SCREENING HARD RED SPRING WHEAT CULTIVARS FOR REDUCED PHOSPHORUS FERTILIZER REQUIREMENT

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

Phosphorus (P) is a common macronutrient required for hard red spring (HRS) wheat (*Triticum aestivum* L.) growth and yield expression, and is a significant expense for farmers. The objective of this study was to screen 89 cultivars of historical, current, and pending HRS wheat genotypes for relative P requirement. The cultivars were grown in a greenhouse over two years, using four rates of sodium phosphate for a rate response to the fertilizer. The genotypes were assessed using the Klepper-Haun technique for Haun stage and tiller initiation, and the plant material was analyzed for total P. It was found that as P rate increased, so did dry matter production, Haun stage, tiller initiation, P concentration, and P uptake. Significant cultivar and P*cultivar interactions were observed and regression analysis indicated that rapidly developing cultivars tillered less and required more P fertilizer for initiation of T1 + T2 tillers than slowly developing cultivars.

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INTRODUCTION AND LITERATURE REVIEW

Ten soil-derived nutrients are essential to all plants including hard red spring (HRS) wheat (*Triticum aestivum* L.) for lifecycle completion; one of these nutrients is phosphorus (P). Phosphorus is one of the macro fertilizer nutrients HRS wheat needs for optimum growth and yield potential. It is a nutrient that is found at higher concentrations in young plant tissue and concentration tends to decrease as plants mature. The concentration of total P expressed on a dry matter basis for most plants is 0.1- 0.8% (Mengel and Kirkby, 2001; Raven et. al., 1986). The P is used in all plant organs for normal growth. Phosphorus is mobile within the plant. The nutrient is taken up by the roots into the xylem of the wheat plant and transported upward or downward through the phloem into the stems and leaves and from older leaves to younger leaves (Mengel and Kirkby, 2001; Raven et. al., 1986). When the P is taken up by the roots and stored in the phloem. During times of low need for P in the plant, the uptake is suppressed while in times of greater need, the uptake is activated (Mengel and Kirkby, 2001). Once the P has been taken up into the plant, it is converted into phospholipids, nucleic acids, nucleotides, coenzymes, adenosine triphosphate (ATP), adenosine diphosphate (ADP), adenosine monophosphate (AMP), and sugars (Raven et. al., 1986).

Phospholipids are made up of a glycerol atom attached to two fatty acids and a molecule of P which makes up the cellular membrane with the P end as hydrophilic and the fatty acid end as hydrophobic (Raven et. al., 1986). Phosphorus also contributes to nucleic acids that are made up of a phosphate group, sugar (pentose), and a nitrogenous base (Raven et. al., 1986). There are two nucleic acids, DNA (genetic information storage) and RNA (translation and transcription of genetic information) (Raven et. al., 1986). Phosphorus is also found in nucleotides, which are made up of a phosphate molecule and a nitrogenous base, two of these combined creates a dinucleotide and contributes to coenzymes such as nicotinamide adenine dinucleotide (Raven et. al., 1986). Adenosine triphosphate (ATP) is the main energy source for cells in plants and is composed of three phosphate groups, adenine, and sugar (ribose) (Raven et. al., 1986). When the plant cells use, the energy produced from the ATP, a phosphate group is removed and transferred to another molecule where phosphorylation occurs, the ATP then becomes ADP and if the process continues it will eventually become AMP (Raven et. al., 1986). Glucose and fructose are naturally formed sugars in plants and when a phosphate group is added to glucose or fructose by phosphorylation or the breakdown of ATP, it becomes sucrose, a source of energy for plants to use (Raven et. al., 1986).

When the plants use the P for growth, the amount of P in the tissue is greater in younger tissue than in older tissue (Mengel and Kirkby, 2001). In wheat, this occurs from plant emergence through vegetative growth, and as the plant reaches maturity, the plant tissues senesce, and most of the P taken up is transferred from the tissue to the seeds, especially in grain crops (Mengel and Kirkby, 2001). Mengel and Kirkby (2001) also found that as plants mature the nutrients nitrogen, potassium, calcium, and magnesium also decrease in most plants parts. As the amount of nutrients decrease in the plant with maturity it is recommended that if nutrient analysis is conducted the plant tissue sampling should be done at the same physiological stage (Mengel and Kirkby, 2001). As plants grow they remove nutrients from the soil for growth. Before the introduction of water-soluble P fertilizers, only manure and crop residues were available to supply P to the soil. With the introduction of modern P fertilizers, the occurrence of over fertilizing with any nutrient is possible. While only a small portion of P fertilizer is removed by a crop every year, the remaining fertilizer precipitates in the soil and with a continuous application of fertilizer the P pool increases (Alessi and Power, 1980). This increase helps to promote future crop-growth and enrichment of the surrounding soil (Alessi and Power, 1980).

Phosphorus is a naturally occurring nutrient in soil due to native phosphate minerals found in the soil. There are over 250 known minerals that contain phosphate in the world, the most common phosphate minerals found in the lithosphere come from the apatite family with 2% of the total P in the earth belonging to the apatite family, the other 98% of P in the earth are tied up in silicate minerals in the lower mantel and core and are unavailable (Sun and Nesbitt, 1977; Nriau and Moore, 1984; Smith, 1981). The native phosphate minerals are naturally formed from the lower mantel or the core of the earth (Nriau and Moore, 1984). The minerals are released in the form of igneous and metamorphic rocks that break down over time to release the minerals in more soluble forms. Many phosphorus-bearing minerals occur naturally in soil, or as a result of fertilization, such as brushite, monetite, whitlockite, crandallite, wavellite, taranakite, millisite, variscite, and strengite. From these common phosphates, the ionic forms that go into the soil solution and are available for plant uptake are dihydrogen phosphate ($H_2PO_4^-$) and hydrogen phosphate (HPO_4^{2-}), also known as orthophosphates (Havlin et. al., 2005; Lindsay, 1979).

The available ionic forms of P available in the soil solution depend on the pH of the soil. In acidic soils, plants take up $H_2PO_4^-$, while in alkaline soils, plants take up HPO_4^{2-}. The theoretical pH, when $H_2PO_4^-$ and HPO_4^{2-} are equal in the soil solution, would be 7.2 (Lindsay, 1979; Havlin et. al., 2005). Acidic soils have a greater ability to fix P than neutral or alkaline soils, due to reactions with aluminum and iron (Lindsay, 1979; Havlin et. al., 2005). To increase the available P in acid soils, the soil is limed; this increases the P solubility as acidic soils can fix up to two times more P than neutral or calcareous soils (Havlin et. al., 2005).

