there were significant differences between trial years. The 2013 growing season experienced significantly lower average rainfall. This lack of precipitation resulted in the linear response of yield to irrigation. The yield response between the 6" and 12" treatments was non-significant. This suggests that in 2014 season maximum yield potential was reached at the 6" irrigation level and the crop was not able to effectively utilize any additional water beyond the 6" treatment. In 2013, the similar maximum yield potential was reached at 12" irrigation level. In other words, 12" irrigation in 2013 and 6" irrigation in 201d resulted in similar yield.

Similar yield responses to irrigation in wheat were also reported by Zhang, et al. They concluded that when water was limited there would be a nearly linear response to irrigation until yield potential is reached and response tapers off (Zhang et al., 2004). Yield response to nitrogen per irrigation treatment was seen in figure 3-4. The experimental design has nitrogen treatments nested within irrigation treatments. Nitrogen treatments did not influence yield as much as irrigation treatments. And the response to nitrogen treatments becomes more visible as irrigation levels increase. Irrigation by nitrogen figure is grouped by irrigation treatment and then by nitrogen treatment. the first value on the x-axis is 0" of irrigation and 0lbs/N the sixth is 6" of irrigation and 0lbs/N. (Figure 3-5).

Figure 3-4: Yield response to irrigation. Yield across all nitrogen and varieties was averaged. Different letters denote statistically different groups at p=0.05.

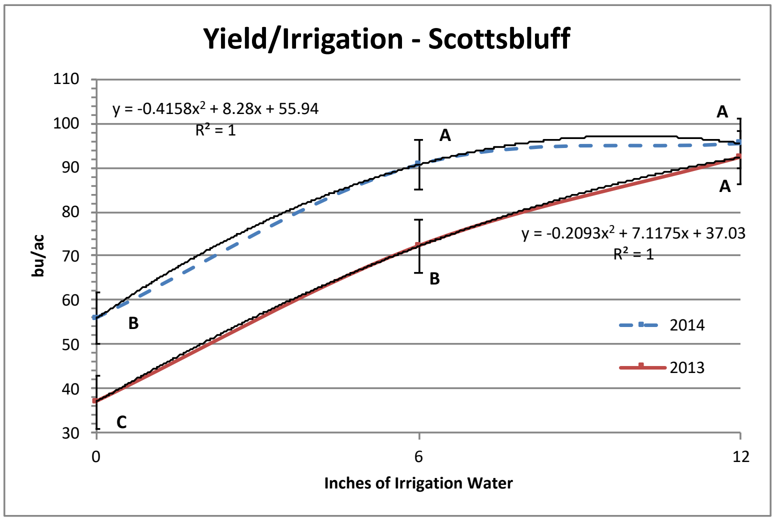
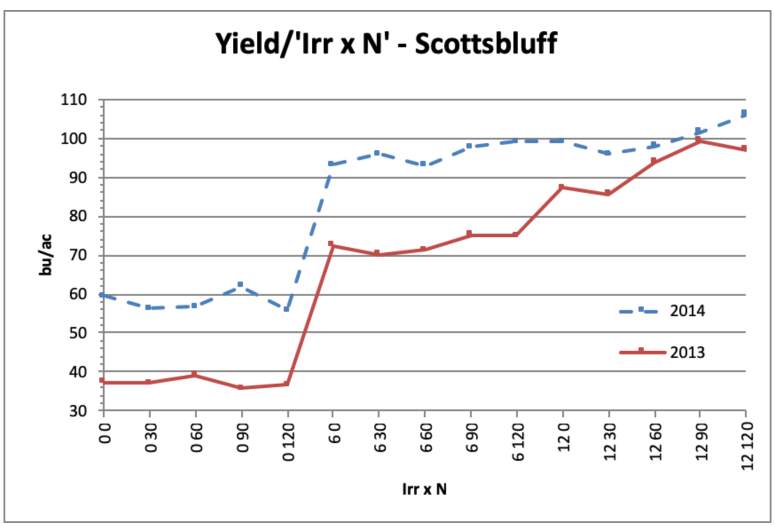


Figure 3-5: Yield response of each irrigation and nitrogen treatment. Yield of all varieties were averaged. Different letters denote statistically different groups at p=0.05.



Yield response to nitrogen:

In 2013 at Scottsbluff, yield response to different nitrogen treatments between 0 lbs/a to 90 lbs/a was positive and differences were significant (Fig.3-3). However, the yield difference between 90 lbs/a to 120 lbs/a was nonsignificant. In 2014 at Scottsbluff, there was some positive yield response to nitrogen treatments. However, yield differences between treatments were non-significant. There were some significant differences among yield response to nitrogen treatments; however, these differences were sporadic and inconsistent (Fig 3-3 and 3-4). While not displayed, there was also no relationship between nitrogen and yield when each cultivar was evaluated separately.

There were no significant differences in yield response to different nitrogen treatments at Mead in either 2013 or 2014. There were no meaningful trends. Overall the response was relatively flat. Yield response to nitrogen treatments was small at Scottsbluff and there was difference between years. The 2013 had a significant response and 2014 did not. At Mead, the yield was not responsive to nitrogen treatments and there were no trends. Averaging the two experiment years, Mead had lower yields than Scottsbluff.

It may be possible that we were not able to adequately deplete the residual soil nitrate or that our treatment methods were not adequate for applying this type of treatment. Soil tests were taken, and it was determined that residual soil nitrate levels (>20lbs/acre) were not high enough to justify an adjustment to our experiment. Sub-soil nitrate below 20 inches did increase dramatically, but it was thought at the time that there should be no reason for that to affect wheat because the rooting zone isn't that deep. Overall, the lack of response relative to fertilizer treatments is not immediately explainable by anything that was recorded or any nitrogen treatments applied.

Figure 3-6:Yield response to nitrogen treatments at Scottsbluff in 2013 and 2014. Yield averaged across all irrigation treatments and cultivars. Different letters denote statistically different groups at p=0.05.

