IMPACT OF PLANTING DATE, CULTIVAR, PHOSPHORUS, POTASSIUM, AND FUNGICIDE SEED TREATMENTS ON WINTER WHEAT SURVIVAL AND YIELD

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ABSTRACT

Field experiments and greenhouse studies were conducted to evaluate the effects of phosphorus (P), potassium (K), and fungicides on winter survival, and yield of winter-wheat in North Dakota. The study was conducted as a RCBD with a split-plot of planting date, and a factorial combination of cultivars and seed treatments.

Of the factors included, cultivar was the most contributing factor for fall emergence, spring stand count, and yield. Planting date was confounded by insufficient autumn soil moisture, delaying emergence approximately 50% at Minot, Williston, and Hettinger. Phosphorus, K, and fungicide treatment effects were not consistent across locations, but fungicide, priming and selected P and K treatments increased stand count or yield at Hettinger, Williston, and Lisbon.

These data indicate the use of winter-hardy cultivars, fungicides, and favorable conditions in the fall for emergence are critical factors for growing winter wheat in North Dakota.

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INTRODUCTION

North Dakota (ND) agriculture is diverse and productive. The state produces more than twenty different agricultural crop commodities and is the highest producer in the nation for nine of those commodities (NASS, 2011a). Of the three classes of wheat (*Triticum aestivum* L.) grown in North Dakota, hard red winter wheat (HRWW) only comprises about 1% of the nation's total winter wheat production. The area of HRWW planted in North Dakota has fluctuated considerably during the last decade, ranging from 32,000 to 255,000 ha (NASS, 2011b).

Hard red winter wheat provides many benefits over hard red spring wheat (HRSW), such as higher yield potential, lower input costs, reduced competition for labor at planting and harvesting with other crops, reduced wind and water erosion of top soil during the fall, winter, and spring months, and better cover for wildlife during key nesting periods (Wiersma and Ransom, 2005).

Despite the benefits, HRWW seedlings can be adversely affected by the long cold North Dakota winters. Management practices that reduce seedling winter injury include: choosing a cultivar with good winter hardiness, planting near the recommended planting date, and planting into standing crop residue (Peel et al., 1997). Even when these recommendations are followed, there is still a chance of winter injury in some years.

OBJECTIVES

The objectives of this research were to determine the effect of planting date, cultivar selection, and P, K and fungicide seed treatments on fall emergence, winter survival, and yield of winter wheat in North Dakota.

LITERATURE REVIEW

Injury of winter cereals caused by sub-freezing temperatures less than 0°C is a common occurrence during the winter in northern regions of the United States, especially in North Dakota. Winter hardiness is a major criterion in selecting HRWW cultivars to be planted in this region. The most winter hardy varieties should be planted in the most northern regions, especially if planting into little or no residue (Wiersma and Ransom, 2005). Winter hardiness is a genetic trait (Pan et al., 1994). However, management practices (i.e. planting date and previous crop residue) can influence winter survival of all cultivars (Peel et al., 1997).

Winter Survival

Hard red winter wheat requires a period of cold temperatures before it will undergo a transition of the apical meristem from vegetative to reproductive growth, known as vernalization (Michaels and Amasino, 2000). Vernalization of HRWW is a slow physiological process requiring prolonged cool temperatures of approximately 3°C (Trione and Metzger, 1970). To achieve vernalization, winter annual plants must be sown in the fall if they are to flower and produce seed the following summer.

Minimum vernalization temperatures for HRWW range from 1-7°C, with some cultivars requiring temperatures as low as -6°C (Michaels and Amasino, 2000). Average length of time required for the seedlings to complete vernalization is cultivar dependent, but typically ranges from 2-10 wks.

For HRWW to survive winter months, the crown of the plant needs to go through a cold acclimation process known as “hardening”. In HRWW the process of cold acclimation is under the control of a genetic system induced by low temperature (Fowler and Gusta, 1977). Both vernalization and cold acclimation require plant growth when morning and afternoon soil

temperatures are below 7°C and 10°C (Fowler, 2013b). Energy required for the process of cold acclimation is supplied either from seed reserves or from photosynthesis (Gusta et al., 1977). The process of hardening requires 3-6 wks depending on cultivar. Wiersma and Ransom (2005) suggest that well developed HRWW seedlings that have properly hardened crowns are capable of surviving soil temperatures as low as -15°C, but the specific temperature varies by cultivar. Survival of the crown, however, does not ensure that the plant will live. Chen et al. (1983) found plant roots to be less winter hardy than the crown under a controlled environment, with roots killed at -8°C. When favorable conditions returned the authors found that new roots were produced. However, if the plant does not have sufficient energy to recover from the loss of roots the plant will likely die before new roots can develop.

Soil has a high capacity to buffer changes in temperature, but extreme winter conditions require additional insulation from snow to prevent winter injury to plants in most years (Decker et al., 2003). The primary way to increase the depth of snow cover is by trapping snow that falls on the area, or is blown in from adjacent fields using standing residue from the previous crop. Depth of snow cover has a direct effect on insulating the soil from sub-freezing temperatures (Bauer and Black, 1990). Standing residue collects and holds snow through the winter months, which insulates and protects the crown of the wheat plant from being potentially damaged by sub-freezing air temperatures (Aase and Siddoway, 1979). Bauer and Black (1990) found significantly greater post-winter plant populations of HRWW with an increase in stubble height of the previous crop. The lowest residue height (0 cm) resulted in consistently lower plant populations, with as low as 0% winter survival for some HRWW cultivars tested. The tallest residues (20 and 36 cm) consistently resulted in the highest post-winter plant populations.

Soybean (*Glycine max* L.), field pea (*Pisum sativum* L.), and other annual legume crops, do not always provide enough standing plant post-harvest residue to effectively retain the 7.6 cm to 15 cm depth of snow required for insulation, which is recommended by Wiersma and Ransom (2005). Without this residue, winter winds can blow the snow off of the field, increasing the chance that the crown will be exposed to lethal freezing temperatures.

Phosphorus

Phosphorus is an essential nutrient for plant growth and is crucial in energy storage and transfer in plants (Havlin et al., 2005). Energy captured during photosynthesis is converted to phosphate compounds that are used to produce energy storage compounds for later release to sustain growth and reproductive processes. In cereal crops, P increases the rate of root growth and the extent of tillering (Fageria, 2009). Placing P with or near the seed in wheat makes the P more readily available to the developing roots and often result in a healthier plant (Sander and Eghball, 1999). Gusta and Fowler (1979) reported that P encouraged carbohydrate accumulation in the winter wheat crown and suggested that P may increase spring recovery from freezing injury, rather than promoting increased cold hardiness. In addition, it was also speculated by Willemot (1975) that adequate levels of P were required for regeneration in tissues damaged by freezing and for promotion of spring regrowth. A study conducted by Grant et al. (1984) showed a 70.6% survival increase with the addition of 10.9 kg P ha^{-1} when no nitrogen (N) fertilizer was added. However, percent survival decreased with increasing amounts of N, regardless of P level.

Knapp and Knapp (1978) reported many benefits to P fertilizer banded between the rows in the fall. The addition of P produced a significantly greater number of spikelets, along with a significant yield increase. Greater winter survival was observed in wheat receiving P compared to treatments receiving none. Additionally, a yield increase of up to 60% has been reported in

winter wheat with fall P fertilization compared with no P applied in the fall (Sweeney et al., 2000), while others have reported a 20% yield increase (Sander and Eghball, 1999).

Phosphorus efficiency and grain yield can be influenced by soil pH. Fiedler et al. (1989) recorded increased grain yields in seed-placed P over broadcast P at low soil P levels. However, with the increase of soil pH from 6.0 to 8.0 and as the soil test P increased, the advantage of seed placed P became less pronounced. McConnell and colleagues (1986) reported increased grain yields at all locations with P additions. Yield increases ranged from 9% to 103% and 5% to 99% in the first and second year, respectively. However, most grain yield increases were the result of meeting the general need for P and not winter survival.

Potassium

Potassium is also an important plant nutrient and ranks second in plant uptake only to N (Havlin et al., 2005). Potassium has many vital roles in plants including root growth, water and nutrient uptake, maintenance of turgor, and regulation of CO_2 absorption through leaf stomata (Fageria, 2009). Potassium is relatively immobile in the soil, but is more mobile than P. For this reason, both P and K must be placed close to the seed in order for them to be absorbed by the roots of seedlings when root mass is small. Potassium is essential in many crop quality characteristics due to its involvement in the synthesis and transport of photosynthates to plant reproductive and storage organs, and subsequent conversion into carbohydrates, proteins, oils, and other products (Havlin et al., 2005).

Applications of K and P are associated with increased cold hardiness of alfalfa (*Medicago sativa* L.) and strawberries (*Fragaria ananassa* L.) (Jung and Smith, 1959; Ragan and Nylund, 1977; and Zurawicz and Stushnoff, 1977). Jung and Smith (1959) concluded that the best plant survival and top growth production occurred when alfalfa plants were fertilized

with 224 kg ha^{-1} of K and 44-89 kg ha^{-1} of P. The percent of plant survival decreased when either element was increased or decreased and when the K and P ratio declined from five to two.

Visual K deficiency symptoms appear first on the older low leaves and progress towards the younger top leaves as deficiency severity increases (Havlin et al., 2005). Potassium deficiency can also occur in young leaves of high-yielding, fast maturing crops such as cotton (*Gossypium hirsutum* L.) and wheat. Potassium deficiencies can lead to: slow growth, poor root development, weak stems in wheat, and increased susceptibility to bacterial, fungal diseases and insect and mite infestation.

Tennant (1976) found an increase in the total number of roots formed with increasing amounts of K up to the recommended application rate. Recommended K rates are crop and location dependent since soil parent material, CEC, soil moisture, soil temperature and soil pH affect K availability. Applications of K exceeding 156 kg ha^{-1} suppressed root development. When K was deficient, root formation was also affected. Tennant found that after 10 d of K deficiency, the deficient root system had 3-5 seminal roots compared with 5-6 in non-deficient treatments.

Seed Coating

Coating seed with fungicides and insecticides has become a common practice among farmers globally as an inexpensive way to protect sown seed from insects and soil born fungi (Taylor and Harman, 1990). Ahmed and colleagues (2001) found wheat seedling emergence was more rapid when seeds were treated with fungicide/insecticide mixtures than when not treated. Improved emergence and higher plant populations using a fungicide and insecticide combination seed treatments as compared to the untreated seed was attributed to the prevention of wheat seedling diseases caused by soil borne fungi. Smiley and Patterson (1995) reported a 5% (185 kg

ha^{-1}) increase in grain yield for winter wheat grown in eastern Oregon in response to seed treatments intended mainly for smut (*Tilletia tritici, T. laevis*) control.