The adsorption and desorption of P in the soil is affected by the minerals in the soil that can come into contact with the solution and the pH (Lindsay, 1979; Havlin et. al., 2005). Many soils in the upper Midwest are near-neutral in pH or calcareous, and added P often precipitates as dicalcium phosphate (DCP) or dicalcium phosphate dihydrate (DCPD) in the soil solution (Lindsay, 1979). Over time these minerals will eventually return into apatite minerals (Lindsay, 1979; Havlin et. al., 2005). In calcareous soils, added P can also be adsorbed on calcium carbonate surfaces, as well as the surface of aluminum and iron oxides (Lindsay, 1979; Havlin et. al., 2005). In acidic soils, the activity of iron and aluminum is greater than in neutral or alkaline soils, and P fixation increases (Lindsay, 1979; Havlin et. al., 2005).

The concentration of the P solution in the soil depends on the P rate and the method in which the fertilizer is applied (Havlin et. al., 2005). When the soluble P in the soil solution decreases with plant uptake, P-bearing minerals will dissolve, resupplying the soil solution with soluble P (Havlin et. al., 2005). To keep the soil P solution at a certain concentration, soils that have a higher fixation rate need larger P fertilizer applications than soils that tend to fix less P (Havlin et. al., 2005). Methods of application also affects plant uptake. There are two common methods to apply P fertilizer to the soil, banding and broadcast incorporation. Band placement is where added P is placed with or near the seed, and is better used on soils that have low P levels or where the farmer must limit P application for economic reasons. Band application increases the utilization of the P fertilizer for plant uptake over broadcast and incorporated applications (Havlin et. al., 2005).

Phosphorus is the tenth most abundant mineral in the lithosphere at 0.1%, while 0.08% of the mineral total is found in the soil (Nriau and Moore, 1984). Typical values of total P in topsoil are between 0.005 to 0.15% (Lindsay, 1979; Havlin et. al., 2005). Phosphorus is found in both inorganic and organic forms in topsoil. Phosphorus fertilizers are made from rock phosphate. According to the 2016 United States Geological Survey (USGS), in 2015 the average cost of marketable phosphate rock was $73 per ton. The United States is one of the world's largest miners of phosphate rock for fertilizer production. In 2015, 26.1 million metric tons of phosphate rock was mined in Florida, North Carolina, Idaho, and Utah (USGS, 2016). Between imported phosphate rock and locally mined rock, the United States consumed 28.4 million metric tons with an average of 4.5 million metric tons of phosphate (P_2O_5) used in fertilizers every year. Due to finite resources, P has become an ever-increasing expense for agriculture around the world and the quality of the mineral fertilizer has begun to decline.

According to Van Vuuren et al. (2010), by 2100 more than half of the world's reserve, reserve base, and additional resources of phosphate rock will be depleted. As the high-quality ore around the world is depleted, mines are left with lower quality ore that has higher heavy metal content and other impurities than in previously-used deposits. To extract P from the rock phosphate, the ore is processed with sulfuric acid, forming phosphoric acid. From phosphoric acid, commercial P fertilizers like monoammonium phosphate (MAP), diammonium phosphate (DAP), and ammonium polyphosphate (APP) are produced. These are the most common P fertilizers used.

The MAP and DAP fertilizers are usually applied in granular form, and APP as a solution. These forms are all water-soluble fertilizers that dissolve rapidly in the soil allowing the nutrients to reach the roots of plants. In general, DAP should be applied away from the seed, or broadcast on the surface and incorporated before seeding, because the ammonium may cause seedling injury. This problem is greater in calcareous or alkaline soils (Havlin et. al., 2005). The use of MAP has increased over time, but DAP is still widely used, because ammonium can increase P uptake by the plant. When DAP dissolves in water, the pH increases to > 8, and when MAP dissolves in water, the pH decreases to < 4, so DAP is often preferred for acidic soils to raise the pH, and MAP is often preferred for alkaline soil, to lower the pH in the vicinity of the fertilizer granule (Lindsay, 1979; Havlin et. al., 2005). However, the final pH of DAP is lower than MAP, and is preferred in neutral to calcareous soils (Lindsay, 1979; Havlin et. al., 2005). Over time, the available P in soil is used by plants, or converted into less soluble forms, thus annual applications of P fertilizer are needed for most crops including HRS wheat.

There is evidence that wheat genotypes differ in P requirement. In one study, Liao et. al. (2008) screened 198 wheat genotypes on P deficient soil and selected 15 genotypes for further evaluation on two different soil types with two different soil P levels. The outcome showed there were significant differences between the shoot biomass and the P uptake in the P deficient and P sufficient soils (Liao et. al., 2008). Liao et. al. (2004) also found in an earlier greenhouse study with 18 wheat genotypes grown on two different soils that “differences in plant biomass and tissue P concentrations between genotypes resulted in significant genotypic differences in total phosphorus uptake.” They also found a positive correlation “between shoot biomass and total phosphorus uptake” (Liao et. al. 2004) speculating that shoot biomass could be a parameter of a measure for P uptake efficiency testing (Ozturk et. al. 2005).

Ozturk et. al. (2005) conducted a greenhouse study in Turkey where 39 HRS wheat and 34 durum wheat (*Triticum durum* L.) genotypes were grown with a soil that was deficient in soil P and two rates of P were added to determine a rate response. The number of genotypes of the HRS and durum wheat cultivars allowed for genetic variation in P efficiency. From the study, it was concluded that the ability of a genotype to take up P is an important factor for P efficiency (Ozturk et. al., 2005). It was also concluded “shoot dry matter production and total amount of P per shoot at low P rate were the most reliable parameters in assessing wheat genotypes for their P efficiency at the vegetative stage." They concluded that studies like this will assist in the future for breeding P efficient genotypes that will also produce high yields (Ozturk et. al., 2005). In these prior studies, the response of wheat plants was measured using growth and P uptake as response factors for identification of cultivars with lower P fertilizer requirement. None of these earlier studies (Liao et. al., 2004, Liao et. al., 2008, Ozturk et. al., 2005) screening wheat cultivars for relative P requirement used the precise methods of Klepper et al. (1982) and Haun (1973) to document plant development as a function of P fertilization.

Klepper and colleagues developed a quantitative characterization of the vegetative development in small cereal grains by providing a precise method of documenting leaf and tiller formation. While studying smaller plants, it was noted that the system of Feekes (Large, 1954) would not adequately differentiate the early development stages, as tillering began at Feekes stage 2 and ended at Feekes stage 3 (Klepper et. al., 1982). In 1973, Haun developed a method to measure the degree of main stem development by the number of leaves produced on the stem, but the tillers were not included in his method (Klepper et. al., 1982). Jewiss (1972) developed a method for describing and numbering the tillers produced on a grass plant. Later Klepper and coworkers developed a method that incorporated both Haun's and Jewiss's methods into one, to give a detailed description of a growing wheat plant (Klepper et. al., 1982).