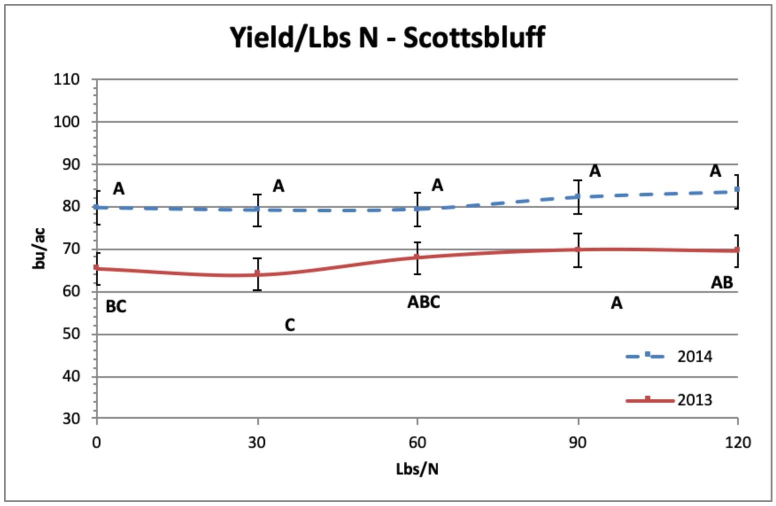
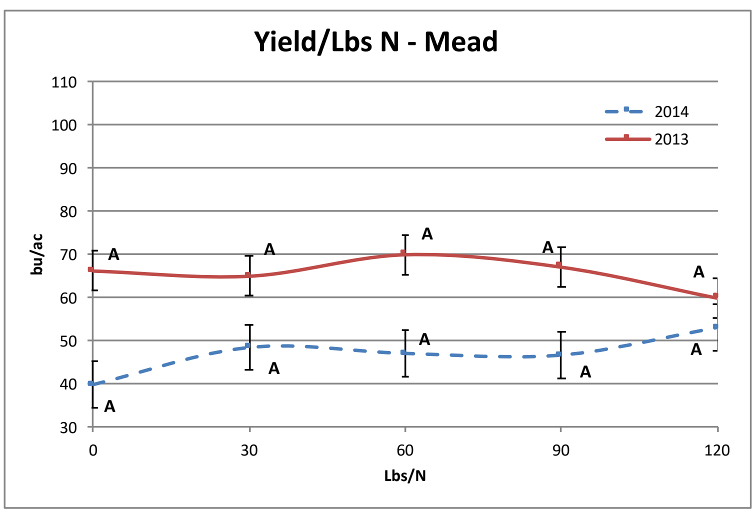


Figure 3-7: Yield response to nitrogen treatments in Mead for both 2013 and 2014. Yield averaged across all irrigation treatments and cultivars. No significant differences in either year. Different letters denote statistically different groups at p=0.05.



Yield response between varieties

At Scottsbluff in 2013 (Fig.3-5), yields of Settler-CL and Snowmass were highest but were not statistically different. The yields of Anton, Armour, and Wesley were lowest yielding varieties but statistically similar to each other. At Scottsbluff in 2014 (Fig.3-5), Settler-CL and Anton were the highest yielding variety. Armour and Anton were no statistically different. Armour, Snowmass, and Wesley were lowest yielding varieties and not statistically different from one another. Yields were higher in 2014 and there was more separation between varieties. Settler-CL is a consistently high yielding variety in both 2013 and 2014 (Figure 3-8).

At Mead in 2013 (Fig.3-9) there were no significant differences between cultivars. However, Settler-CL was the highest yielding cultivar. At Mead in 2014 (Fig.3-9) there were still no significant differences between cultivars with Settler-CL still being the highest yielding cultivar. Yields in 2014 were lower, but there were similar levels of variability in both years. Settler-CL was the highest yielding variety at both the location except in 2013 at Scottsbluff where Settler-CL and Snowmass were not discernibly different. Scottsbluff produced higher yield than Mead during the trial period. Variety differences were clearer as precipitation increased.

Settler-CL is a modern HRW cultivar developed in Nebraska and is intended to be produced in the region. That might be the reason why its yield reduction due to low rainfall in 2013 was not as severe as other three cultivars (Anton, Armour, and Wesley). On the other hand, Snowmass, a non-Nebraska cultivar, was uncharacteristically high yielding relative to other cultivars in the experiment. This may be the fact that it was bred for dryland production on the plains of Colorado, this climate is very similar to western Nebraska. When water was limited in 2013 at Scottsbluff, yield reduction in Snowmass was not as bad as other thee cultivars (Anton, Armour, and Wesley).

Figure 3-8: Yield differences between varieties at Scottsbluff for both 2013 and 2014. Yields of all irrigation and nitrogen treatments averaged. Different letters denote statistically different groups at p=0.05.