The incorporation of nutrients in seed coatings may provide an opportunity to supply each seed sown with an appropriate supply of nutrients early, and gives the seedling the best chance of survival. Unfortunately, research into fertilizer seed coatings has not received as much attention as fungicide and insecticide seed treatments (Scott, 1989). Seed coated or banded P and K may be helpful as the critical P and K concentration in the soil solution required for maximum growth of wheat seedlings from Feekes 1 to 5 (Feekes, 1941) is far greater than later in the plant's life at Feekes10.1 to 11 (Sutton et al., 1983).

Karanam and Vadez (2010) reported that pearl millet (*Pennisetum glaucum* L.) shoot biomass increased significantly in all the P seed coating treatments in the range of 18% to 85% over the non-coated control in a low P soil. The highest biomass response was seen in the P seed coating treatment with 77.5 mg P g^{-1} seed. This response was expressed in all hybrids used except one.

Peltonen-Sainio and colleagues (1997) found crop management practices that support early growth and vigor are likely to result in higher biomass production of oats (*Avena sativa* L.). With early growth and even seedling emergence, canopy closure accelerated thereby reducing weed pressure, and increasing yields. The coating of pearl millet seeds with P delayed the germination and emergence of plants for about a day, regardless of genotype (Karanam and Vadez, 2010). However, despite this short delay, there was a rapid and dramatic effect of the coating on the shoot biomass in the initial 2-4 wks after emergence of the plants. Smid and Bates (1971) found that small additions of fertilizer in seed coatings were three to four times as effective in providing an early supply of P to maize (*Zea mays* L.) seedlings compared to band

placement near the seed. Close placement and availability of nutrients to seedlings appears to be most important for elements which are immobile such as P, especially under cool conditions, which restrict P uptake (Klepper et al. 1983).

Seed Priming

Seed priming, as defined by Heydecker (1973), is a pre-sowing treatment in which seeds are soaked in an osmotic solution for several hours which allows the seed to imbibe water and go through the first stages of germination, but does not permit radicle protrusion through the seed coat. After the period of imbibition, seeds can promptly be dried to their original moisture content and stored in cool, dry conditions, or planted via conventional techniques.

Priming of wheat seed with a solution may improve germination and emergence (Ashraf and Abu-Sakra, 1978) and promote vigorous root growth (Carceller and Soriano, 1972) under low soil water potential compared with checks. It has also been reported that seed priming improves stand establishment, grain and straw yields, and harvest index in maize (Farooq et al., 2008).

Harris (1996) found that conditions after sowing had a large influence on emergence and seedling vigor in sorghum (*Sorghum bicolor* L.) and argued that speed of germination and emergence were important determinants of successful establishment. Rapidly germinating seedlings had the capacity to emerge and produce deep root systems before the upper layers of the soil dried out, or became non-conducive to seedling growth. Delayed emergence reduces the subsequent relative growth rate of the seedling and, in general, healthy plants with well-developed root systems can withstand adverse conditions better than plants whose development and growth have been interrupted at an early stage (Harris 1996).

Planting Date

The optimal planting dates for HRWW vary depending on the location within the state of North Dakota, harvest of the previous crop, and weather conditions. On average, HRWW producers in North Dakota, normally plant around the middle of September. Producers in the northern regions of North Dakota, however, plant a wk earlier to ensure proper germination and growth before the first killing frost in the fall. Producers in the southern regions tend to plant a wk later than northern regions of the state.

Planting too early in the season can diminish soil moisture reserves and increase the chances of diseases, such as wheat streak mosaic virus (Potyviruses group). This disease is problematic with early planting as there is inadequate time for the green bridge of summer grasses and the new winter wheat plants to be broken (Peel et al., 1997). The green bridge is commonly referred to as continual living green plant material from one growing season to the next, which allows the vector of the disease, the wheat curl mite (*Aceria tosichella* K.), to survive. The green bridge is broken when green plant material is desiccated during the fall by chemicals, or natural weather conditions, and thereby prohibiting the wheat curl mite to survive.

Early planting can also lead to excessive fall plant growth, which can reduce winter survival. However, planting later than the recommended date can significantly increase winter injury, and inhibit germination from lack of moisture and cooler temperatures (Lafond and Fowler, 1989). Pittman and Andrews (1961) reported a marked decrease in winter wheat yield in Alberta, Canada when planting before or after the recommended date. In their study, as little as one wk difference in planting date produced significant differences in winter survival. Sander and Eghball (1999) reported winter wheat grain yield reductions of up to 15% or more in Nebraska when the optimal planting date was not used.

MATERIALS AND METHODS

Field and greenhouse experiments were conducted to examine the effect of planting date, cultivar, P and K fertilizer and fungicide treatments which are placed with HRWW seed on winter wheat survival and yield.

Field Research

Field experiments were conducted in 2012-2013 at five locations in North Dakota: Lisbon, Prosper, Minot, Williston, and Hettinger. Table 1 lists the soil series, taxonomy, and slope of each experimental location.

Plots were 1.5 m wide and 5.5 m long at all locations except Hettinger where they were1.5 m wide and 8.5 m in length. Individual plots contained seven rows that were evenly spaced 18 cm at all locations. Experiments were planted no-till during the fall of 2012 in the following crop residues: HRSW at Lisbon, and Prosper, field pea at Minot, dry bean (*Phaseolus vulgaris* L.) at Williston, and lentils (*Lens culinaris* Medik.) at Hettinger. The erect residue remaining was 13 cm tall at Prosper and Lisbon. No remaining erect residue was present at Minot, Williston, and Hettinger. Border plots were planted on the two outermost columns of plots to ensure similar light, moisture and nutrient competition as interior plots.

Germination tests were performed on seed representing both cultivars and were determined by placing 100 seeds from each cultivar on a moist paper towel for one wk at room temperature (25°C). After one wk, seeds with the coleoptile showing were considered viable and were counted as viable seeds. Both cultivars had high germination percentages with Jerry being 95%, and SY Wolf being 93%. Seeding rates were based on viable seeds per hectare.

Table 1**.** Soil series, taxonomy, and slope of experimental locations at Prosper, Lisbon, Minot, Hettinger, and Williston ND, during the 2012-2013 growing season.

Location	Soil Series†	Soil Taxonomy‡	% Slope
Prosper	Bearden–Lindaas	Fine-silty, mixed, superactive, frigid Aeric Calciaquolls Fine, smectitic, frigid Typic Argiaquolls	0-2
Lisbon	Barnes –Svea	Fine-loamy, mixed, superactive, frigid Udic Haploborolls	3-6
	and	Fine-loamy, mixed, superactive, frigid Pachic Udic Haploborolls	
	Gwinner–Peever–Parnell	Fine, smectitic, frigid Pachic Vertic Argiudolls Fine, smectitic, frigid Vertic Argiudolls Fine, smectitic, frigid Vertic Argiaquolls	
Minot	Aastad-Tonka	Fine-loamy, mixed, superactive, fridgid, Pachic Argiudolls	0-3
	and	Fine, smectic fridgid Argiaquic Argialbolls	
	Forman-Aastad	Fine-loamy, mixed superactive, frigid, Calcic Argiudolls	0-3
Hettinger	Belfield–Savage–Daglum	Fine, smectitic, frigid Glossic Natrustolls	0-2
Willistion	Williams-	Fine-loamy, mixed, superactive, frigid Typic Argiustolls	0-3 *and*
	Bowbells	Fine-loamy, mixed, superactive, frigid Pachic Argiustolls	0-6

† Soil data obtained from (USDA-NRCS, 2013).
‡ Soil Taxonomy listed on individual lines based on hyphenated soil series name.

Winter wheat was planted at all locations at a density of 2.96 million live seeds ha^{-1}. At Prosper and Lisbon, plots were sown using a Great Plains 3P605NT no-till drill (Great Plains Mfg. Inc., Salina, KS). Hettinger plots were sown using a Fabro™ planter with AcraPlant ACRADrill™ (Fabro Enterprises Ltd, Swift Current, Saskatchewan, Canada). At Williston a custom made Fabro self-propelled cone seeder (Fabro Enterprises Ltd, Swift Current, Saskatchewan, Canada) was used, and Minot was planted with a no-till small plot drill.

Experimental design was a randomized complete block with a split-plot restriction. The whole plot was planting date (2 levels) and the sub-plots consisted of a factorial combination of

cultivar (2 levels) and P, K, and fungicide seed treatments (10 levels). These treatments are summarized in Table 2. Treatments were replicated four times at each location.

Table 2. Factors and levels of each factor included in field studies at Hettinger, Williston, Minot, Prosper, and Lisbon ND 2013.

Planting Date	Cultivar	P, K fertilizer and Seed Treatment
Early Planting	Jerry	1- Check
Late Planting	SY Wolf	2- IF 28 kg P_2O_5, 18 kg K_2O ha^{-1} †
		3- IF 56 kg P_2O_5, 37 kg K_2O ha^{-1}
		4- FST ‡
		5- FST + IF 28 kg P_2O_5, 18 kg K_2O ha^{-1}
		6- FST+ IF 56 kg P_2O_5, 37 kg K_2O ha^{-1}
		7- Seed Priming with H_2O
		8- Seed Priming with KH_2PO_4
		9- Seed Coat 5.6 kg P_2O_5, 3.7 kg K_2O ha^{-1}
		10- Seed Coat 11.1kg P_2O_5, 7.3 kg K_2O ha^{-1}

†IF= in-furrow
‡FST= fungicide seed treatment.

The two planting dates that were compared consisted of an optimum date and another date approximately three wks later (Table 4). Minot and Williston were the first locations planted on September 14, 2012, Lisbon, Prosper, and Hettinger were planted on September 18, and 19, respectively. The second planting date occurred from October 10-12, 2012 with the northern sites planted before the southern sites (Table 4).

The two winter wheat cultivars used were chosen for the experiment based on their winter hardiness. Jerry, a cultivar released from North Dakota State University (NDSU) in 2001 was the most commonly grown cultivar in North Dakota during the time period of the studies due to its “good” winter hardiness rating. The other cultivar, SY Wolf, was released by Agripro in 2012 and has a winter hardiness rating of “fair”.

Ten phosphorus-potassium and fungicide treatments were used to determine the effect of P, K, and fungicide on seedling winter survival. These treatments consisted of the following: 1)

check, 2) naked seed + IF 28 kg P_2O_5, 18 kg K_2O ha^{-1}, 3) naked seed + IF 56 kg P_2O_5, 37 kg K_2O ha^{-1} , 4) fungicide seed treatment (FST), 5) FST + IF 28 kg P_2O_5, 18 kg K_2O ha^{-1}, 6) FST + IF 56 kg P_2O_5, 37 kg K_2O ha^{-1}, 7) seed priming with water, 8) seed priming with a KH_2PO_4 solution, 9) seed coated with 5.6 kg P_2O_5, 3.7 kg K_2O ha^{-1}, 10) seed coated with 11.1 kg P_2O_5, 7.3 kg K_2O ha^{-1}, refer to in Table 2. The fertilizer that was used for all treatments was a refined mono-potassium-phosphate (KH_2PO_4) 0-52-34 (Haifa Co., Israel). This fertilizer was chosen for this experiment due to its low salt rating (1% solution = 7.4 EC, and 4.4 pH), and was highly refined to facilitate seed coating.