Klepper et. al. (1982) uses the Haun stage to first number the leaves on the main stem. Haun scores the leaves as 1, 2, 3, and so on counting how many leaves are growing off the main stem. When a partial leaf is formed, that leaf would be compared to the last fully grown leaf and numbered according to how close the leaf was to maturity. For example, if there were six mature fully expanded leaves and a seventh partially grown leaf that only came up half way on the sixth leaf, the main stem Haun stage of the plant would be labeled as 6.5 according to the method by Klepper et. al. (1982). Klepper then added Jewiss's method to Haun's to number the leaves and tillers.

The leaves of the main stem "are numbered acropetally" as L1, L2, L3 and so on "beginning with the first leaf". The tillers that grow from the main stem are numbered according to the "leaf that subtends them". Therefore, the tiller growing from the axil of L1 would be T1 and the tiller growing from the axil of L2 is T2. This continues for every tiller growing from the main stem. The leaves grown from each tiller are then numbered according to the main stem leaf and tiller with two digits. The first leaf from the first tiller of the first main leaf is labeled as L11 and the second is L12, this can be done for each leaf at each tiller on the entire plant. As plants get larger, tillers can form tillers, called subtillers. For example, the tiller that forms from the base of leaf 1 of tiller T1 (leaf L11), would be identified as T11 tiller. So, the first leaf, L1, can have a T1 tiller with one or even two subtillers labeled as T10 (from the junction of leaf 1 and the main stem), and T11 (from the base of L11). This system can become quite complex by the time a wheat plant reaches full maturity, but is capable, in theory, of quantitative identification of every leaf and culm on a wheat plant.

Preliminary studies in the 1990s in North Dakota indicated that wheat cultivars differ in P requirement, with fast-growing cultivars like Butte 86 requiring more P for tillering and grain yield than slower-growing cultivars like Marshall (Fanning and Goos, 1992; Goos, 1995). The objectives of this study were: 1) to screen historical HRS wheat cultivars for their relative need for P fertilizer, 2) to screen current and pending HRS wheat cultivars for their relative need for P fertilizer, and 3) to provide a detailed database of the nature of main stem and tiller development of these cultivars, along with their P response characteristics, for the possible subsequent studies to discover of the genetic markers for these traits. Two studies encompassed 89 HRS wheat cultivars, to understand the complex nature of wheat response to P and to potentially identify P efficient wheat cultivars for production of tillers, relative yield, etc. The screening of the HRS wheat cultivars using the Klepper-Haun system as well as by growth and P uptake should increase our understanding how this important crop responds to this important nutrient.

MATERIALS AND METHODS

Screening Historical Hard Red Spring Wheat Cultivars for Phosphorus Fertilizer Efficiency

Historical HRS wheat cultivars (USDA-GRIN, 2016) were screened during 2015 at the USDA Northern Crops greenhouse on the North Dakota State University campus. The experimental design was a randomized complete block design with a split plot, which consisted of 47 historical HRS wheat cultivars, four rates of P applied as sodium phosphate fertilizer, and four replications. Each replicate was split by four rates of P, and the 47 cultivars randomized within each rate of P. Due to the number of pots in one replication, and the time required to grow the plants to a target stage of growth, one replication of the plants was grown for one month, so that the four replications were grown over a four-month period. To illustrate one replication: there were four pots of each of the 47 cultivars with each cultivar treated with the four fertilization rates totaling 188 pots. For four replications, there were 752 pots of wheat grown over four months in the greenhouse.

The soil that was used for the experiment was an unfertilized Renshaw topsoil (0-15cm) collected from the Central Grasslands Research Extension Center (46.71515°, -99.44852°) in the summer of 2011. The Renshaw soil classification is a "fine-loamy soil over sandy or sandy-skeletal, mixed, superactive, frigid Calcic Hapludoll" that is usually excessively drained and runoff is negligible to high (Soil Survey Staff, 2004). The soil is usually cropped with small grains and alfalfa and the soil series is distributed throughout eastern North Dakota and Western Minnesota. The field where the soil was collected had not been fertilized with P for many years, making it a suitable soil for conducting P uptake efficiency experiments. The soil was collected in the field, air-dried on greenhouse benches, mixed every day during the drying process, crushed to pass through a 2-mm screen, and mixed again. An experimental unit consisted of a one liter closed-bottom greenhouse pot lined with a plastic bag that held one kg of soil: sand mixture. The soil mixture was 500 grams of Renshaw sandy loam soil and 500 grams of 20-40 mesh white sand. Each bag of sand was treated with two basal fertilizer treatment solutions, the P treatment solution and then mixed with the soil. A sample of the topsoil was tested at the North Dakota State University Soil Testing Laboratory to determine the nutrient content and chemical composition of the soil. Table A1 shows soil tests for two years. The two batches of soil were collected in the same location 3 years apart with similar soil test results as there was not enough soil for both experiments from the 2011 batch.

The two basal solutions provided 50 mg of N, 70 mg of potassium, 10 mg of sulfur, 8 mg of magnesium, 1 mg of manganese, 1 mg of copper, 1 mg of zinc, 0.1 mg of boron, and 0.1 mg of iron (Table A2). The basal levels of nutrients were based on plant uptake estimates, and prior experience of growing wheat in the greenhouse on this soil. Only one rate of sodium phosphate fertilizer was added to each fertilized pot, and the rates were 0, 5, 10, and 20 mg of P.

After adding the two basal fertilizer solutions and the P treatment solutions with the sand, the sand was mixed. The sand was mixed with soil, placed in the pot, and 100 mL of the sand: soil mixture removed. One hundred mL of water was added to each pot, and the nutrients allowed to react with the soil for one week. Eight seeds per cultivar sown into each pot and the 100 mL of soil, previously reserved, were used to cover the seed. A filter paper was placed on the surface of the soil that was moistened with 10 mL of water twice a day to retain the moisture for germination of the seeds. Ammonium nitrate was added one week after seeding as a top-dress solution to provide an additional 50 mg of N. The pots were thinned to four plants per pot, watered every day with distilled water to a predetermined weight that was chosen during planting. The weight was determined by averaging the weight of the pots after the seeds were sown and the 100 mg of soil added back into the pot. The plants were grown in the greenhouse until the average number of leaves on the main stem was between 5.5 and 6.0 Haun stage at the highest P rate of 20 mg for the cultivar Butte.

During harvest of each replicate, all plants in each pot were then analyzed for the main stem Haun stage, the presence of tiller 0 (T0) also known as a coleoptile tiller, tiller 1 (T1), and tiller 2 (T2). Later tillers, such as tiller 3 (T3) and subtiller 10 (T10) were placed in the "other" tiller category. The plants were then cut off at the soil surface, all four plants of each sample were placed into one bag, dried at 65 °C and the dry weight recorded. The four plants ground to <0.1 mm as one combined sample. A 0.2 g sample of plant material was dry ashed at 550 °C and analyzed colorimetrically for total P content using the molybdate blue method with a spectrophotometer (Frank et.al., 2012). A list of the historic cultivars, place of origin, and year of release is listed in Table A3.