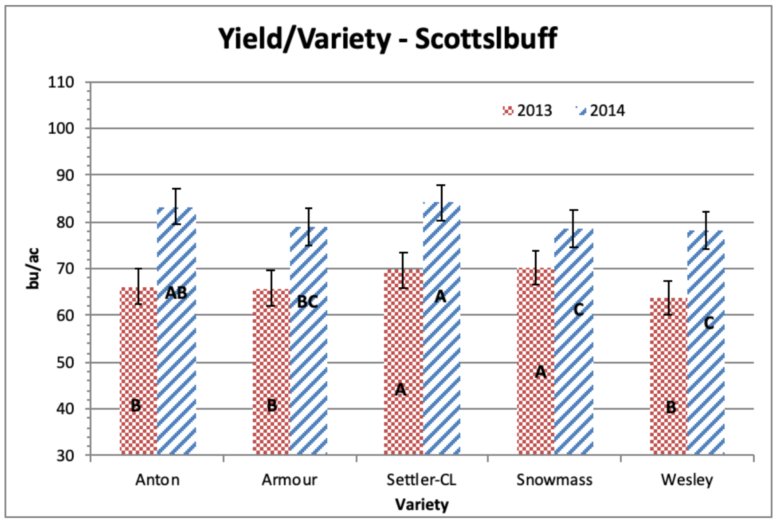
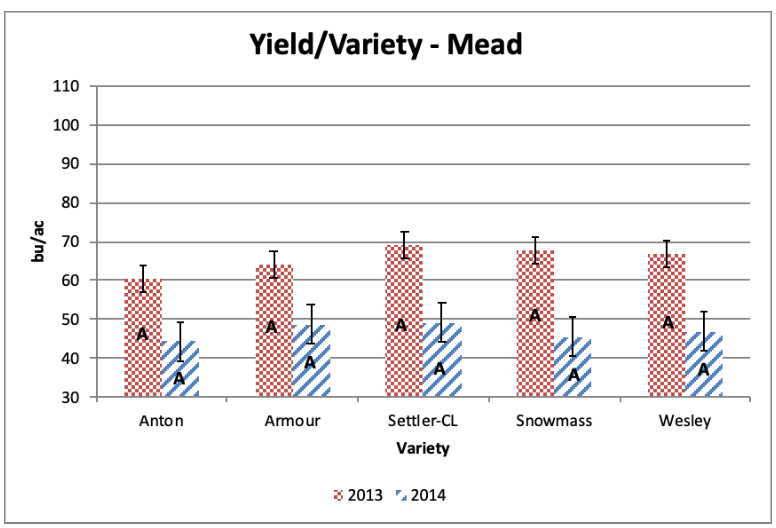


Figure 3-9: Yield differences between varieties at Mead for both 2013 and 2014. Yields of all nitrogen treatments averaged. Different letters denote statistically different groups at p=0.05.



TEST WEIGHT

Test weight response to different irrigation rates

There were no irrigation treatments at the Mead location because rainfall was higher than crop water needs. Therefore, the results presented here are based on two years of trial data at the Scottsbluff location only. At Scottsbluff in 2013, when water was limiting, TWT was significantly higher at the 6" than the 0" treatment, but the 12" treatment was not different from the 6" treatment. In 2014, when water was more available, TWT was higher than in 2013 but did not respond to any of the irrigation treatments (Figure 3-10). Irrigation by nitrogen interaction did not produce any significant trends beyond what was already seen in the irrigation treatments (Figure 3-11). Standard TWT in wheat is 56lbs/bushel, and during both trial years at Scottsbluff, the TWT was above this level. Even the worst TWT response at Scottsbluff was higher than the standard TWT value. Based on basic agronomic understanding, the test weight should increase with irrigation. Possible reasons for this unexpected outcome could be related to ample soil moisture and ideal growing conditions. Irrigation by nitrogen figure is grouped by irrigation treatment and then by nitrogen treatment. the first value on the x-axis is 0" of irrigation and 0lbs/N the sixth is 6" of irrigation and 0lbs/N (Figure 3-11)

Figure 3-10: TWT response to irrigation. TWT averaged across all varieties and nitrogen treatments. Different letters denote statistically different groups at p=0.05.

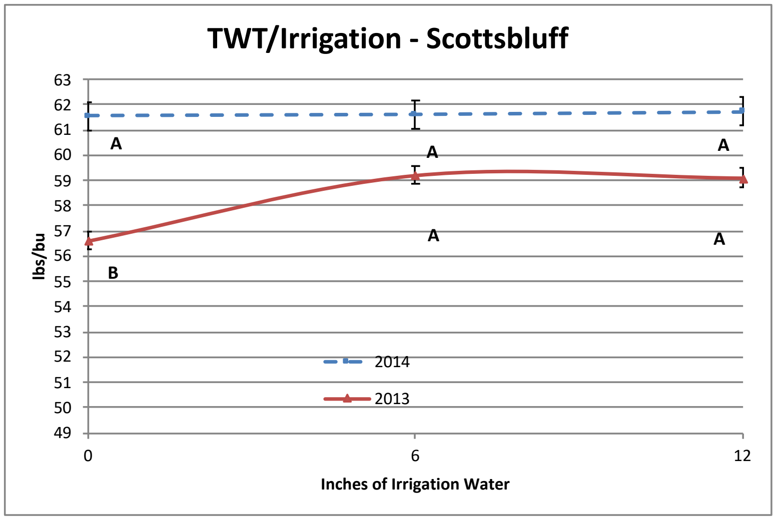
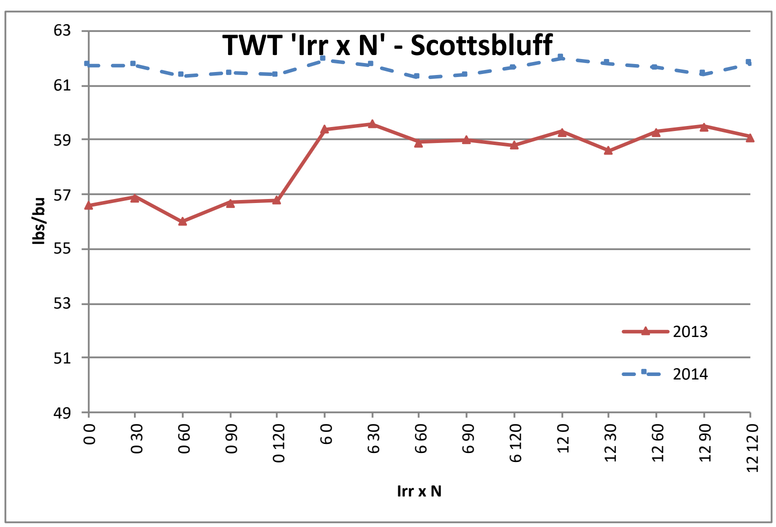


Figure 3-11: TWT response to each irrigation and nitrogen treatment. TWT of all varieties were averaged. Different letters denote statistically different groups at p=0.05.