Conventional P and K fertilizer treatments were weighed before planting, pre-packaged and applied with the seed at planting by first emptying the seed out of a separate pre-weighed seed packet, followed by the fertilizer packet into the planter. The three in-furrow P and K fertilizer treatments, which were planted with or without fungicide, were intended to determine the effect of fungicide on seedling emergence and survival at the different levels of P and K fertilizer.

The seed treatment fungicide used was a combination of tebuconazole (alpha-[2-(4-chlorophenyl) ethyl]-alpha-(1, 1-dimethyl-ethyl)-1H-1,2,4-triazole-1-ethanol) at a rate of 0.02 mg a.i. g^{-1} seed, and metalaxyl (N-(2,6-dimethylphenyl)-N-(methoxyacetyl)alanine methyl ester) at a rate of 0.21 mg a.i. g^{-1} seed. Fungicide was applied to the seed using a Hege-11 motorized liquid seed treater (Wintersteiger Seed Mech., Salt Lake City, UT).

Seed priming was conducted by rinsing the seed with tap water to wash off impurities and chaff. The seed was then placed in a plastic bucket and distilled water was added until the water completely covered the seed. The seed was left in the water for 12 h and stirred every 4 h with a screwdriver for agitation. At the end of 12 h, the seed was removed from the bucket,

rinsed with tap water, and placed in mesh sacks in a drying room at 30°C. Sacks were mixed and rotated every three hours until seeds reach 11-12% kernel moisture.

Priming seeds in the fertilizer solution was conducted similarly, except that the seeds were soaked in a 1% w/v solution of KH_2PO_4 for 12 h. At the end of priming, the seed was rinsed off twice using tap water and placed in a drying room at 30°C until seeds reach the desired 11-12% kernel moisture.

The two seed coating fertilizer treatments were: a low rate of 5.6 kg P_2O_5, 3.7 kg K_2O ha^{-1} and a high rate of 11.1 kg P_2O_5, 7.3 kg K_2O ha^{-1}. Seeds were coated with P and K using a starch based water soluble all-purpose adhesive (Zinsser, Somerset, NJ) at the rate of 1 g for every 150 g of seed. The adhesive and 20.0 ml of water were added together in a small beaker and mixed thoroughly. The adhesive solution was then added to the seed in a bucket and mixed until all the seeds were evenly coated. The pre-weighed fertilizer, which varied depending on the treatment, was then gradually added to the newly coated seed while mixing to ensure even coverage of all the seed. When completed, the seed was placed in a brown paper bag and left to dry overnight at room temperature. To apply the low rate of fertilizer, 34.5 g of mono-potassium-phosphate (MKP) was weighed and applied to the seed; the high rate required 69.0 g of MKP.

In the fall of 2012, soil samples were taken at depths of 0-15 cm and 15-60 cm at each location before planting. The second depth was taken from the same hole as the first sample. The samples were analyzed for N, P, K, pH, and organic matter (OM) at the NDSU soil analysis lab, and are reported in Table 3. The soil analysis was not used to adjust N-P-K rates at any locations; however, it was used to help determine the likely availability of essential macro-nutrients. No P or K was added to the plots besides what was incorporated during planting for individual treatments.

In the spring of 2013, winter wheat plots at all locations were fertilized at a rate of 123 kg N ha^{-1} using urea (46-0-0) combined with a urease inhibitor NBPT (N-(n-butyl)-thiophosphoric triamide, and N-methyl-2-pyrrolidone) (Agrotain Ultra) at a rate of 3 ml kg^{-1} of N. The nitrogen was applied before tillering at Feekes 3, and within seven days before a rainfall event occurred.

A fall burn down application of glyphosate (N-(phosphonomethyl) glycine) at a rate of 3.4 kg a.e. ha^{-1}, tank mixed with a non-ionic surfactant (NIS), Class Act™, at a rate of 2 L ha^{-1} was applied two wks before planting at the Lisbon and Prosper sites to break the green bridge to reduce the likelihood of wheat streak mosaic virus and to reduce weed pressure during seedling emergence. Minot, Williston and Hettinger were planted into legume crop stubble and did not require herbicide treatments in the fall due to dry weather after the harvest of the previous crop.

Table 3. Nitrogen, P, K, pH and organic matter levels by sampling depth at Lisbon, Prosper, Minot, Williston, and Hettinger in the fall of 2012.

Location	Depth	N	P	K	pH	OM†
	(cm)	(kg ha^{-1})	(mg kg^{-1})	(mg kg^{-1})		%
Lisbon	0-15	38.0	5 (L) ‡	205 (VH)	6.9	5.2
	15-61	50.5	2 (VL)	50 (L)	7.8	3.2
Prosper	0-15	53.8	25 (VH)	150 (H)	6.7	3.4
	15-61	50.5	7 (L)	80 (M)	8.0	1.8
Minot	0-15	16.8	9 (M)	415 (VH)	6.9	2.8
	15-61	33.6	3 (VL)	140 (H)	8.0	2.1
Williston	0-15	45.9	15 (H)	375 (VH)	6.1	2.4
	15-61	50.5	3 (VL)	95 (M)	7.8	2.0
Hettinger	0-15	165.8	20 (VH)	410 (VH)	6.3	3.1
	15-61	104.2	5 (L)	190 (VH)	7.3	2.3
Greenhouse§	-	-	22 (VH)	-	-	-

† OM = Organic Matter
‡ Letter(s) in parentheses represent a fertility scale based on NDSU's fertilizer recommendation guide (Franzen, 2010). VL=very low, L=low, M=medium, H=high, and VH=very high.
§LC1 Sunshine potting mix.

Two spring herbicide applications were used to control grassy and broadleaf weeds at the Lisbon location. The first application was a premix of florasulam [N-(2,6-difluorophenyl)-8-fluoro-5-methoxy (1,2,4)triazolo(1,5-c)pyrimidine-2-sulfonamide] at a rate of 15 g a.i. ha^{-1},

fluuroxypyr 1-methylheptyl ester [((4-amino-3,5-dichloro-6-fluoro-2-pyridinyl)oxy) acetic acid, 1-methylheptyl ester] at a rate of 2.8 g a.i. ha^{-1}, and pyroxsulam [N-(5,7-dimethoxy[1,2,4] triazolo[1,5-a]pyrimidin-2-yl)-2-methoxy-4(trifluoromethyl)-3-pyridinesulfonamide], at a rate of 99 g a.i. ha^{-1}, tank mixed with the same NIS product as previously mentioned at the same rate. The second herbicide application was applied three wks later using a sequential application method of propyxycarbazone-sodium (methyl 2-[[[(4,5dihydro-4-methyl-5-oxo-3-propoxy-1H-1,2,4-triazol-1-yl)carbonyl]amino]sulfonyl]benzoate, sodium salt) at a rate of 44 g a.i. ha^{-1}. Followed by a mix consisting of 140 g a.i. ha^{-1} of the octanoic and heptonoic esters of bromoxynil (3, 5-dibromo-4-hydrozybenzonitrile), 0.9 g a.i. ha^{-1} fenoxaprop-p-ethyl (ethyl 2-[4-[(6-chloro-2-benzoxazolyl)oxy] phenoxy], and 40 g a.i. ha^{-1} pyrasulfotole ((5-hydroxy-1,3 dimethyl-1H-pryrazol-4yl)[2-methylsulfonyl)-4(trifluoromethyl)phenyl]methanone), for control of grass and broadleaf weeds, tank mixed with a pre-boot fungicide of propiconazole (1-[[2 (2,4Dichlorophenyl)-4-propyl-1,3-dioxolan-2-yl]methyl]1-H-1,2,4-triazole) at a rate of 80 g a.i. ha^{-1}, and trifloxystrobin (benzeneacetic acid (E,E)-alpha-(methoxyimino)-2-[[[[1-[3 (trifluoromethyl)phenyl]ethylidene] amino]oxy]methyl]- methylester) at a rate of 80 g a.i. ha^{-1}.

The same mix of fenoxaprop-p-ethyl, pyrasulfotole, bomoxynil octanoate, and bromoxynil heptanoate, was tank mixed with a fungicide premix of propiconazole, and trifloxystrobin at the same rate as Lisbon, and was applied at Prosper, Minot, and Williston locations to control broadleaf and grassy weeds and early-season leaf diseases. A second fungicide application was applied at flowering at all locations except Hettinger, using a premix of prothioconazole (2-[-(1-chlorocycloproplyl)-3-(2-chlorophenyl)-2-hydroxypropyl]-1,2-dihydro-3H-1,2,4-triazole-3-thione) at a rate of 99 g a.i. ha^{-1}, and tebuconazole (alpha-[2-(4-

chlorophenyl)ethyl]-alpha-(1,1-dimethylethyl)-1H-1,2,4-triazole-1-ethanol) at a rate of 99 g a.i. ha^{-1}, to control fusarium head blight (*Fusarium graminearum*) and foliar diseases.

All sites except Prosper and Hettinger were desiccated in late summer after plots had reached physiological maturity (Feekes 11) to hasten harvest (Wiersma and Ransom, 2005). At Lisbon and Minot an application of paraquat dichloride (1, 1'-dimethyl-4, 4'-bipyridinium dichloride), at a rate of 0.78kg a.i. ha^{-1} was used, and at Williston glyphosate was used at a rate of 3.36 kg a.e. ha^{-1}. At Lisbon and Prosper all pesticide applications were applied using a backpack sprayer and hand held boom, except for the fall herbicide application which was applied with a tractor mounted sprayer. Pesticides applied at Hettinger, Minot, and Williston used a similar tractor mounted tank sprayer to apply all pesticides.

Table 4. Dates of important measurements and field applications at Lisbon, Prosper, Hettinger, Williston, and Minot, ND 2012- 2013.