The data were analyzed using the Proc ANOVA module of SAS for F-protected LSD (P=0.05) for mean separation (SAS, 2016). All the direct measurements were analyzed, as well as variables derived from these measurements. Relative dry matter yield was calculated as $100*A*B^{-1}$, where A is the dry matter yield for a given cultivar at 0, 5, or 10 mg P pot^{-1}, and B is the dry matter yield for a given cultivar at 20 mg P pot^{-1}. Phosphorus uptake was calculated as: C=D*E*10, where C= P uptake, mg pot^{-1}, D= dry matter yield, g pot^{-1}, and E= P concentration in the plant tissue. Phosphorus uptake efficiency (PUE) was calculated as: $PUE= 100 *(F- G) *H^{-1}$, where F= the P uptake by a given cultivar at 5, 10, or 20 mg pot^{-1} of P, G= the P uptake by a given cultivar at 0 mg pot^{-1} of P, and H= the rate of P represented by F (5, 10, or 20 mg P pot^{-1}).

Screening Current and Pending Hard Red Spring Wheat Cultivars for Phosphorus Fertilizer Efficiency

The experiment to screen the current and pending HRS wheat cultivars was conducted in the USDA Northern Crops Science Lab greenhouse on North Dakota State University campus in 2016. The experimental design was identical to the experimental design for the historic cultivars, except for the cultivars used. There were 38 current and pending HRS wheat cultivars, 4 historic cultivars, four rates of sodium phosphate fertilizer, and four replications. The four reference cultivars included two cultivars with a relatively low P requirement (Marshall, World Seeds 1812) and two cultivars with a relatively high P requirement (Butte, 2375). There were four pots of each of the 42 cultivars with each cultivar treated with the four P rates adding up to a total of 168 pots, with four replications there were 672 pots of wheat grown over four months.

The procedures used to prepare the soil for seeding were the same as those used for the historic cultivars. The soil was collected in 2014 from the same location in the same field sampled in 2011. A sample of the topsoil (0-15 cm) was also tested at the North Dakota State University Soil Testing Laboratory and the results were similar, except that the soil test for P was somewhat higher, 10 mg kg^{-1} in 2016, versus 8 mg kg^{-1} in 2015 (Table A1). The measurements of plant development, tillering, etc., analysis, were the same as for the historical cultivars, except that T10 and T3 tillers were also identified, and not placed in the "other" category. A list of the current and pending cultivars, place of origin, and year of release is shown in Table A4. Methods of chemical analysis of the plant material, and statistical analyses were the same.

RESULTS AND DISCUSSION

Phosphorus Effect on Historical Cultivars

The 47 historical cultivars grown in 2015 were evaluated on 12 variables to determine the overall effect of P on the cultivars. The variables evaluated were dry matter production (Table A5), dry matter relative yield (Table A6), main stem Haun stage (Table A7), T0 tiller initiation (Table A8), T1 tiller initiation (Table A9), T2 tiller initiation (Table A10), T1 + T2 tiller initiation (Table A11), other tiller initiation (Table A12), total tiller initiation (Table A13), P concentration in plant tissue (Table A14), P uptake (Table A15), and P uptake efficiency (Table A16).

The effects of cultivar, P fertilization, and the P rate on plant dry matter production are shown in Table A5. The cultivar effect was highly significant ($P < 0.0001$). Averaged across P rates, dry matter production ranged from 1.4 g P pot^{-1} for Era, to 2.3 g P pot^{-1} for Selkirk. Regarding the P*cultivar interaction, an example would be to compare Era and Selkirk. Adding 20 mg P increased the yield of Era by 0.8 g pot^{-1} over the control of 0 mg P, (0.9 to 1.7), but adding 20 mg of P to Selkirk increased yield by 1.4 g pot^{-1} (1.5 to 3.0). Averaged across cultivar, dry matter production was 1.2, 1.6, 2.1, and 2.3 g pot^{-1} for 0, 5, 10, and 20 mg P pot^{-1}, respectively.

The effect of cultivar and P rate on dry matter relative yield, relative to the 20 mg rate, is shown in Table A6. The F tests for cultivar and P rate were both significant, but the interaction was not significant. Averaged across 0, 5, and 10 mg P, Wared showed the largest relative dry matter response to P, with 59.7% relative yield, by contrast, Oslo showed the least response to P, with an average relative yield of 76.3%. Average across cultivar, relative dry matter yield was 50.6, 70.5, 88.8, and 100% for 0, 5, 10, and 20 mg P pot^{-1}, respectively.

The effect of cultivar, P rate, and the P*cultivar interaction on main stem Haun stage is shown in Table A7. The F tests for cultivar and P rate were significant, but the interaction was not. Averaged across P rate, the number of leaves on the main stem ranged from 4.8 leaves $plant^{-1}$ for Renown to 6.4 leaves $plant^{-1}$ for Butte, a range of over 1.5 leaves $plant^{-1}$. Rate of main stem development is an important component of heading date and maturity, and cultivars differed greatly with regards to this parameter. Averaged across cultivar, there were 5.2, 5.5, 5.5, and 5.6 leaves $plant^{-1}$ on the main stem Haun stage for 0, 5, 10, and 20 mg P pot^{-1}, respectively.

The effect of cultivar and P rate on T0 tiller initiation is shown in Table A8. The F tests for cultivar, P rate, and P*cultivar interaction were all significant. Cultivars differed greatly in their ability to initiate T0 tillers. Averaged across P rate, the initiation of T0 tillers ranged from 0 tillers $plant^{-1}$ for Butte, Stoa, and Gus to 0.6 tillers $plant^{-1}$ for Marquis. Averaged across cultivar the T0 tiller initiation was 0, 0.1, 0.2, and 0.4 tillers $plant^{-1}$ for 0, 5, 10, and 20 mg P pot^{-1}, respectively.

The effect of cultivar and P rate on T1 tiller initiation is shown in Table A9. The F tests for cultivar, P rate, and P*cultivar interaction were all significant. At 0 mg World Seeds 1809 and Stoa did not produce any T1 tillers, while Selkirk, and World Seeds 1812 initiated 0.9 T1 tillers $plant^{-1}$ at 0 mg P pot^{-1}. The cultivars differed in how much P was required for >0.9 T1 tillers $plant^{-1}$. For example, World Seeds 1809 required 20 mg P pot^{-1}, whereas most cultivars reached this level of tiller initiation with 5 mg P pot^{-1}. Averaged across P rate, the production of T1 ranged from 0.4 tillers $plant^{-1}$ for World Seeds 1809 to 1.0 tillers $plant^{-1}$ for World Seeds 1812. Averaged across cultivar the T1 tiller initiation was 0.5, 0.9, 1.0, and 1.0 tillers $plant^{-1}$ for 0, 5, 10, and 20 mg P pot^{-1}, respectively.