Test weight response to nitrogen rate

Test weight was lower in 2013 than in 2014, and in 2013 TWT averaged 58lbs/bu. The only time that significant differences were seen for TWT was at Scottsbluff during 2014. Differences were very subtle, but they were significant. It was anticipated that TWT would increase with nitrogen rate, but this response was not seen. The 0# treatment was not significantly different than the 30 and 120# treatment. The 60 and 90# treatments were significantly lower than the 0# rate (Fig 3-9). There were no significant differences in either year at Mead. Also, the standard error for the data in 2014 was very high. However, in 2014 there were also no trends in the data (Fig 3-10). On average, over the two trail years, Scottsbluff had higher TWT levels. Based on available agronomic knowledge, there was no expectation of any effect on TWT from nitrogen fertilization. TWT was higher during 2014 in Scottsbluff likely due to the more favorable growing conditions, more timely rains. In both Mead and Scottsbluff, TWT response was similar and increased as growing conditions improved between years.

Figure 3-12: TWT response to nitrogen treatments at Scottsbluff for both 2013 and 2014. TWT of irrigation treatments and variety were averaged. Different letters denote statistically different groups at p=0.05.

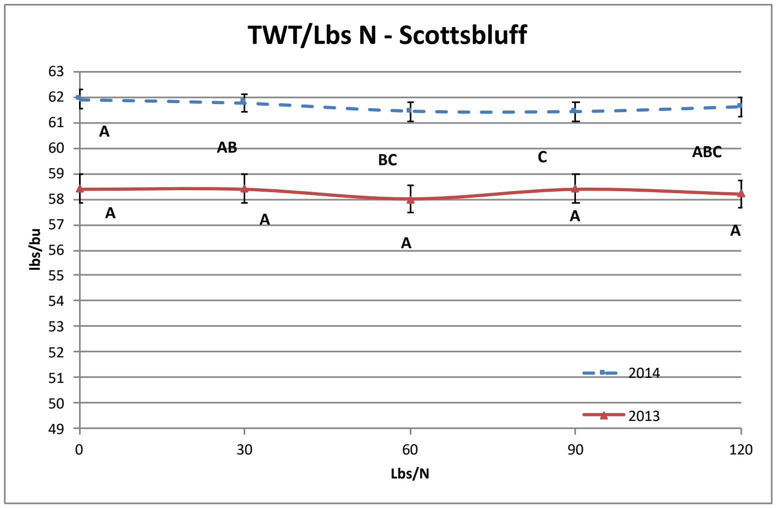
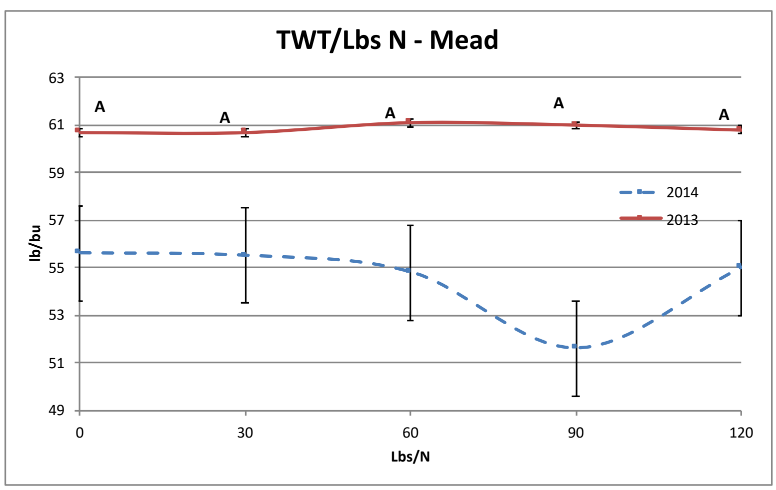


Figure 3-13: TWT response to nitrogen treatments at Mead for both 2013 and 2014. Yields of all varieties were averaged. Different letters denote statistically different groups at p=0.05.



Test weight comparison between varieties

In 2013 at Scottsbluff, TWT was lower for all varieties than in 2014. Anton and Snowmass were not significantly different but had significantly higher TWT levels than Armour, Settler-CL, and Wesley. Settler-CL had significantly higher levels than Armour and Wesley, and Armour and Wesley were not different from each other. In 2014 at Scottsbluff, Anton had the highest TWT levels but was not significantly different from Wesely. Wesley was higher than Snowmass but they were not significantly different from each other. Armour and Settler-CL were not different from each other but were both significantly lower than Snowmass. in 2013 at Mead, TWT values were higher for all varieties than in 2014. Snowmass had the highest TWT levels but was not statistically different from Arton, Settler-CL. These three varieties were significantly higher than Wesley, which was significantly higher than Armour. in 2014 at Mead, there were no significant differences between varieties. Settler-CL had highest TWT levels. However, the standard error in 2014 was high.

It is difficult to see which variety produces the highest TWT levels, but it is more clear that Armour has consistently lower TWT levels than other varieties. The inconclusive results for TWT is an excellent example of why state variety trials have many locations. The data set must be large enough to overcome the effect of the environment and various other sources of error. This experiment was likely too small to provide enough data for a trait like TWT.

Figure 3-14: TWT differences between varieties at Scottsbluff for both 2013 and 2014. TWT of all irrigation and nitrogen treatments were averaged. Different letters denote statistically different groups at p=0.05.