Measurement/ Application	Lisbon	Prosper	Hettinger	Williston	Minot
	---------- Date ----------				
			2012		
Fall herbicide	4-Sep	4-Sep	N/A	N/A	N/A
Early planting date	18-Sep	18-Sep	19-Sep	14-Sep	14-Sep
Late planting date	11-Oct	11-Oct	12-Oct	10-Oct	10-Oct
Fall stand count	15-Nov	15-Nov	17-Dec	N/A	7-Dec
			2013		
Spring stand count	13-May	13-May	27-May	11-May	11-May
N fertilizer	13-May	13-May	25-May	11-May	11-May
Weed control	6-Jun	6-Jun	4-Jun	8-Jun	26-Jun
Pre-boot fungicide	6-Jun	6-Jun	N/A	8-Jun	26-Jun
Fungicide/head blight	9-Jul	9-Jul	N/A	2-Jul	19-Jul
Desiccant	5-Aug	N/A	N/A	1-Aug	13-Aug
Harvest	14-Aug	15-Aug	27-Aug	21-Aug	22-Aug

Fall stand counts were taken at Hettinger and Minot by counting the number of plants within a random 1 m length of rows 4 and 5, which was approximately 1 m in from front edge of the plot. The number of plants from both rows were then averaged, and recorded into the field book. At Lisbon and Prosper, stand counts were taken by counting the number of plants in a

randomly selected 30 cm length of rows two, three, five and six, then averaging the number of plants from the four rows. At Williston no fall data were obtained due to early snow cover. To quantify spring survival, stand count data were collected after snow melt between Feekes 1 to 3 stages using the same methods used in the fall, with Williston being collected using the same methods as Hettinger, and Minot. Stand count data at Hettinger, Williston, and Minot were taken from all treatments in the experiment. However, stand count data for Lisbon and Prosper were taken for two replications of the early planting date only. When analyzing the data from Lisbon and Prosper, planting date was excluded as a factor. At Lisbon and Prosper stakes were placed in rows where data were collected to ensure accurate spring stand counts. Stand count data were adjusted to m^2.

Hettinger, Williston, Minot, Prosper and Lisbon were harvested when the wheat plants reached Feekes 11, and had dried to approximately 13% moisture. Winter wheat was harvested at Lisbon and Prosper using a Wintersteiger Classic™ plot combine (Wintersteiger Ag, Ried, Austria). At Hettinger plots were harvested using a Kincaid 8XP™ plot combine (Kincaid Equipment Manufacturing, Haven, KS), and plots at Williston and Minot were harvested using a Wintersteiger Elite™ plot combine (Wintersteiger Ag, Ried, Austria). All seven rows of each plot were harvested. Once harvested, the seed was dried (if necessary) and cleaned. Moisture and test weight were recorded for all locations using a GAC 2100™ moisture/test weight tester (DICKEY-John Corp., Minneapolis, MN). At Hettinger only, yield was determined using a weighing system (Kincaid Equipment Manufacturing, Haven, KS) on the plot combine. At all other locations, yield was determined in the lab using a digital scale to measure the weight of the whole plot and adjusting to a moisture content of 13.5%. At harvest, plot lengths were recorded and yield was adjusted using the length of the plots. Grain protein was measured using a 0.5 kg

sub-sample of seed from each plot with a Diode Array 7200 NIR Analyzer™ (Perten Instruments, Springfield, IL) and expressed on a 13.5% moisture basis. Yield and protein data from Lisbon were not used in the results and discussion due to extensive weed pressure at the site, and the subsequent inaccuracy of the data collected.

Data were analyzed using a mixed model approach (PROC MIXED) with SAS 9.0 for Windows (SAS Institute, Cary, NC). Location and replicates were considered random effects while planting date, cultivar, and fertilizer treatments were considered fixed effects. Means were separated using a paired t comparison at the 5% level of confidence.

Greenhouse Research

The greenhouse experiments were conducted in Fargo, on the campus of NDSU. Experiments were conducted to determine winter survivability, and seedling vigor.

Winter Survivability

The purpose of this study was to determine if P, K, and fungicide treatments increased winter survivability under controlled environmental conditions in the greenhouse. The study was arranged as a randomized complete block with a split plot restriction. The whole plot consisted of two environments, and the sub-plots consisted of a factorial combination of two cultivars, and ten fertilizer treatments, replicated five times. Environments consist of the greenhouse, and a refrigeration chamber (Table 5).

Seeds were planted in a tray of sheet pots. Each tray contained 20 cells that were 5 cm long by 6.3 cm wide by 7 cm deep. Prior to planting, P and K fertilizer was measured and placed in envelopes at a rate of 20 mg and 40 mg MKP, representing the 28 and 56 kg $ha^{-1}$of P_2O_5, and 18 and 37 kg ha^{-1} of K_2O used in the field study, respectively. Each tray was filled with Sunshine LC1 potting soil mix (Sun Gro Horticulture, Agawam, MA) and saturated with water before

planting. A seed was planted in a furrow of each cell made with a finger at a depth of 2.5 cm. Seeds planted in the cells were of visual uniform size. For treatments requiring P, and K in-furrow, a pre-measured packet of P and K fertilizer was added in the furrow with the seed. The seed was promptly covered and the potting soil was lightly compacted to ensure proper soil to seed contact.

Table 5. Factors and levels of each factor included in winter survivability and seedling vigor experiments conducted at greenhouses on the campus of NDSU, 2013.

Environment†	Cultivar	Fertilizer‡
Greenhouse	Jerry	1- Check
Refrigeration Chamber	SY Wolf	2- IF 28 kg P_2O_5, 18 kg K_2O ha^{-1}§
		3- IF 56 kg P_2O_5, 37 kg K_2O ha^{-1}
		4- FST¶
		5- FST+ IF 28 kg P_2O_5, 18 kg K_2O ha^{-1}
		6- FST+ IF 56 kg P_2O_5, 37 kg K_2O ha^{-1}
		7- Seed Priming with H_2O
		8- Seed Priming with KH_2PO_4
		9- Seed Coat 5.6 kg P_2O_5, 3.7 kg K_2O ha^{-1}
		10- Seed Coat 11.1kg P_2O_5, 7.3 kg K_2O ha^{-1}

† This factor was not included in the seedling vigor experiment.
‡ Only fertilizer treatment numbers 1, 7, 8, 9, and 10 were used in the seedling vigor experiment.
§ IF=in-furrow
¶FST= fungicide seed treatment.

The cultivars and fertilizer treatments used in this experiment were similar to those used in the field study as previously described. After planting, five trays were placed in the greenhouse for five d at a temperature of 20°C to initiate germination. On the fifth d, the trays were transferred to the refrigeration chamber (Bally Refrigerated Boxes, Inc., Morehead City, NC) for six wks at 2°C to stimulate vernalization and typical autumn cooling temperatures. The other five trays were directly placed in the refrigeration chamber to start germination and cold acclimation.

After the cold acclimation process in the refrigeration chamber all viable seeds had emerged and seedlings were at the Feekes 1. Trays were then transferred to an ESPEC BTU-433 Criterion temperature (environmental) chamber (ESPEC North America, Inc., Hudsonville, MI) where the chamber was programed to gradually decrease the temperature from 2°C to -15°C. The seedlings were subjected to -15°C for 20 min. After 20 min at the deep freeze stage the temperature in the chamber gradually increased to 2°C, completing the cycle which took approximately 18 h. At the completion of this process, five trays were removed and the other five trays were placed in the environmental chamber to undergo the same process. After the environmental chamber all trays were placed in the refrigeration chamber for at one d to allow the soil media to return to 2°C. After thawing, the five trays that started in the refrigerated chamber remained in the chamber, and the other five trays were placed in the greenhouse. Both locations were watered and maintained for two wks until plant vigor data were collected. No fertilizer was added to the trays while in the greenhouse or refrigeration chamber. The experiment took approximately nine wks to complete.

Emergence data were collected every d after planting until all seedlings had emerged. Two wks after being frozen in the temperature chamber, vigor data were collected on trays in the greenhouse and refrigeration chamber. The method used to determine vigor was a visual rating of 0-5, with 0 being dead and 5 being alive and healthy looking.

Data were analyzed using a mixed model approach (PROC MIXED) with SAS 9.0 for Windows (SAS Institute, Cary, NC). Replicates were considered random effects while environment, cultivar, and fertilizer treatments were considered as fixed effects. Means were separated using a paired t comparison at the 5% level of confidence.

Seedling Vigor

The objective of this study was to determine if priming and seed coating P and K fertilizer improved seedling vigor, and if seedling P uptake increased. This study was conducted in a greenhouse on the campus of NDSU similar to the winter survivability study. The study was arranged as a randomized complete block design with a factorial combination of two cultivars, and five fertilizer treatments. The experiment was repeated four times with five replicates per run. Each run took approximately four wks to complete.

Seeds were planted in a similar manner to the winter survivability study. The cultivars used in this study are the same as was used in the field study and the greenhouse study of winter survivability (Table 5). The fertilizer treatments used were similar to the treatments explained in the winter survival study but were limited to 1) check, 2) seed priming with water, 3) seed priming with MKP solution, 4) seed coated with 5.6 kg ha^{-1} P_2O_5, and 3.7 kg ha^{-1} K_2O and 5) seed coated with 11.1 kg ha^{-1} P_2O_5, 7.3 kg ha^{-1} K_2O. The same refined KH_2PO_4 was used for the P and K fertilizer seed treatments.

Within the first wk, seedling emergence was recorded similar to the previously described winter survivability study. At the end of four wks in the greenhouse, seedling plant height was measured from the top of the soil to the tip of the longest tiller, tillers were also counted in each cell. Plant height data were not recorded for runs one and two. The shoot was then severed at the soil surface and placed in a paper bag and placed in a dryer at 32^0C for seven d. Samples were then taken out and dry weight was measured on a scientific scale.

Data were analyzed using a mixed model approach (PROC MIXED) with SAS 9.0 for Windows (SAS Institute, Cary, NC). Replicates and runs were considered random effects while

cultivar, and fertilizer treatments were considered fixed effects. Means were separated using a paired t comparison at the 5% level of confidence.

RESULTS AND DISCUSSION

Weather Conditions

Precipitation during the month of September 2012 was much below average (NDAWN, 2013). Average precipitation in the western half of North Dakota was approximately 0-1 cm while the eastern half of the state received approximately 0.5-1.5 cm. Neither region received sufficient precipitation to start the germination process of winter wheat and sustain seedling growth for the first planting date at any location. However, precipitation averages did increase throughout North Dakota in October after the second planting date, to approximately 1-10 cm. This rainfall was suitable for even germination and emergence for any seeds that had not germinated from the first planting date. The first killing frost (below -2^{0}C) in 2012 occurred on October 4, 4, 5, 6, and 5, at the Hettinger, Minot, Williston, Prosper, and Lisbon, respectively (NDAWN, 2013).

At the NDAWN weather stations near Hettinger, Minot, Williston, Prosper, and Lisbon the average daily bare soil temperature did not drop below 0^{o}C until November, 11, 25, 24, 26, and 23, respectively (NDAWN, 2013). Snow cover in November was minimal at the southern locations accumulating only 0-13 cm in Hettinger, Prosper, and Lisbon. The northern locations, Minot and Williston, accumulated 13-51 cm during the month of November. Total snow fall accumulation for North Dakota ranged from 76 cm in the south-west corner of the state and gradually increased to 203 cm in the north central and north eastern locations of the study (Figure 1).