The effect of cultivar and P rate on T2 tiller initiation is shown in Table A10. The F tests for cultivar, P rate, and P*cultivar interaction were all significant. At 0 mg, most of the cultivars did not produce any T2 tillers, while World Seeds 1812 and Renown produced over 0.4 T2 tillers plant^{-1} without P fertilization. At 5 mg Renown was the only cultivar to reach 0.9 T2 tillers plant^{-1}. With an increase of P many cultivars reached 0.9-1.0 T2 tillers plant^{-1}. Averaged across P rate, the production of T2 ranged from 0.2 T2 tillers plant^{-1} for Lee and 2369 to 0.8 tillers plant^{-1} for Renown. Averaged across cultivar the T2 tiller initiation was 0, 0.3, 0.8, and 0.9 tillers plant^{-1} for 0, 5, 10, and 20 mg P pot^{-1}, respectively. In general, it took more P for adequate T2 tillering than for adequate T1 tillering.

The effect of cultivar and P rate on T1 + T2 tiller initiation is shown in Table A11. The F tests for cultivar, P rate, and P*cultivar interaction were all significant. At 0 mg, there were no cultivars that had initiated 90% of their T1 + T2 tillers (1.8 tillers plant^{-1}), while at 5 mg Renown and World Seeds 1812 produced over 1.8 T1 + T2 tillers plant^{-1}. With an increase of P most cultivars reached 1.8 - 2.0 T1 + T2 tillers plant^{-1}, but five cultivars did not reach 1.8 T1 + T2 tillers plant^{-1}, even with 20 mg P pot^{-1}. It has been previously shown in field studies that 1.8 T1 + T2 tillers plant^{-1} is a good indicator of adequate early-season nutrition of wheat for both phosphorus (Goos and Johnson, 2001, Goos et. al., 1994), and nitrogen (Goos and Johnson, 1999, Goos et. al., 1999). Adequate initiation of T1 + T2 tillers is important, as >90% of grain yield comes from the main stem, T1, and T2 tillering (Goos and Johnson, 1996). Averaged across P rate, the production of T1 + T2 ranged from 0.8 tillers plant^{-1} for World Seeds 1809 and 1.8 tillers plant^{-1} for World Seeds 1812. Averaged across cultivar the T1 + T2 tiller initiation was 0.5, 1.2, 1.7, and 1.9 tillers plant^{-1} for 0, 5, 10, and 20 mg P pot^{-1}, respectively. To show the range in P requirements for T1 + T2 tillering, the response of the cultivars World Seeds 1812, Renown, Olaf, 2369, Lee, and World Seeds 1809 are shown in Figure B1.

The effect of cultivar and P rate on later ("other") tiller initiation is shown in Table A12. The F tests for cultivar, P rate, and P*cultivar interaction were all significant. All other tiller types included T10, T11, T20, and T21 were recorded as "other" in 2015. Most of the cultivars produced no other tillers. However, the cultivars Kitt, World Seeds 1812, and Renown produced over 0.6 other tillers plant^{-1} at the 20 mg rate. Averaged across cultivar the other tiller initiation was 0, 0, 0.1, and 0.2 tillers plant^{-1} for 0, 5, 10, and 20 mg P pot^{-1}, respectively.

The effect of cultivar and P rate on total tiller initiation is shown in Table A13. The F tests for cultivar, P rate, and P*cultivar interaction were all significant. At the 5 mg rate the cultivars Marquis, Renown, and World Seeds 1812 produced greater than 2 tillers plant^{-1} and with 10 mg the cultivar World Seeds 1812 produced more than 3 tillers plant^{-1}. When 20 mg was added 6 cultivars produced less than 2 tillers plant^{-1} and 9 cultivars produced greater than 3 tillers plant^{-1}. Averaged across P rate, the production of total tillers ranged from 0.8 tillers plant^{-1} for World Seeds 1809 to 2.7 tillers plant^{-1} for World Seeds 1812. Averaged across cultivar the total tiller initiation was 0.5, 1.3, 2.0, and 2.5 tillers plant^{-1} for 0, 5, 10, and 20 mg P pot^{-1}, respectively.

The effect of cultivar and P rate on P concentration in plant tissue is shown in Table A14. The F tests for cultivar and P rate were significant while P*cultivar interaction was not significant. With an increase of P, the P concentration in plant tissue also increased. At the 20 mg rate the cultivars Renown and Lee had 0.3% of P in the plant tissue and Marshall had 0.5% P. Averaged across P rate, the P concentration ranged from 0.2% for Renown to 0.3% for Marshall.

Averaged across cultivar the P in plant tissue was 0.2, 0.2, 0.3, and 0.4% for 0, 5, 10, and 20 mg P pot^{-1}, respectively.

The effect of cultivar and P rate on plant P uptake is shown in Table A15. The F tests for cultivar and P rate were significant while P*cultivar interaction was not significant. With an increase of P fertilizer, the P uptake also increased. Averaged across P rate, the P uptake ranged from 3.9 mg pot^{-1} for Walera to 5.5 mg pot^{-1} for 2375. Averaged across cultivar the P uptake was 1.8, 3.2, 5.1, and 8.3 mg pot^{-1} for 0, 5, 10, and 20 mg P pot^{-1}, respectively.

The effect of cultivar and P rate on PUE is shown in Table A16. The F tests for cultivar was significant, and the F tests for P rate and P*cultivar interaction were not significant. Averaged across P rate, the PUE ranged from 26% with Chris to 38% for the cultivar 2375. These two cultivars had similar concentrations of P in the plant tissue (Table A14), but 2375 had a greater increase in dry matter production with added P (Table A5), thus providing for a greater PUE with 2375. Averaged across cultivar the PUE was 29.2, 33.0, and 32.8% for 5, 10, and 20 mg P pot^{-1}, respectively. These values are higher than commonly observed in the field (Alessi and Power, 1980). These results were obtained in a closed system with intense rooting whereas in the field P would not be in as close contact with the roots.

Table A17 summarizes the experiment with the historical cultivars. The Renshaw soil had a limited history of P fertilization, and addition of P fertilizer significantly increased all the plant growth and development parameters measured, such as dry matter, main stem Haun stage, and tillering at all positions. Averaged across P rate, cultivar effects were significant for all measured parameters, except for PUE. To determine which factors varied the most among cultivars, a “relative range” of the cultivar averages was calculated as: relative range, %= 100*(I-J) $*L^{-1}$, where I=the greatest cultivar average, averaged across P rate, J= the least cultivar average, averaged across P rate, and L= the average for all cultivars, averaged across P rates. The relative range was the least, 23%, for dry matter relative yield, that is, the dry matter yield at 0, 5, or 10 mg P pot^{-1}, divided by the dry matter yield at 20 mg P pot^{-1}. Many parameters (MS Haun, P concentration, P uptake, PUE) had a range of 30-37% among cultivars, averaged across P rate. Dry matter production had a relative range of 52%. By far, however, the greatest differences between cultivars were observed with tillering, ranging from 67% with T1 tillering to 880% for later-appearing tillers (tillers other than T0, T1, and T2).