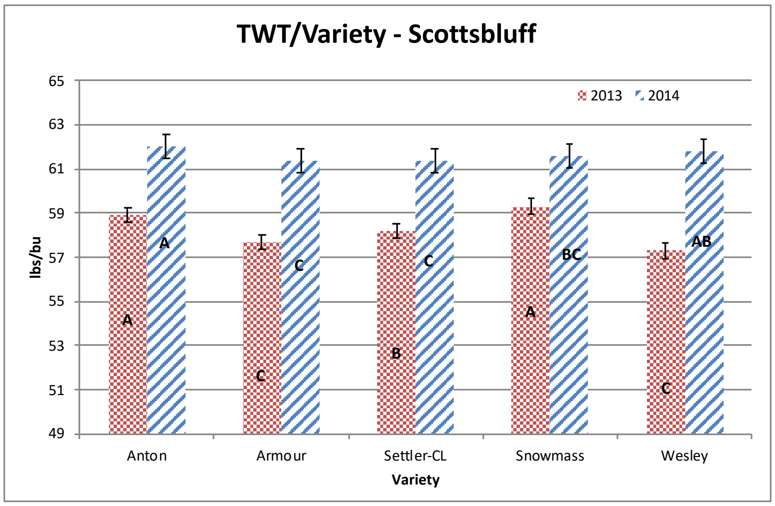
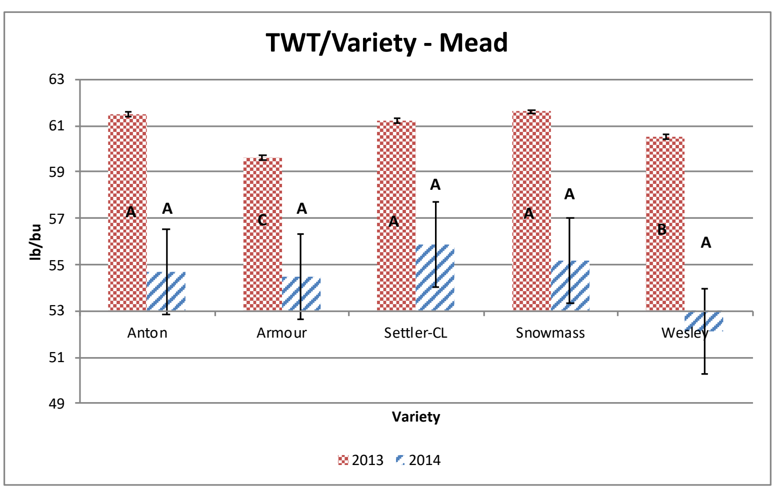


Figure 3-15: TWT differences between varieties at Mead for both 2013 and 2014. TWT of all nitrogen treatments averaged. Different letters denote statistically different groups at p=0.05.



Protein

Protein response to different irrigation rates

There were no irrigation treatments at Mead because rainfall was higher than crop water needs. At Scottsbluff protein levels were higher in 2013 than in 2014. Also, there were no significant differences between irrigation treatments in either 2013 or 2014. Agronomic convention says that protein is inversely related to irrigation levels and that is seen here, where 2013 was dryer and yield was lower while protein levels were higher. A second trend that was observed in both trial years was that the 6" treatment was consistently lower than the 12" treatment, which was consistently lower than the 0" treatment (Fig. 3-13). Data was double checked for errors and none were found. Irrigation by nitrogen figure is grouped by irrigation treatment and then by nitrogen treatment. the first value on the x-axis is 0" of irrigation and 0lbs/N the sixth is 6" of irrigation and 0lbs/N (Figure 3-16).

Figure 3-16: Protein response to irrigation at Scottsbluff for both 2013 and 2014. Protein response of all nitrogen treatments and varieties were averaged. Different letters denote statistically different groups at p=0.05.

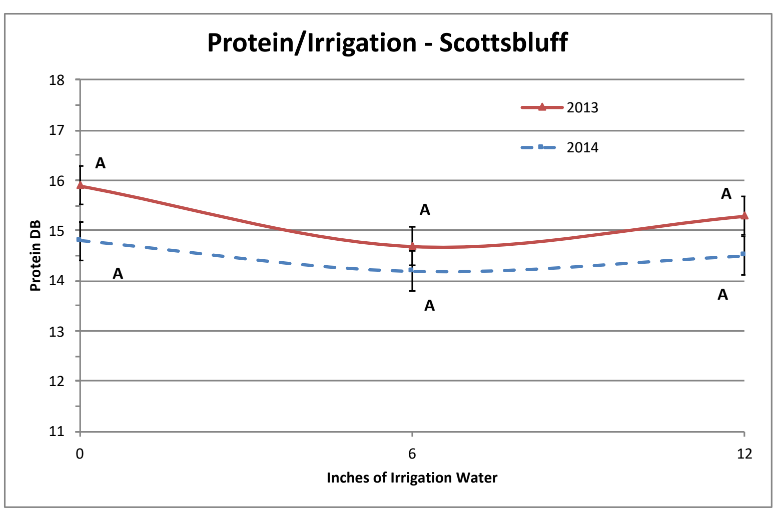
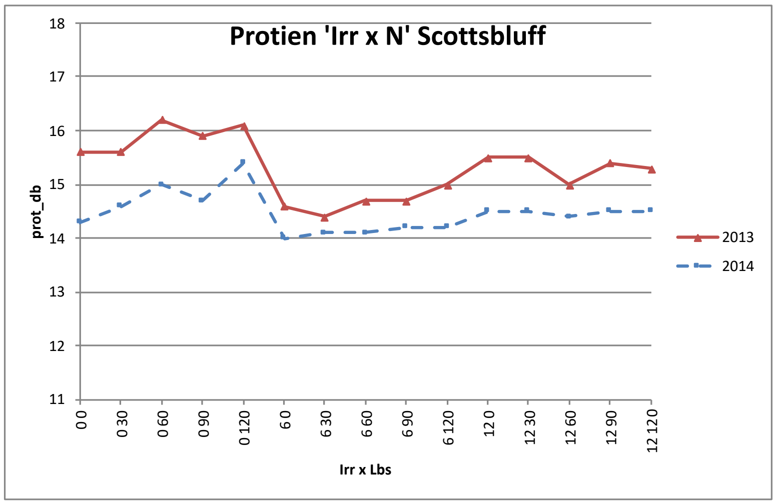


Figure 3-17: Protein response of each irrigation and nitrogen treatment. Protein levels of all varieties were averaged. Different letters denote statistically different groups at p=0.05.