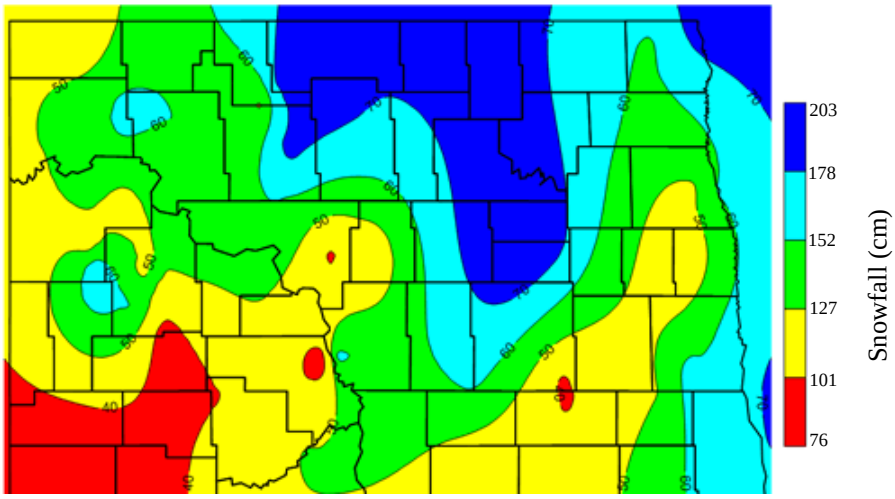

Figure 1. Total snowfall in North Dakota winter of 2012-2013. (Data from NWS Cooperative Network; Image from ND State Climate

Early snow accumulations in October and November subsided enough to allow fall stand counts data to be taken at all locations of the study except at Williston where snow cover persisted. Significant snow accumulation to buffer soil temperatures did not occur until January, causing seedlings to be exposed to soil temps of approximately -3^{0}C during December at Hettinger, and Minot (Table 6).

Fall Stand Count 2012

Fall stand counts were taken to determine the effect of P and K fertilizer and fungicide treatments, planting date, and cultivar on fall emergence. Emergence varied considerably across planting dates and locations due to different weather and soil conditions at planting (Table 7). At Minot, emergence at the later planting date was approximately 50% less than at the early planting date. The effect of planting date on fall stand count suggests that seedling stand establishment is greater when HRWW is planted earlier at the recommended planting date as opposed to the later date.

Table 6. Monthly average temperatures that were recorded by automated weather stations near Hettinger, Minot, Williston, Prosper, and Lisbon, ND.

Location	Month	Year	Max. Temp.	Min. Temp.	Normal Min. Temp.	Bare† Soil Temp.
			^{0}C	^{0}C	^{0}C	^{0}C
Hettinger	Nov.	2012	7.1	-6.6	-7.7	1.0
	Dec.	2012	-1.2	-13.8	-13.8	-3.5
	Jan.	2013	-2.1	-13.1	-14.8	-2.9
	Feb.	2013	2.6	-8.6	-12.7	-2.1
	Mar.	2013	4.2	-9.2	-7.5	0.7
Minot	Nov.	2012	1.4	-7.4	-7.8	0.0
	Dec.	2012	-6.6	-17.0	-15.1	-2.7
	Jan.	2013	-6.2	-17.0	-17.3	-4.3
	Feb.	2013	-3.4	-13.6	-14.7	-3.3
	Mar.	2013	-4.6	-16.2	-8.3	-2.0
Williston	Nov.	2012	2.1	-7.3	-6.7	1.1
	Dec.	2012	-5.1	-13.8	-13.7	-3.8
	Jan.	2013	-5.3	-14.9	-15.3	-3.2
	Feb.	2013	-0.9	-9.9	-12.4	-2.5
	Mar.	2013	-1.1	-12.2	-6.4	-2.1
Prosper	Nov.	2012	3.2	-6.3	-7.2	1.3
	Dec.	2012	-6.0	-14.7	-15.2	-1.7
	Jan.	2013	-6.3	-18.6	-18.7	-2.4
	Feb.	2013	-6.2	-16.4	-15.7	-2.7
	Mar.	2013	-2.8	-15.3	-7.7	-1.7
Lisbon	Nov.	2012	3.7	-6.4	-6.3	1.3
	Dec.	2012	-5.4	-14.6	-13.8	-1.2
	Jan.	2013	-5.6	-18.0	-16.9	-2.8
	Feb.	2013	-5.3	-16.3	-14.0	-2.8
	Mar.	2013	-2.9	-14.3	-7.2	-1.7

†Bare soil temperature is the temperature of bare soil with no vegetation at 10 cm below the soil surface.

Table 7. Planting date effects on fall stand count averaged over cultivar, P, K, and fungicide treatments, at Hettinger and Minot, ND 2012.

Planting Date	Hettinger	Minot	Combined†
	-------- Seedlings m^{-2} --------		
Early	46 a‡	120 a	83 a
Late	0 b	55 b	27 b

†Combined analysis of locations listed above, ran at the 95% level of confidence using a paired t-test.
‡Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$) using a paired t-test.

When data were analyzed using a combined analysis for all locations fall stand counts were not significantly impacted by P and K fertilizer or fungicide treatments. At individual locations, Hettinger emergence was better with the low seed coated P and K rate, priming with P and K, and the fungicide seed treatment with 28 kg ha^{-1} P_2O_5 and 18 kg ha^{-1} K_2O compared to the check (Table 8). The low rate of seed coated P and K at Minot also had better fall emergence compared to the check. Emergence at Lisbon was improved using the high rate of seed coated P and K, both priming treatments, and all three fungicide seed treatment factors as compared to the check. Depending on the environment the treatments of seed coating, priming and a fungicide seed treatment with P showed potential for improving fall stand establishment. Ashraf and Abu-Shakra (1978) also found that priming of wheat seed with water improved germination and emergence.

Table 8. Phosphorus, K and fungicide treatment effects on fall stand count averaged over planting dates and cultivars at Hettinger, Minot, Prosper, and Lisbon, ND 2012.

Treatment	Hettinger	Minot	Prosper	Lisbon	Combined†
	----------Seedlings m^{-2} ----------				
Check	17 de‡	89 bcd	93 a	9 g	26 a
IF 28§	25 bcd	93 abc	133 a	14 efg	31 a
IF 56	24 bcd	82 cd	123 a	18 efg	28 a
SC Low P¶	30 abc	106 a	122 a	23 defg	34 a
SC High P	19 cde	104 ab	125 a	27 cdef	32 a
Prime Water	8 e	84 cd	136 a	32 bcde	27 a
Prime P	36 a	83 cd	127 a	36 abcd	32 a
FST††	20 bcde	76 d	141 a	41 abc	28 a
FST 28	32 ab	83 cd	124 a	45 ab	31 a
FST 56	19 cde	77 cd	120 a	50 a	28 a

† Combined analysis of locations listed above, ran at the 95% level of confidence using a paired t-test.
‡ Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$) using a paired t-test.
§ IF = in-furrow P_2O_5 at 28, 56 kg ha^{-1}, and K_2O at 18, 37 kg ha^{-1}.
¶ SC = seed coat with a rate of P_2O_5 at 5.6, 11.1 kg ha^{-1}, and K_2O at 3.7, 7.3 kg ha^{-1}.
†† FST = fungicide seed treat.

The planting date x P and K fertilizer and fungicide treatments (Table 9) indicated that stand counts decreased approximately 50% at the later planting date compared to the early planting date. Lafond and Fowler (1989) found a 1.3 d increase in the delay in emergence for every degree the temperature dropped from 20 to 5°C. Stand counts of the late planting date at Minot show a low number of emerged seedlings, which is possibly due to cool soil, and freezing temperatures (Table 7). The stand counts in the combined analysis show that a combination of either early planting and seed coating with Low P or early planting with FST 28 kg ha^{-1} P_2O_5, and 18 kg ha^{-1} K_2O will improve fall stand counts compared to the check. Increasing the amount of P and K in the treatment did not seem to improve emergence at the early planting date.

Table 9. Planting date x P, and K fertilizer and fungicide treatment effects on fall stand counts averaged over cultivars at Hettinger, and Minot, ND 2012.

Plant Date	Treatment	Hettinger	Minot	Combined†
		---------- Seedlings m^{-2} ----------		
Early				
	Check	35 c‡	115 abcd	75 bc
	IF 28§	51 bc	127 abc	89 ab
	IF 56	48 bc	127 abc	87 ab
	SC Low P¶	61 ab	132 ab	96 a
	SC High P	38 c	136 a	87 ab
	Prime Water	17 d	103 de	60 c
	Prime P	72 a	106 bcd	89 ab
	FST††	39 c	111 bcd	75 bc
	FST 28	64 ab	123 abcd	93 a
	FST 56	38 c	124 abcd	90 ab
Late				
	Check	0 d	64 fg	32 def
	IF 28	0 d	59 fghi	29 defg
	IF 56	0 d	37 ij	18 fg
	SC Low P	0 d	79 ef	40 d
	SC High P	0 d	71 f	35 de
	Prime Water	0 d	66 f	33 def
	Prime P	0 d	60 fgh	30 defg
	FST	0 d	41 hij	20 efg
	FST 28	0 d	43 ghij	21 efg
	FST 56	0 d	31 j	15 g

† Combined analysis of locations listed above, ran at the 95% level of confidence using a paired t-test.
‡ Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$) using a paired t-test.
§ IF = in-furrow P_2O_5 at 28, 56 kg ha^{-1}, and K_2O at 18, 37 kg ha^{-1}.
¶ SC = seed coat with a rate of P_2O_5 at 5.6, 11.1 kg ha^{-1}, and K_2O at 3.7, 7.3 kg ha^{-1}.
†† FST = fungicide seed treat.

Spring Stand Count 2013

Combined and analyzed spring stand count data from all locations were non-significant at both late and early planting dates (Table 10). Moreover, spring stand counts at individual locations did not show any differences between the early and late planting dates. It was anticipated that spring stand counts would indicate which planting date was superior for spring

re-growth. This did not occur, however, most likely due to the dry soil conditions at the early planting date which precluded early germination. It is presumed some seeds may have started germinating at the time of planting but did not have sufficient moisture to complete the process and died, or seeds may have deteriorated due to fungal or other soil pathogens while awaiting sufficient moisture to germinate. Stand count data collected in the spring tended to be higher than the fall stand counts. This could be due in part to the fact that not all the seeds planted emerged from the soil surface in the fall, but were able to emerge in the spring. This made analyzing fall stand counts and winter survival impractical.

Table 10. Planting date effects on spring stand count averaged over cultivars, P and K fertilizer and fungicide treatments at Hettinger, Williston, and Minot ND 2013.