Correlations were performed between selected variables. Some of the variables were taken at the highest rate of P, 20 mg P pot^{-1}, and are considered to be characteristics of the cultivars in the absence of P deficiency. Other variables were taken as the value for each cultivar, averaged across P rate, and are considered to be a measure of the responsiveness of each cultivar to P fertilization. For example, in Table A11, the cultivar World Seeds 1809 had a large P requirement for T1 + T2 tiller initiation, producing 0, 0.3, 0.9, and 1.8 T1 + T2 tillers plant^{-1} at 0, 5, 10, and 20 mg P pot^{-1} respectively. By contrast, World Seeds 1812 had a much lower P requirement for T1 + T2 tiller initiation, giving 1.4, 1.9, 2.0, and 2.0 T1 + T2 tillers plant^{-1} at 0, 5, 10, and 20 mg P pot^{-1}, respectively. These differences are integrated into a single value by averaging across P rate, 0.8 and 1.8 T1 + T2 tillers plant^{-1} for World Seeds 1809 and 1812, respectively. The data used for the correlation analyses are shown in Table A18.

The selected variables were correlated with dry matter production at 20 mg P pot^{-1}, and main stem Haun stage at 20 mg P pot^{-1}. In other words, how do cultivar characteristics and P-response characteristics correlate with cultivars that grow fast (greater dry matter production), or develop fast (greater number of leaves on the main stem)? These correlations are shown in Table A19.

Dry matter production at the highest P rate was not significantly correlated with main stem Haun stage or tiller initiation at the highest P rate. However, main stem Haun stage at the highest P rate was negatively correlated with tiller initiation at all positions measured, being statistically significant for T0, T1, and total tiller initiation. In other words, cultivars that developed the fastest, requiring the fewest growing degree days to produce a new leaf on the main stem, tended to tiller less than cultivars that develop more slowly.

Dry matter production at the highest P rate was not correlated to dry matter relative yield, averaged across P rate, suggesting that the P requirement for dry matter production did not differ between faster and slower growing cultivars. P concentration in the plant tissue, averaged across P rate, was negatively correlated with dry matter production at the highest P rate. It is to be expected, at a fixed rate of a nutrient, that the concentration of the nutrient in the plant tissue would go down, as dry matter production increases. Phosphorus uptake and PUE were positively correlated with dry matter production, indicating that faster-growing cultivars were better able to take up and recover P added to the soil.

Main stem Haun stage at the highest P rate was positively correlated with P uptake, averaged across P rate. This suggests that faster developing cultivars take up P more readily than slower developing cultivars. Main stem Haun stage was negatively correlated with T1 + T2 tiller initiation, averaged across P rate. This suggests that, in general, the more rapid the normal main stem development of a cultivar, the more P fertilizer is needed for full initiation of T1 + T2 tillers. This agrees with observations in the 1990s, where the rapidly developing cultivar Butte 86 required more P than the more slowly developing cultivar Marshall. (Fanning and Goos, 1992; Goos, 1995).

Phosphorus Effect on Current and Pending Cultivars

The 38 current and pending cultivars and four historical cultivars grown in 2016 were evaluated on 14 variables to determine the overall effect of P on the cultivars. The variables evaluated were dry matter production (Table A20), dry matter relative yield (Table A21), main stem Haun stage (Table A22), T0 tiller initiation (Table A23), T1 tiller initiation (Table A24), T2 tiller initiation (Table A25), T1 + T2 tiller initiation (Table A26), T3 tiller initiation (Table A27), T10 tiller initiation (Table A28), other tiller initiation (Table A29), total tiller initiation (Table A30), P concentration in plant tissue (Table A31), P uptake (Table A32), and P uptake efficiency (Table A33).

The effects of cultivar, P fertilization, and the P*cultivar interaction on plant dry matter production are shown in Table A20. The F tests for cultivar and P rate were both significant, and the interaction was not significant. Averaged across P rates, dry matter production ranged from 1.5 g pot^{-1} for HRS-3419, to 2.2 g pot^{-1} for Select, Brick, and Prevail. Averaged across cultivar, relative dry matter production was 1.4, 1.9, 2.0, and 2.2 g for 0, 5, 10, and 20 mg P pot^{-1}, respectively.

The effect of cultivar and P rate on dry matter relative yield, relative to the 20 mg rate, is shown in Table A21. The F tests for cultivar and P rate were both significant, and the interaction was not significant. Averaged across 0, 5, and 10 mg P, 2375 showed the largest relative dry matter response to P, with 75.6% relative yield, by contrast, Velva showed the least relative dry matter response to P, with an average relative yield of 90.9%. Averaged across cultivar, relative dry matter yield was 65.8, 85.6, 93.2, and 100% for 0, 5, 10, and 20 mg P pot^{-1}, respectively.

The effect of cultivar, P rate, and the P rate on main stem Haun stage is shown on Table A22. The F tests for cultivar and P rate were significant, but the interaction was not. Averaged across P rate, the number of leaves on the main stem ranged from 5.0 for MS-Stingray to 6.5 leaves plant^{-1} for LCS-Breakaway, a difference of about 1.5 leaves plant^{-1}, similar to that observed for the historic cultivars (Table A7). Averaged across cultivar, there were 5.6, 5.7, 5.7, and 5.7 leaves plant^{-1} on the main stem Haun stage for 0, 5, 10, and 20 mg P pot^{-1}, respectively.

The effect of cultivar and P rate on T0 tiller initiation is shown in Table A23. The F tests for cultivar, P rate, and P*cultivar interaction were all significant. An example of a P*cultivar interaction would be that some cultivars (HRS-3419 and Butte) did not produce any T0 tillers, regardless of P rate, while others (MS-Chevelle, World Seeds 1812) had almost complete initiation of T0 tillers at the highest rate of P. Averaged across cultivar, the T0 tiller initiation was 0, 0.1, 0.2, and 0.3 tillers plant^{-1} for 0, 5, 10, and 20 mg P pot^{-1}, respectively.