Protein response to different nitrogen rates

At Scottsbluff in 2013, the protein levels were higher than in 2014. However, there were no significant differences between treatments. There was a trend that followed increasing fertilizer rates. At Scottsbluff in 2014, there were significant differences between the treatments. the 0# treatment was significantly lower than the 120# treatment. The 30, 60, and 90# treatments were not different from any other treatments (Fig 3-15). At Mead in 2013 the protein levels were lower than in 2014. There were no significant differences between treatments and errors were higher in this year. At Mead in 2014 there were significant differences between the treatments and positive trends. The 60,90,120# treatments were not different from one another but were all significantly higher than the 0# treatment. The 30# treatment was not different from any other treatment (Fig 3-16). The highest single year protein levels were seed at Mead during 2014. However, Scottsbluff had the highest levels when averaging the two years of data. There was no apparent relationship that linked positive trends to nitrogen treatments. Response to nitrogen was very subtle compared to other treatment effects. The 60# treatment had the most significant effect on improving protein while using the least amount of fertilizer.

Figure 3-18: Protein response to nitrogen treatments at Scottsbluff for both 2013 and 2014. Protein response to irrigation treatments and variety were averaged. Different letters denote statistically different groups at p=0.05.

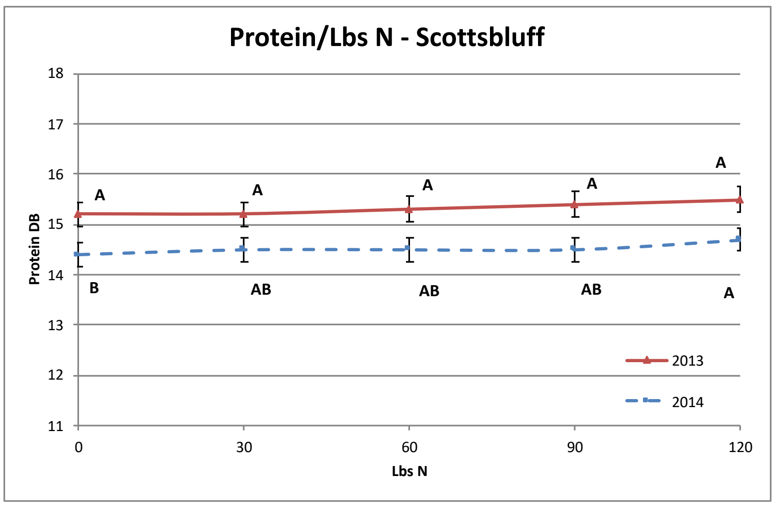
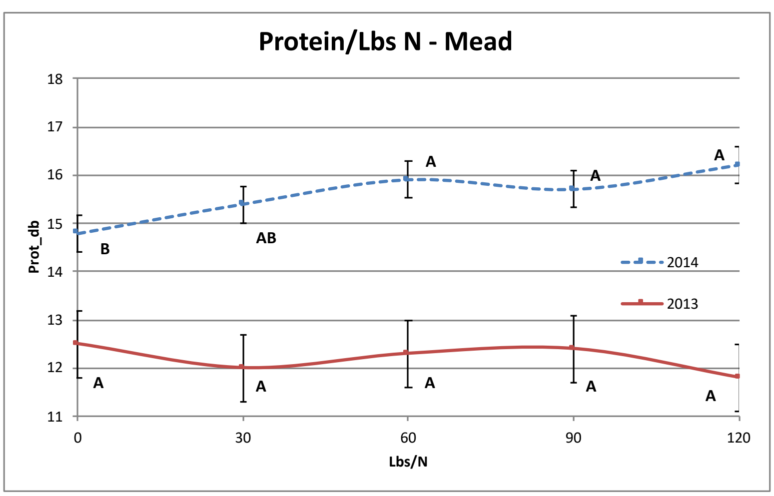


Figure 3-19: Protein response to nitrogen treatments at Mead for both 2013 and 2014. Protein levels averaged across all variety. Different letters denote statistically different groups at p=0.05.



Protein response between different varieties

At Scottsbluff in 2013, protein levels were higher than in 2014. Wesley had significantly higher levels than all other varieties. At Scottsbluff in 2014, Wesley still had significantly higher protein levels than all other varieties. Relationships between varieties did not change from 2013 to 2014. Anton and Armour didn't perform differently and were significantly lower in protein levels than Wesley. Settler-CL was lower than Anton and Armour. Snowmass was lower than Settler-CL in 2013 (Fig 3-17). At Mead in 2013, protein levels were lower than in 2014. Anton had the highest protein levels. However, Anton was not significantly different from Armour, Settler-CL, or Wesely. Snowmass was significantly lower than everything else in 2013. At Mead in 2014, Anton had the highest protein levels and was not different from Armour. Anton and Armour were significantly higher than Wesley, which was significantly higher than Settler-CL and Snowmass. Just as in Scottsbluff, relationships between varieties did not change from 2013 to 2014. Anton and Armour performed similarly, although in Mead they were among the highest at Mead where Wesley was highest at Scottsbluff (Fig 3-18).

Scottsbluff produced significantly higher protein levels than Mead. Dryer growing conditions lead to higher protein levels. Snowmass had consistently low protein levels at both locations and in both trial years. Wesely had the highest protein levels at Scottsbluff, whereas Anton had the highest levels at Mead. Anton and Armour were always similar in their protein levels. In terms of achieving the highest protein content, the growing location has a dramatic effect on the performance of any variety. In the west, Wesley was the apparent leader in protein levels. In the east, the difference in protein levels was not nearly as pronounced. It is generally assumed that white wheat (Anton and Snowmass) should have higher protein levels. This was not seen in the two trial years of this experiment.

Figure 3-20: Protein differences between varieties at Scottsbluff for both 2013 and 2014. Protein levels for all irrigation and nitrogen treatments were averaged. Different letters denote statistically different groups at p=0.05.