Planting Date	Hettinger	Williston	Minot	Combined†
	---------- Seedlings m^{-2} ----------			
Early	88 a‡	109 a	124 a	107 a
Late	101 a	119 a	107 a	109 a

† Combined analysis of locations listed above, ran at the 95% level of confidence using a paired t-test.
‡ Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$) using a paired t-test.

At Williston and Minot, Jerry had better spring stand counts than did SY Wolf (Table 11). At Hettinger, SY Wolf had a higher stand count than did Jerry. The response at Williston and Minot is probably an effect of SY Wolf having higher winter injury than Jerry. Stand counts at Prosper and Lisbon were similar, for cultivars. This is probably due to the fact that these locations were planted into spring wheat stubble which captured more blowing snow. Therefore seedlings were better insulated from freezing temperatures during the winter months. Post-winter plant populations of HRWW tend to increase when stubble height is sufficient to catch snow and insulate the seedlings crown from extreme cold (Bauer and Black, 1990).

Table 11. Effects of cultivar on spring stand count averaged over planting date, P, and K fertilizer and fungicide treatments at Hettinger, Williston, Minot, Prosper, and Lisbon, ND 2013.

Cultivar	Hettinger	Williston	Minot	Prosper	Lisbon	Combined†
	---------- Seedlings m^{-2} ----------					
Jerry	84 b‡	123 a	126 a	89 a	92 a	76 a
SY Wolf	105 a	105 b	106 b	92 a	90 a	72 a

† Combined analysis of locations listed above, ran at the 95% level of confidence using a paired t-test.
‡ Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$) using a paired t-test.

At individual locations such as Hettinger, Prosper, and Williston spring stand counts did show a difference between P and K fertilizer and fungicide treatments (Table 12). However, treatments were not consistent at all locations. In Hettinger, the best stands were obtained with a FST, compared to the check. A fungicide seed treatment, and priming with water were significantly better than the check at Prosper. At Williston the check was superior to IF 28, IF 56, and SC High P, but was similar to the rest of the treatments. At Minot and Lisbon the fungicide seed treatment did not seem to have any effect on the spring stand count when compared to any of the other treatments.

Table 12. Effect of P and K fertilizer and fungicide treatments on spring stand count averaged over cultivars, and planting dates, at Hettinger, Williston, Minot, Prosper, and Lisbon, ND 2013.

Treatment	Hettinger	Williston	Minot	Prosper	Lisbon	Combined†
	---------- Seedlings m^{-2} ----------					
Check	87 b‡	138 ab	116 a	70 b	87 a	76 a
IF 28§	92 ab	75 e	128 a	93 ab	101 a	69 a
IF 56	87 b	100 cde	103 a	95 ab	94 a	68 a
SC Low P¶	98 ab	103 bcde	108 a	87 ab	109 a	71 a
SC High P	84 b	85 de	128 a	92 ab	86 a	68 a
Prime Water	87 b	116 abcd	102 a	104 a	100 a	71 a
Prime P	85 b	127 abc	111 a	91 ab	75 a	73 a
FST††	116 a	147 a	129 a	105 a	78 a	87 a
FST 28	101 ab	122 abc	118 a	85 ab	105 a	78 a
FST 56	108 ab	127 abc	117 a	85 ab	80 a	79 a

† Combined analysis of locations listed above, ran at the 95% level of confidence using a paired t-test.
‡ Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$) using a paired t-test.
§ IF = in-furrow P_2O_5 at 28, 56 kg ha^{-1}, and K_2O at 18, 37 kg ha^{-1}.
¶ SC = seed coat with a rate of P_2O_5 at 5.6, 11.1 kg ha^{-1}, and K_2O at 3.7, 7.3 kg ha^{-1}.
†† FST = fungicide seed treat.

There was a significant planting date x cultivar interaction at Minot and Williston for spring stand count which resulted from Jerry having a higher stand count than SY Wolf at the early planting date. There were no differences between cultivars at the later planting date (Table 13). Hettinger had greater spring stand counts from the later planting date than for the early planting date in contrast to Minot. SY Wolf at Hettinger had greater stand counts than Jerry at the later planting date. The reason for this is unknown. However, it may be that the dry soil conditions had a more negative impact on the earliest planted treatment, and SY Wolf was favored by the late germination more so than Jerry. Planting Jerry early at Williston shows a positive effect; unfortunately no significance was detected at the later planting date with either cultivar.

Table 13. Planting date x cultivar effects on spring stand counts averaged over P and K fertilizer and fungicide treatments at Hettinger, Williston, and Minot, ND 2013.

Planting Date	Cultivar	Hettinger	Williston	Minot	Combined†
		----------Seedlings m^{-2} ----------			
Early					
	Jerry	85 b‡	128 a	141 a	118 a
	SY Wolf	90 b	90 b	108 b	96 b
Late					
	Jerry	83 b	116 ab	111 b	103 ab
	SY Wolf	119 a	121 ab	104 b	115 a

† Combined analysis of locations listed above, ran at the 95% level of confidence using a paired t-test.
‡ Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$) using a paired t-test.

Yield 2013

Data from combined analysis of all locations showed that the early planting date had slightly higher yield than the later planting date but was not significant (Table 14). The effect of planting date, however, was not consistent across locations. The yields of the early and late planting dates were similar at Hettinger and Minot. At Williston the later planting date had higher yields. The opposite occurred at Prosper, where the early planting date had significantly higher yields than the late planting date. The effects of planting date on yield are similar to the spring and fall stand count data, which can help explain these differences in yield. Hettinger spring counts were 101 plants m^{-2} for the late as opposed to 86 plants m^{-2} for the early planting date (Table 10). This suggests that higher spring stand counts directly impacted yield. Paulsen (1987) found that adequate wheat stands are needed to achieve the optimal yield potential for the environment. Deficient stands limit grain yields and may increase the need for other production inputs. Yield data at Minot could have been skewed by weed pressure caused by delayed herbicide applications which was caused by a cool wet spring.

Table 14. Effects of planting date on yield averaged over cultivar, P and K fertilizer and fungicide treatments at Hettinger, Williston, Minot, and Prosper, ND 2013.

Planting Date	Hettinger	Williston	Minot	Prosper	Combined†
	---------- Mg ha^{-1} ----------				
Early	4.78 a‡	2.72 b	4.26 a	3.90 a	3.55 a
Late	5.03 a	3.22 a	4.02 a	3.18 b	3.43 a

† Combined analysis of locations listed above, ran at the 95% level of confidence using a paired t-test.
‡ Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$) using a paired t-test.

The effect of cultivar was the only factor that showed differences for yield when all locations were combined and analyzed (Table 15). The individual yield results at Williston, Minot and Prosper indicate that Jerry yielded better than SY Wolf. Under favorable conditions SY Wolf typically has higher yield potential than does Jerry. However, SY Wolf did have lower stand counts in the spring at both Williston and Minot, which could have resulted from winter kill (Table 11). Wiersma and Ransom (2005) suggested that winter wheat cultivar selection is critical for optimizing grain yield, grain quality, and reducing risk of winter kill and economic returns. Fowler (2013) suggested that winter kill can occur when long periods of exposure to temperatures approach the minimum survival temperature of the plant, thus reducing spring stand establishment. Fluctuation of temperature from freezing to non-freezing can also cause plants to become more susceptible to winter kill. SY Wolf is known to be much more sensitive to winter injury than Jerry (Ransom et al., 2012).

Table 15. Effects of cultivar on yield averaged over planting date, P and K fertilizer and fungicide treatments at Hettinger, Williston, Minot, and Prosper, ND 2013.

Cultivar	Hettinger	Williston	Minot	Prosper	Combined†
	---------- Mg ha^{-1} ----------				
Jerry	4.86 a‡	3.26 a	4.56 a	4.08 a	3.77 a
SY Wolf	4.97 a	2.66 b	3.71 b	2.99 b	3.21 b

† Combined analysis of locations listed above, ran at the 95% level of confidence using a paired t-test.
‡ Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$) using a paired t-test.

When data from all locations were combined and analyzed, P and K fertilizer and fungicide treatments did not significantly affect yield (Table 16). However, P and K fertilizer and fungicide treatments resulted in differences in yield at Hettinger. Both FST 28 and FST 56 were significantly higher yielding than Prime P, Prime Water, SC High P, SC Low P, IF 56 and the check. This suggests that the effect of a fungicide seed treatment with P and K in-furrow increased yield. The increase in yield could be an effect of the fungicide seed treatments, which protects the seed from soil born fungi allowing seedlings to become well established (Cook et al., 2002), while P fertilization could have increased the number of heads per plant (Sweeney et al. 2000), optimizing winter wheat yield.

Table 16. Effects of P and K fertilizer and fungicide treatments on yield averaged over planting date and cultivar at Hettinger, Williston, Minot, and Prosper ND, 2013.

Treatment	Hettinger	Williston	Minot	Prosper	Combined†
	---------- Mg ha^{-1} ----------				
Check	4.62 c‡	3.12 ab	4.32 ab	3.58 a	3.46 a
IF 28§	5.07 abc	2.62 b	4.14 ab	3.57 a	3.47 a
IF 56	4.88 bc	2.91 ab	4.10 ab	3.44 a	3.50 a
SC Low P¶	4.94 bc	2.85 ab	4.19 ab	3.64 a	3.52 a
SC High P	4.70 c	2.91 ab	4.19 ab	3.49 a	3.46 a
Prime Water	4.70 c	3.12 ab	4.04 ab	3.48 a	3.41 a
Prime P	4.70 c	2.61 b	4.11 ab	3.56 a	3.33 a
FST††	4.91 bc	3.26 a	4.44 a	3.63 a	3.61 a
FST 28	5.28 a	2.93 ab	3.98 b	3.53 a	3.54 a
FST 56	5.38 a	3.20 a	3.93 b	3.53 a	3.60 a

† Combined analysis of locations listed above, ran at the 95% level of confidence using a paired t-test.
‡ Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$) using a paired t-test.
§ IF = in-furrow P_2O_5 at 28, 56 kg ha^{-1}, and K_2O at 18, 37 kg ha^{-1}.
¶ SC = seed coat with a rate of P_2O_5 at 5.6, 11.1 kg ha^{-1}, and K_2O at 3.7, 7.3 kg ha^{-1}.
†† FST = fungicide seed treat.

Grain Protein 2013

At individual locations, cultivar was the most important factor impacting grain protein (Table 17). Hettinger and Williston both show Jerry having greater grain protein than SY Wolf, with the opposite result at Minot. The greater grain protein of SY Wolf compared to Jerry at Minot may be associated with the relatively low yield of SY Wolf at this location (Table 15). Terman et al. (1969) found that increases in yield usually result in a decrease of protein content in the grain, due to a dilution of the protein that is accumulated.

Table 17. Effect of cultivar on grain protein averaged over planting date, P and K fertilizer and fungicide treatments at Hettinger, Williston, Minot, and Prosper, ND 2013.