The effect of cultivar and P rate on T1 tiller initiation is shown in Table A24. The F tests for cultivar, P rate, and P*cultivar interaction were all significant. At 0 mg 16 cultivars initiated 0.9-1.0 T1 tillers plant^{-1}. The cultivar LCS-Breakaway was the only cultivar that had not reached 0.9 tillers plant^{-1} at the 10 mg rate. At 20 mg P pot^{-1}, all cultivars reached >0.9 T1 tillers plant^{-1}. Averaged across P rate, the production of T1 ranged from 0.6 T1 tillers plant^{-1} for LCS-Breakaway to 1.0 plant^{-1} for eight cultivars. Averaged across cultivar the T1 tiller initiation was 0.8, 1.0, 1.0, and 1.0 tillers plant^{-1} for 0, 5, 10, and 20 mg P pot^{-1}, respectively.

The effect of cultivar and P rate on T2 tiller initiation is shown in Table A25. The F tests for cultivar, P rate, and P*cultivar interaction were all significant. At 0 mg, most of the cultivars did not produce a T2 tiller, while World Seeds 1812 and LCS-Albany had complete initiation of T2 tillers at 0 mg of P. At 5 mg, there were 7 cultivars that produced 0.9-1.0 T2 tillers plant^{-1}. At 20 mg P pot^{-1}, most cultivars reached 0.9-1.0 T2 tillers plant^{-1} initiation. The exceptions were the cultivars Bolles and LCS-Breakaway that tillered poorly at the T2 position, regardless of P rate. Averaged across P rate, the production of T2 ranged from 0.1 tillers plant^{-1} for Bolles and 1.0 tillers plant^{-1} for LCS-Albany. Averaged across cultivar the T2 tiller initiation was 0.1, 0.5, 0.8, and 0.9 T2 tillers plant^{-1} for 0, 5, 10, and 20 mg P pot^{-1}, respectively.

The effect of cultivar and P rate on T1 + T2 tiller initiation is shown in Table A26. The F tests for cultivar, P rate, and P*cultivar interaction were all significant. At 0 mg, the cultivars World Seeds 1812 and LCS-Albany had at least 90% initiation of T1 + T2 tillers (>1.8 T1 + T2 tillers plant^{-1}), while at 5 mg 13 cultivars produced > 1.8 of T1 + T2 tillers plant^{-1}. At 20 mg of P, all but four cultivars reached 1.8 T1 + T2 tillers plant^{-1} initiation. Averaged across P rate, the production of T1 + T2 ranged from 0.7 tillers plant^{-1} for LCS-Breakaway to 2.0 tillers plant^{-1} for LCS-Albany. Averaged across cultivar the T1+ T2 tiller initiation was 0.9, 1.5, 1.8, and 1.9 tillers plant^{-1} for 0, 5, 10, and 20 mg P pot^{-1}, respectively. To show the range in the responses obtained, the effect of P rate on the numbers of T1 + T2 tillers produced by six cultivars is shown in Figure B2.

The effect of cultivar and P rate on T3 tiller initiation is shown in Table A27. The F tests for cultivar, P rate, and P*cultivar interaction were all significant. At 0 mg, none of the cultivars initiated T3 tillers. With the addition of 10 and 20 mg the cultivar LCS-Albany produced 0.9 T3 tillers plant^{-1}. Even at the highest P rate, most cultivars did not initiate T3 tillers. Averaged across P rate, the initiation of T3 ranged from 0 for most cultivars to 0.6 tillers plant^{-1} for LCS-Albany. Averaged across cultivar the T3 tiller initiation was 0 T3 tillers plant^{-1} for 0, 5, 10, and 20 mg P pot^{-1}, respectively.

The effect of cultivar and P rate interaction on T10 tiller initiation is shown in Table A28. The F tests for cultivar, P rate, and P*cultivar interaction were all significant. Most of the cultivars produced few or no T10 tillers. Four cultivars, MS-Stingray, Marshall, WS1812, and

LCS-Albany had ≥0.5 T10 tillers plant^{-1} at the highest P rate. Averaged across P rate, the production of T10 ranged from 0 for most cultivars to 0.81 tillers plant^{-1} for LCS-Albany. Averaged across cultivar the T10 tiller initiation was 0, 0, 0.1, and 0.1 T10 tillers plant^{-1} for 0, 5, 10, and 20 mg P pot^{-1}, respectively.

The effect of cultivar and P rate on other tiller initiation is shown in Table A29. The F tests for cultivar and P*cultivar interaction were significant, while P rate was not significant. All other tiller types included T11, T20, and T21 tillers. Most cultivars did not produce these late-appearing tillers. However, the cultivar LCS-Albany produced over 0.8 other tillers plant^{-1} at the 20 mg rate. Averaged across P rate, the production of other tillers ranged from 0 for most cultivars to 0.5 tillers plant^{-1} for LCS-Albany. Averaged across cultivar the other tiller initiation was 0 tillers plant^{-1} for 0, 5, 10, and 20 mg P pot^{-1}, respectively.

The effect of cultivar and P rate on total tiller initiation is shown in Table A30. The F tests for cultivar, P rate, and P*cultivar interaction were all significant. At 0 mg, the cultivars World Seeds 1812 and LCS-Albany produced greater than 2 tillers plant^{-1}. At the 5, 10, and 20 mg rates LCS-Albany produced more than 4 tillers plant^{-1}. When 20 mg was added 7 cultivars produced fewer than 2 tillers plant^{-1} and Marshall and World Seeds 1812 produced more than 3 tillers plant^{-1}. Averaged across P rate, the production of total tillers ranged from 0.8 tillers plant^{-1} for LCS-Breakaway to 4.0 tillers plant^{-1} for LCS-Albany. Averaged across cultivar the total tiller initiation was 1.0, 1.6, 2.1, and 2.4 tillers plant^{-1} for 0, 5, 10, and 20 mg P pot^{-1}, respectively.

The effect of cultivar and P rate on P concentration in plant tissue is shown in Table A31. The F tests for cultivar, P rate, and P*cultivar interaction were significant. With an increase in the rate of P, the P concentration in plant tissue also increased. Averaged across P rate, the P concentration in plant tissue ranged from 0.3% for Prevail to 0.3% for Rollag. Averaged across cultivar the P concentration in plant tissue was 0.2, 0.2, 0.3, and 0.4% for 0, 5, 10, and 20 mg P pot^{-1}, respectively.

The effect of cultivar and P rate interaction on P uptake is shown in Table A32. The F tests for cultivar, P rate, and P*cultivar interaction were significant. With an increase of P fertilizer, the P uptake also increased. Averaged across P rate, the P uptake ranged from 4.5 mg pot^{-1} for LCS-Albany to 5.6 mg pot^{-1} for Focus. Regarding the P*cultivar interaction, an example would be to compare LCS-Albany and HRS-3530. Adding 20 mg P increased the P uptake of LCS-Albany by 5.5 mg pot^{-1} over the control (2.2 to 7.7), but adding 20 mg P to HRS-3530 increased P uptake by 6.7 mg pot^{-1} (2.7 to 9.4). Averaged across cultivar the P uptake was 2.7, 4.2, 5.4, and 8.4 mg pot^{-1} for 0, 5, 10, and 20 mg P pot^{-1}, respectively.