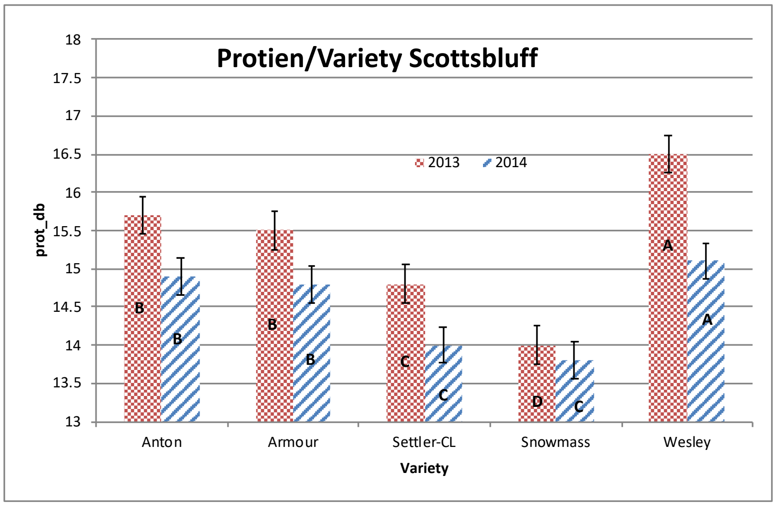
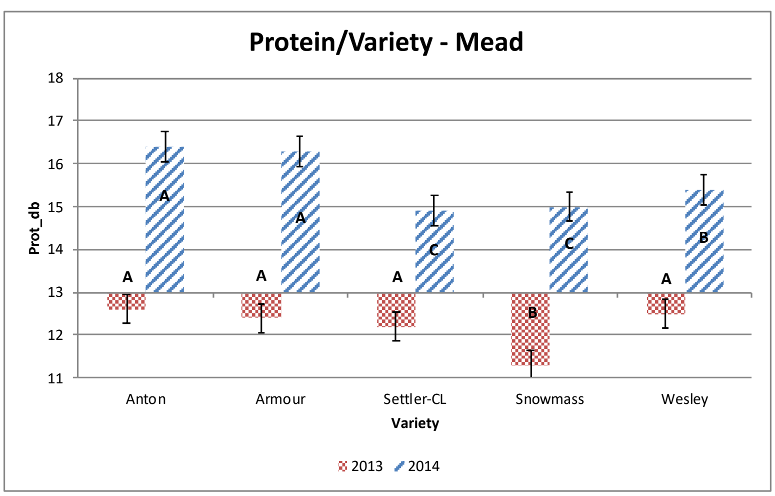


Figure 3-21: Protein differences between varieties at Mead for both 2013 and 2014. Protein levels for all nitrogen treatments were averaged. Different letters denote statistically different groups at p=0.05.



GLUTEN

Gluten response to different irrigation rates

There were no irrigation treatments at Mead because rainfall was higher than crop water needs. At Scottsbluff in 2013, gluten levels were higher than in 2014. There were no significant differences between treatments in either year. (Fig 3-19). Gluten appears to be even less responsive to irrigation than total protein content. However, the trend of the response to irrigation is similar to the protein response. Protein levels in wheat are a sum of all proteins in the grain; this is more than just gluten. Protein ratios are predicated on the genetics of the crop, while the overall protein levels can increase the ratios should remain relatively constant. This experiment didn't address the composition or ratios of various proteins in the flour. Irrigation by nitrogen figure is grouped by irrigation treatment and then by nitrogen treatment. the first value on the x-axis is 0" of irrigation and 0lbs/N the sixth is 6" of irrigation and 0lbs/N (Figure 3-23).

Figure 3-22: Gluten response to irrigation at Scottsbluff for both 2013 and 2014. Gluten levels across all nitrogen treatments and varieties were averaged. Different letters denote statistically different groups at p=0.05.

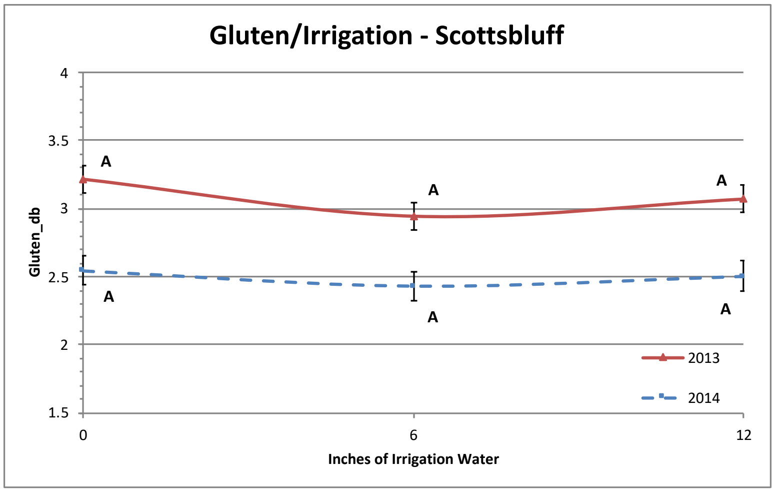
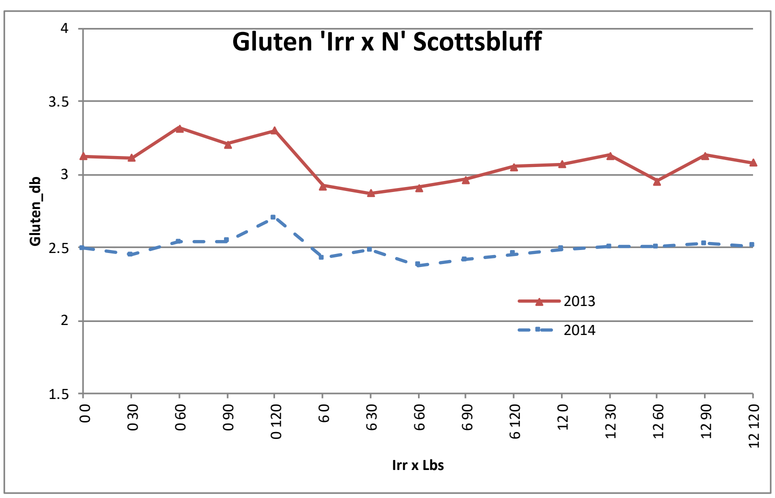


Figure 3-23: Gluten response to each irrigation and nitrogen treatment at Scottsbluff for both 2013 and 2014. Gluten levels of all varieties were averaged. Different letters denote statistically different groups at p=0.05.