Cultivar	Hettinger	Williston	Minot	Prosper	Combined†
	---------- % Protein ----------				
Jerry	14.4 a‡	13.1 a	14.5 b	14.8 a	14.2 a
SY Wolf	13.9 b	12.8 b	15.4 a	14.9 a	14.3 a

† Combined analysis of locations listed above, ran at the 95% level of confidence using a paired t-test.
‡ Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$) using a paired t-test.

Phosphorus and K fertilizer and fungicide treatments did not have an effect on grain protein at Hettinger and Williston compared to the check (Table 18). However, at Minot, SC High P was better than the check, and at Prosper, FST 28, SC High P, and SC Low P were significantly better than the check.

Table 18. Phosphorus and K fertilizer and fungicide treatment effects on grain protein averaged across planting date and cultivar at Hettinger, Williston, Minot, and Prosper, ND 2013.

Treatment	Hettinger	Williston	Minot	Prosper	Combined†
	---------- % Protein ----------				
Check	14.2 ab‡	13.0 a	14.9 b	14.4 b	14.2 a
IF 28§	14.2 ab	13.1 a	15.0 ab	14.8 ab	14.4 a
IF 56	14.3 a	13.0 a	15.1 ab	14.9 ab	14.4 a
SC Low P¶	14.1 b	13.2 a	14.8 b	15.0 a	14.4 a
SC High P	14.3 a	13.1 a	15.3 a	15.1 a	14.5 a
Prime Water	14.2 ab	13.3 a	14.8 b	14.7 ab	14.3 a
Prime P	14.2 ab	12.2 b	14.9 b	14.9 ab	14.2 a
FST††	14.1 b	12.8 ab	14.9 ab	14.9 ab	14.2 a
FST 28	14.2 ab	12.7 ab	15.0 ab	15.1 a	14.4 a
FST 56	14.2 ab	12.9 a	14.9 ab	14.7 ab	14.3 a

† Combined analysis of locations listed above, ran at the 95% level of confidence using a paired t-test.
‡Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$) using a paired t-test.
§ IF = in-furrow P_2O_5 at 28, 56 kg ha^{-1}, and K_2O at 18, 37 kg ha^{-1}.
¶ SC = seed coat with a rate of P_2O_5 at 5.6, 11.1 kg ha^{-1}, and K_2O at 3.7, 7.3 kg ha^{-1}.
†† FST = fungicide seed treat.

The planting date x cultivar interaction for grain protein was significant at Hettinger (Table 19). Both early and late planting dates of Jerry were greater than SY Wolf. At Minot the effect of planting date x cultivar indicates that grain protein was greatest in SY Wolf, at the later planting date. Protein content in the late planted Jerry at Williston was greater than both early and late planted SY Wolf, but was similar to early planted Jerry. Due to the inconsistency of the results at each location the combined analysis of all locations does not show any significant differences between treatments.

Table 19. Effect of planting date x cultivar on grain protein averaged across P and K fertilizer and fungicide treatments at Hettinger, Williston, Minot, and Prosper ND 2013.

Treatment	Cultivar	Hettinger	Williston	Minot	Prosper	Combined†
		---------- % Protein ----------				
Early						
	Jerry	14.4 a‡	12.9 ab	14.5 c	14.9 a	14.2 a
	SY Wolf	14.1 b	12.7 b	15.2 b	14.7 a	14.3 a
Late						
	Jerry	14.5 a	13.3 a	14.5 c	14.7 a	14.3 a
	SY Wolf	13.8 c	12.9 b	15.6 a	15.0 a	14.5 a

† Combined analysis of locations listed above, ran at the 95% level of confidence using a paired t-test.
‡ Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$) using a paired t-test.

Seedling Survival

Cultivars differed significantly with seedling survival in the environment of the refrigeration chamber (Table 24). Jerry survived better than SY Wolf when subjected to -15^{0}C. These results are similar to the findings of Ransom et al. (2012). This difference was only expressed in the refrigeration chamber. Both cultivars were completely killed within the other environment when survival ratings were taken.

Table 20. Effect of cultivar on seedling survival averaged over P and K fertilizer, and fungicide seed treatments.

Cultivar	Greenhouse	Refrigeration Chamber
	---------- 0-5† ----------	
Jerry	0.0 a‡	2.3 a
SY Wolf	0.0 a	1.0 b

† Based on a visual score of 5 being the best.
‡ Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$) using a paired t-test.

Greenhouse Seedling

Seedling height was related to cultivar at individual runs and when runs were combined (Table 22). The results indicated that Jerry grew taller than SY Wolf. SY Wolf is considered a semi-dwarf cultivar, as compared to Jerry which is considered to be of conventional height (Ransom et al., 2012).

Table 21. Effect of cultivar on seedling height of two runs of the seedling vigor study, averaged over fertilizer.

Cultivar	Run 3	Run 4	Combined†
	---------- cm ----------		
Jerry	31.2 a‡	28.2 a	29.7 a
SY Wolf	23.4 b	26.2 a	24.8 b

† Combined analysis of locations listed above, ran at the 95% level of confidence using a paired t-test.
‡ Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$) using a paired t-test.

No differences were found on the effect of priming and seed coating P on plant height (Table 23). Dry weight data collected from this study did not indicate any significant differences between cultivars, and P and K fertilizer treatments. This excluded it from this text.

Table 22. Effect of priming and seed coating P and K on plant height of run 3, and run 4 of the seedling vigor study, averaged over cultivar.

Treatment	Run 3	Run 4	Combined†
	---------- cm ----------		
Check	29.7 a‡	28.2 a	28.9 a
Prime Water	26.2 a	27.7 a	26.9 a
Prime P	27.7 a	27.4 a	27.4 a
SC Low P§	22.6 a	27.7 a	25.1 a
SC High P	30.9 a	24.4 a	27.4 a

† Combined analysis of locations listed above, ran at the 95% level of confidence using a paired t-test.
‡ Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$) using a paired t-test.
§ SC=seed coat with a rate of P_2O_5 at 5.6, 11.1 kg ha^{-1}, and K_2O at 3.7, 7.3 kg ha^{-1}.

Greenhouse Emergence

The emergence of Jerry in the greenhouse was quicker than the emergence of SY Wolf when runs were combined (Table 20). In run one, Jerry emerged a day earlier than did SY Wolf, with the opposite occurring in run three.

Table 23. The effect of cultivar on emergence of four runs in the greenhouse of the seedling vigor study, averaged over P, K, and fungicide treatments.

Cultivar	Run 1	Run 2	Run 3	Run 4	Combined†
	---------- Days to Emergence ----------				
Jerry	3.3 a‡	3.3 a	3.7 b	3.3 a	3.4 a
SY Wolf	4.2 b	3.8 a	3.2 a	3.8 a	3.8 b

† Combined analysis of locations listed above, ran at the 95% level of confidence using a paired t-test.
‡ Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$) using a paired t-test.

In this greenhouse study, the FST 56 was the first to emerge at 9 days (Table 21). This was not significantly different from the check however, which emerged one day later. It was different though from all of the other treatments except FST, and the check. This suggests that seed priming did not hasten germination and emergence in the greenhouse. The cause of this is

probably associated with the high P level in the soil media that was used (Table 3). In the refrigeration chamber, seedlings took approximately four times as long to emerge compared to the greenhouse. No differences were detected amongst treatments in the refrigeration chamber.

Table 24. Effect of P and K fertilizer and fungicide treatments on emergence in the greenhouse, and refrigeration chamber, averaged over cultivars.

Treatment	Greenhouse	Refrigeration Chamber
	---------- Days to Emergence ----------	
Check	10 abc†	46 a
IF 28‡	12 bc	42 a
IF 56	11 bc	51 a
SC Low P§	12 c	49 a
SC High P	11 bc	44 a
Prime Water	11 bc	46 a
Prime P	12 c	48 a
FST¶	10 ab	43 a
FST 28	11 bc	45 a
FST 56	9 a	49 a

† Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$) using a paired t-test.
‡ IF = in-furrow P_2O_5 at 28, 56 kg ha^{-1}, and K_2O at 18, 37 kg ha^{-1}.
§ SC = seed coat with a rate of P_2O_5 at 5.6, 11.1 kg ha^{-1}, and K_2O at 3.7, 7.3 kg ha^{-1}.
¶ FST = fungicide seed treat.

CONCLUSIONS

The effect of planting date was not conclusive as soil moisture constrained emergence, especially in the early planted treatments in several of the environments. As a result, emergence occurred later and seedlings appeared smaller than optimal, and the beneficial effect of a larger seedling in the fall with earlier planting did not occur. However, the results indicate that although planting date may over many experiments be important, the presence and persistence of favorable soil moisture for seedling emergence and development is even more important.

Of the factors evaluated, cultivar was the most important. Jerry had close to 20% higher spring stand counts than SY Wolf in Minot and Williston. These data support the recommendation of growing winter hardy cultivars in North Dakota. Even though the yield potential of Jerry is less than that of SY Wolf, it consistently out-yielded it because of the superior spring stand associated with its better winter survival.

The P and K fertilizer and fungicide treatment results were not consistent across environments. The fungicide seed treatment results at Hettinger, Williston, and Minot had improved spring stand count and often yield when compared to other treatments, demonstrating the value of protecting seeds when conditions are favorable for disease. Seed priming hastened seedling emergence at Hettinger, and Lisbon. However, seed priming did not hasten emergence at any of the other two locations, or any run conducted in the greenhouse. Additional research is required to determine the effect of priming, and banding P and K fertilizer on, emergence, spring stand counts, and yield of winter wheat in North Dakota.

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APPENDIX

Table A1. ANOVA for fall stand count, spring stand count, yield, and protein at Hettinger, ND 2013.

		Fall SC†		Spring SC		Yield		Protein	
SOV†	df†	MS†	F Value	MS	F Value	MS	F Value	MS	F Value
REP	3	149.6	1.0	4166.5	0.6	183.9	1.2	0.8	4.18
A [Planting Date]	1	84870.0	261.2 **	7728.4	1.4	570.2	3.8	0.1	0.7
REP x A (error a)	3	149.6	0.4	6727.5	4.2 **	150.6	3.2 *	0.2	1.4
B [Cultivar]	1	200.2	0.6	17223.0	10.8 **	98.2	2.1	9.4	63.9 **
A x B	1	200.2	0.6	9455.6	5.9 *	236.7	5.1 *	1.1	7.3 **
C [Fertilizer]	9	1069.1	3.3 **	1903.3	1.2	217.8	4.7 **	0.1	1.0
A x C	9	1069.1	3.3 **	2159.7	1.3	80.3	1.7	0.1	0.4
B x C	9	603.4	1.9	2433.5	1.5	30.9	0.7	0.1	0.6
A x B x C	9	603.4	1.9	2174.1	1.4	62.1	1.3	0.1	1.0
Error	113	334.1		1600.4		46.5		0.1	

†SOV = source of variance, df = degrees of freedom, SC = stand count, MS = mean square

* ** Significant at ($p \leq 0.05$), ($p \leq 0.01$)

Table A2. ANOVA for fall stand count, spring stand count, yield, and protein at Minot, ND 2013.

		Fall SC†		Spring SC		Yield		Protein	
SOV†	df†	MS†	F Value	MS	F Value	MS	F Value	MS	F Value
REP	3	928.4	0.6	25669.0	9.3 *	627.8	1.3	0.9	7.5
A [Planting Date]	1	170564.0	114.7 **	11306.0	4.1	507.4	1.1	1.9	15.0 *
REP x A (error a)	3	1486.5	3.0 *	2765.1	1.5	464.2	5.4 **	0.3	0.4
B [Cultivar]	1	122.5	0.2	16749.0	9.2 **	6417.1	74.8 **	32.7	109.3 **
A x B	1	722.5	1.4	6540.8	3.6	38.1	0.4	1.2	4.0 *
C [Fertilizer]	9	1666.9	3.4 **	1587.5	0.9	73.9	0.9	0.4	1.4
A x C	9	1428.6	2.9 **	2212.5	1.2	124.5	1.4	0.2	0.6
B x C	9	240.65	0.5	3466.4	1.9	36.3	0.4	0.7	2.5 *
A x B x C	9	1044.5	2.1 *	875.7	0.5	109.3	1.3	0.2	0.8
Error	113	495.2		1814.3		85.7		0.3	

†SOV = source of variance, df = degrees of freedom, SC = stand count, MS = mean square

* ** Significant at ($p \leq 0.05$), ($p \leq 0.01$)

Table A3. ANOVA for fall stand count, spring stand count, yield, and protein at Prosper, ND 2013.

		Fall SC†		Spring SC		Yield		Protein	
SOV†	df†	MS†	F Value	MS	F Value	MS	F Value	MS	F Value
Rep	1	52434	1.0	27723.0	1.0	56.3	1.6	0.9	2.6
A [Cultivar]	1	47.3	0.3	19.6	0.14	10459.0	341.07 **	0.4	0.5
B [Fertilizer]	9	165.4	1.04	98.2	0.74	11.3	0.37	0.8	1.1
A x B	9	263.7	1.65	109.9	0.84	43.6	1.42	0.6	0.9
Error	19	159.4		130.9		30.7		0.7	

†SOV = source of variance, df = degrees of freedom, SC = stand count, MS = mean square
* ** Significant at ($p \leq 0.05$), ($p \leq 0.01$)

Table A4. ANOVA for spring stand count, yield, and protein at Williston, ND 2013.

		Spring SC†		Yield		Protein	
SOV†	df†	MS†	F Value	MS	F Value	MS	F Value
Rep	3	33846.0	3.8	2988.94	185.5 **	1.3	0.7
A [Planting Date]	1	3841.6	0.4	2439.19	151.4 **	3.8	1.9
Rep x A (error a)	3	8891.3	3.5 *	16.11	0.1	2.0	2.61
B [Cultivar]	1	11628.0	4.5 *	3459.04	27.7 **	4.21	5.4 *
A x B	1	18404.0	7.1 **	516.31	4.1 *	0.8	1.0
C [Fertilizer]	9	8338.7	3.2 **	176.34	1.4	1.3	1.7
A x C	9	2795.2	1.1	168.09	1.3	1.1	1.4
B x C	9	2018.1	0.8	197.49	1.6	0.2	0.3
A x B x C	9	2116.9	0.8	74.75	0.6	2.1	2.6 **
Error	113	2578.9		127.74		0.8	

†SOV = source of variance, df = degrees of freedom, SC = stand count, MS = mean square
* ** Significant at ($p \leq 0.05$), ($p \leq 0.01$)

Table A5. ANOVA for fall stand count, and spring stand count at Lisbon, ND 2013.

		Fall SC†		Spring SC	
SOV†	df†	MS†	F Value	MS	F Value
Rep	1	2900.8	1.0	28037.0	1.0
A Cultivar	1	0	0.0	11.0	0.1
B Fertilizer	9	186.9	6.3 **	143.8	0.8
A x B	9	0	0.0	96.8	0.5
Error	19	29.5		179.1	

†SOV = source of variance, df = degrees of freedom, SC = stand count, MS = mean square
* ** Significant at ($p \leq 0.05$), ($p \leq 0.01$)

Table A6. Combined ANOVA for fall stand count, spring stand count, yield, and protein at Hettinger, Williston, Minot, Prosper, and Lisbon, ND 2013.

		Fall SC†		Spring SC		Yield		Protein	
SOV†	df†	MS†	F Value	MS	F Value	MS	F Value	MS	F Value
Rep (location)	12	12178.0	19.0 **	29811.0	16.4 **	1005.3	9.9 **	1.1	2.0 *
Location	4	191286.0	15.7 **	361301.0	12.1 **	45444.0	45.2 **	109.3	99.9 **
A [Planting Date]	1	283655.0	62.4 **	56667.0	12.4 *	751.5	2.9	3.8	9.4
REP x A (error a)	3	4546.2	7.1 **	4565.0	2.5	257.7	2.5	0.4	0.7
B [Cultivar]	1	67.3	0.1	2201.2	1.2	13380.0	133.0 **	1.5	2.9
A x B	1	76.9	0.1	19553.0	10.7 **	415.9	4.13 *	0.8	1.6
C [Fertilizer]	9	566.4	0.9	3004.7	1.6	126.6	1.3	1.0	1.8
A x C	9	747.6	1.2	1881.6	1.0	66.3	0.7	0.4	0.8
B x C	9	233.2	0.4	2309.9	1.3	123.6	1.2	0.1	0.2
A x B x C	9	423.1	0.7	700.1	0.4	88.6	0.9	0.7	1.36
Error	733	640.4		1820.3		100.6		0.5	

†SOV = source of variance, df = degrees of freedom, SC = stand count, MS = mean square

* ** Significant at ($p \leq 0.05$), ($p \leq 0.01$)

Table A7. ANOVA for emergence, tillering, and dry weight for run 1, 2013.

		Emergence		Tillering		Dry Weight	
SOV†	df†	MS†	F Value	MS	F Value	MS	F Value
Rep	4	8.4	3.18 *	1.3	1.1	0.2	2.27
A [Cultivar]	1	20.2	30.56 **	2.0	1.65	0.0	0.53
B [Fertilizer]	9	2.9	0.48	1.6	1.34	0.0	0.62
A x B	9	0.7	1.12	1.2	1.05	0.1	0.84
Error	76	50.4		1.2		5.8	

†SOV = source of variance, df = degrees of freedom, MS = mean square
* ** Significant at ($p \leq 0.05$), ($p \leq 0.01$)

Table A8. ANOVA for emergence, tillering, and dry weight for run 2, 2013.

		Emergence		Tillering		Dry Weight	
SOV†	df†	MS†	F Value	MS	F Value	MS	F Value
Rep	4	0.9	0.9	2.2	2.7 *	0.2	3.8
A [Cultivar]	1	4.8	4.6 *	5.3	6.8 *	0.1	3.8
B [Fertilizer]	9	1.1	1.0	0.6	0.7	0.1	0.7
A x B	9	1.2	1.2	0.8	1.0	0.0	0.5
Error	76	1.0		0.8		0.0	

†SOV = source of variance, df = degrees of freedom, MS = mean square
* ** Significant at ($p \leq 0.05$), ($p \leq 0.01$)

Table A9. ANOVA for emergence, plant height, and dry weight for run 3, 2013.

		Emergence		Height		Dry Weight	
SOV†	df†	MS†	F Value	MS	F Value	MS	F Value
Rep	3	0.8	0.4	13.8	1.2	0.0	2.8
A [Cultivar]	1	2.5	1.3	96.9	8.4 **	0.0	27.4 **
B [Fertilizer]	4	1.1	0.6	13.3	1.1	0.0	1.1
A x B	4	1.4	0.7	11.2	1.0	0.0	0.7
Error	27	2.0		11.6		0.0	

†SOV = source of variance, df = degrees of freedom, MS = mean square
* ** Significant at ($p \leq 0.05$), ($p \leq 0.01$)

Table A10. ANOVA for emergence, plant height, and dry weight for run 4, 2013.

		Emergence		Height		Dry Weight	
SOV†	df†	MS†	F Value	MS	F Value	MS	F Value
Rep	3	2.4	3.68 *	2.1	0.5	0.0	0.7
A [Cultivar]	1	2.0	3.0	7.2	1.7	0.0	9.3 **
B [Fertilizer]	4	0.6	0.9	3.0	0.7	0.0	1.0
A x B	4	0.5	0.7	3.9	0.9	0.0	1.2
Error	27	0.7		4.4		0.0	

†SOV = source of variance, df = degrees of freedom, MS = mean square
* ** Significant at ($p \leq 0.05$), ($p \leq 0.01$)

Table A11. Combined ANOVA for emergence, plant height, and dry weight for run 3, and run 4, 2013.

		Emergence		Height		Dry Weight	
SOV†	df†	MS†	F Value	MS	F Value	MS	F Value
Rep	3	1.1	0.6	4.6	0.5	0.0	1.6
Rep (location)	4	1.7	1.3	8.4	1.0	0.0	47.2 **
A [Cultivar]	1	0.0	0.0	78.5	9.3 **	0.0	29.9 **
B [Fertilizer]	4	0.1	0.1	4.8	0.8	0.0	0.7
A x B	4	1.0	0.7	4.8	0.6	0.0	0.6
Error	27	1.3		8.7		0.0	

†SOV = source of variance, df = degrees of freedom, MS = mean square
* ** Significant at ($p \leq 0.05$), ($p \leq 0.01$)

Table A12. ANOVA for emergence, and survival at Refrigeration Chamber, 2013.

		Emergence		Survival	
SOV†	df†	MS†	F Value	MS	F Value
Rep	4	53.9	0.3	3.2	0.6
A [Cultivar]	1	171.1	1.1	40.6	8.2 **
B [Fertilizer]	9	79.8	0.5	3.4	0.7 **
A x B	9	76.9	0.5	0.9	0.2
Error	68	10977		4.9	

†SOV = source of variance, df = degrees of freedom, MS = mean square
* ** Significant at ($p \leq 0.05$), ($p \leq 0.01$)

Table A13. ANOVA for emergence, and survival at New GH, 2013.

		Emergence		Survival	
SOV†	df†	MS	F Value	MS	F Value
Rep	4	3.0	0.5	0.0	0.0
A [Cultivar]	1	1.4	0.2	0.0	0.0
B [Fertilizer]	9	11.6	2.0 *	0.0	0.0
A x B	9	3.2	0.6	0.0	0.0
Error	76	5.7		0.0	

†SOV = source of variance, df = degrees of freedom, MS = mean square
* ** Significant at ($p \leq 0.05$), ($p \leq 0.01$)