Gluten response to different nitrogen rates

Gluten response at Scottsbluff had a very narrow range of response, but in both years there was a significant response trend that aligned with increasing nitrogen rates (Fig 3-21). At Mead, the 2013 data had high error values and there were no significant differences. However, in 2014 there was a positive trend that aligned with increasing fertilizer rates with significant differences between treatments. This response was similar to what was seen in Scottsbluff, (Figure 3-25). Overall, Scottsbluff had higher gluten levels than Mead.

Figure 3-24: Gluten response to nitrogen treatments at Scottsbluff for both 2013 and 2014. Gluten levels across all irrigation treatments and varieties were averaged.

Figure 3-25: Gluten response to nitrogen treatments at Mead for both 2013 and 2014. Gluten levels of all varieties were averaged.

Gluten response between different varieties

At Scottsbluff in 2019, gluten was higher than in 2014. Anton had the highest gluten levels and was not significantly different from Wesley. At Scottsbluff in 2014, Anton had significantly higher gluten levels than Wesley. In both years there was a large amount of variation between each variety (Fig 3-23). At Mead in 2013, gluten levels were lower than in 2014. Anton had the highest gluten levels and was significantly different from the next highest variety. As in Scottsbluff, there is a large amount of significant variation between varieties. At Mead in 2014, Anton had the highest gluten levels and was significantly higher than the next highest variety. There was more differentiation between varieties in 2014 as opposed to 2013 (Fig 3-24). Gluten levels were substantially higher at Scottsbluff than in Mead. Anton had consistently high gluten levels compared to other varieties at both locations and in both years. Whereas Settler-CL often had lower gluten levels. As with protein, gluten levels were higher in the dryer years.

Figure 3-26: Gluten differences between varieties at Scottsbluff for both 2013 and 2014. Gluten levels of all irrigation and nitrogen treatments were averaged. Different letters denote statistically different groups at p=0.05.

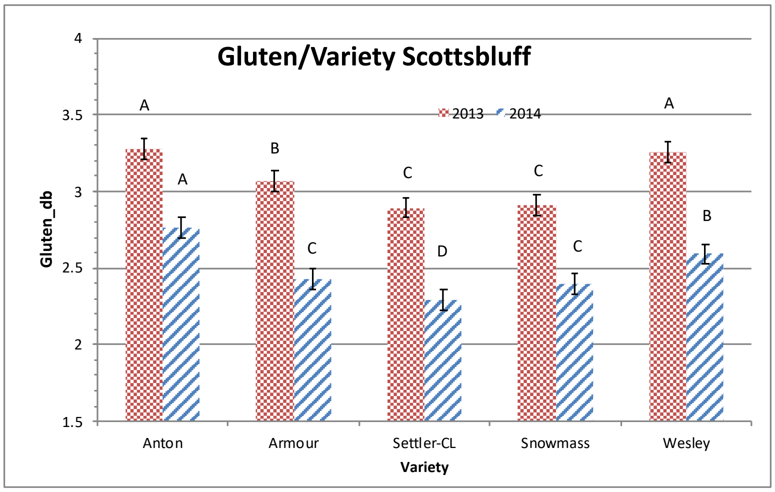
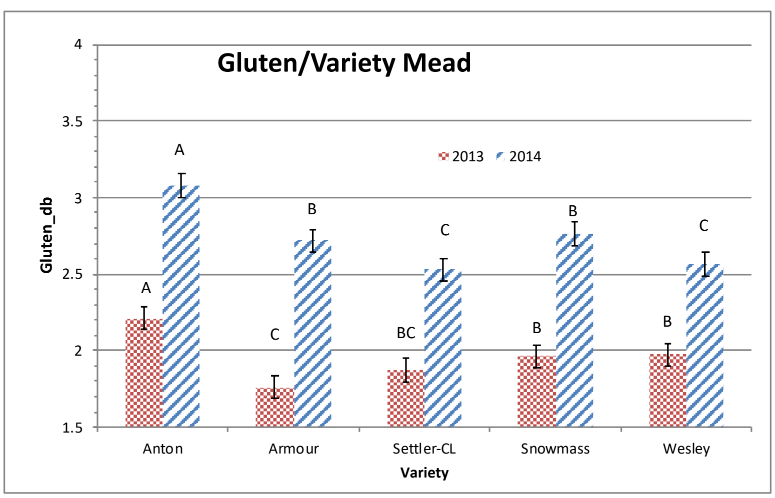


Figure 3-27: Gluten differences between varieties at Mead for both 2013 and 2014. Gluten levels of all nitrogen treatments were averaged. Different letters denote statistically different groups at p=0.05.



Conclusion

The objective of this project was to evaluate the effect of nitrogen, irrigation, and cultivars on wheat yield and quality. Data gathered from this experiment showed that the most critical factor for improving wheat yield is irrigation and the second was cultivar selection. Similarly, to enhance the quality of the grain, the best action is to choose varieties with ideal quality characteristics. Interactions of yield and grain quality attributes (test weight, grain protein, and gluten content) with agronomic factors (irrigation, nitrogen, and cultivar) were very complex.

While the data was of high enough quality, there was not the quantity and breadth necessary to meet the project goals. In literature, the effect of single factors on wheat yield or quality was well documented and well understood. However, the interactions of agronomic factors are not well understood. Especially when considering the synergistic effect that some of those factors may have with each other. Multiple authors in this field reached similar conclusions in their publications that multi-factor experiments have complex interactions. There has been broad consensus among those authors that research on these complex interactions must be continued and more data must be collected before comprehensive conclusions can be reached. There will likely be significant leaps in research as technology helps to reduce cost and complexity of data collection.

This experiment was part of an MS-level thesis and as such, has been an incredible learning experience. There were deficiencies in the planning as well as in the execution of the experiment. However, we are confident in the integrity of the data collected. Nothing about it has been easy, and the skills and information gained have set the stage for a lifetime of growth and improvement.

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