The effect of cultivar and P rate on P uptake efficiency (PUE) is shown in Table A33. The F test for cultivar was significant while P rate and P*cultivar interaction were not significant. Values of PUE ranged from 21.9% for Forefront to 34.8% for TGC-Spitfire. Averaged across P rate, the PUE ranged from 21.9-34%. Averaged across cultivar the PUE was 31.2, 27.7, and 28.7% for the rates of 5, 10, and 20 mg P pot^{-1}, respectively.

In Table A34, the averages and significance of the 14 variables for 2016 are given. For comparison, the 2015 data are discussed and reported in Table A17. On average dry matter continually increased from 1.4 g at 0 to 2.2 g at 20 mg P pot^{-1}. The average dry matter relative yield was 50.6% the first year, and 65.8% the second year. The greater overall relative yield in 2016, may have been because a different lot of soil was used from the same field, and the initial soil test for P was greater the second year, 8 mg kg^{-1} in 2015 and 10 mg kg^{-1} in 2016 (Table A1).

The average main stem Haun stage also increased from 5.6 leaves plant^{-1} to 5.7 leaves plant^{-1}, a 0.1 leaf plant^{-1} increase with the highest rate of P.

The initiation of T0 tillers increased from 0 tillers plant^{-1} with 0 P to 0.3 tillers plant^{-1} with 20 mg P pot^{-1}. In 2015, with the historic cultivars, the average was initiation was 0.4 tillers plant^{-1} at 20 mg P pot^{-1}. Perhaps "modern" wheat cultivars produce fewer T0 tillers than historic cultivars. The T1 initiation, averaged across cultivar, reached 0.9 tillers plant^{-1} at 5 mg P pot^{-1}, and reached nearly 1.0 tillers plant^{-1} initiation at 10 mg P pot^{-1}. The T2 initiation, averaged across cultivar, required the full 20 mg rate to approach full initiation (1.0 tillers plant^{-1}). The initiation of T1 + T2 tillers averaged 0.9 tillers plant^{-1} at 0 mg P pot^{-1}, and was more than 90% (1.9 tillers plant^{-1}) at 20 mg P pot^{-1}. The initiation of T3, T10, and other tillers was uncommon for most cultivars, averaging 0, 0.1, and 0 tillers plant^{-1} respectively, at 20 mg P pot^{-1}. Of the later-appearing tillers, T10 tillers were the most common. The sum of these, 0.2 tillers plant^{-1}, was about the same as for the historic cultivars (0.2 "other" tillers, Table A17). The other tillers in 2016 were made up of T11, T20, T21 tillers, but few cultivars produced these tillers, and there was little effect of P fertilization. The overall average total tillers increased from 0 mg to 20 mg P pot^{-1} with a growth of 1.0 tillers to 2.4 average tillers per cultivar.

The P concentration in plant tissue, averaged across cultivar, ranged from 0.2% with no P added, to 0.4% at 20 mg P pot^{-1}. The average P uptake, averaged across cultivar, was 2.7 mg pot^{-1} to 8.4 mg pot^{-1} with 20 mg P pot^{-1}. The PUE values, averaged across cultivar, ranged from 31.2% at 5 mg P pot^{-1} to 28.7% at 20 mg P pot^{-1}. This study was conducted under greenhouse conditions, in a closed system with intense rooting. In the field, PUE is usually much lower. Alessi and Power (1980) at Mandan, ND studied response of wheat to P over a span of six years. They applied five rates of P at the beginning of the trial, with and without banded P at planting.

The PUE into the grain only approached 30% for low rates of P, and six years of cropping. Single-year recovery of a one-year starter fertilizer application was only about 10%. The relative range in observations for the cultivar, averaged across P rate was <30% for relative dry matter yield, P concentration, and P uptake. Variability between cultivars, as in 2015, was greatest (44-2400%) for tillering.

Correlations between dry matter production at the highest P rate, main stem Haun stage at the highest P rate, and selected response variables for the 2016 study were conducted. The data used for the correlations are found in Table A35. Results of the correlation analyses are shown in Table A36. Unlike the results for 2015 (Table A19), dry matter production and main stem Haun stage were positively correlated, meaning that cultivars that tended to grow the fastest (produces more dry matter) were also the cultivars that developed most quickly (fewer growing degree days to produce a new leaf on the main stem).

Tiller initiation, except for T10 tiller initiation, tended not to be correlated with dry matter production. However, T0 tiller initiation, T10 tiller initiation, and total tiller initiation at the highest P rate was negatively correlated to main stem Haun stage at the highest P rate. In other words, cultivars that tended to develop most quickly tended to tiller less. This was consistent with the results for 2015 (Table A19).

Dry matter relative yield, averaged across P rate, was not correlated to dry matter production, suggesting that faster growing cultivars did not require more P for dry matter production than slower growing cultivars. As with 2015, dry matter production was negatively correlated with P concentration in the plant tissue and positively correlated with P uptake. Unlike 2015, PUE was not correlated to dry matter production. As in 2015, the P requirement for adequate T1 + T2 tillering was not correlated to dry matter production.

Main stem Haun stage, at the highest rate of P, was negatively correlated to P concentration in the plant tissue, and positively correlated to P uptake. Since dry matter production and main stem Haun stage were positively correlated with current and pending cultivars, these correlations may be due to the greater dry matter production associated with the faster developing cultivars studied in 2016.

Phosphorus uptake efficiency was not correlated with main stem Haun stage. As observed with the historical cultivars, there was a negative correlation between Haun stage at the highest P rate, and T1 + T2 tiller initiation, averaged across P rate. In other words, cultivars that developed most quickly, produced leaves on the main stem most quickly, tended to require the most P for initiation of T1 + T2 tillers. This agrees with the results in 2015 (Table A19) and with earlier studies (Fanning and Goos, 1992; Goos, 1995).

SUMMARY/CONCLUSION

The vegetative response of 89 historical, current, and pending cultivars of HRS wheat to P fertilization was measured in two greenhouse experiments of 4 months each in 2015 and 2016. The variables measured in each study were studied for the effects of cultivar and P rate on above-ground dry matter production, dry matter relative yield, main stem Haun stage, tiller initiation by position, T1 + T2 tiller initiation, total tiller initiation, P concentration in the plant tissue, P uptake, and P uptake efficiency. Statistical analyses indicated that P rate, cultivar, and cultivar*P interactions were significant for most of the parameters measured including dry matter production, tiller initiation, P concentration, and P uptake.

Cultivars that tended to grow the fastest, producing more dry matter, tended to tiller less, and take up more P from the soil than slower-growing cultivars. It is to be expected, at a fixed rate of a nutrient, that the concentration of the nutrient in the plant tissue would go down, as dry matter production increases. Cultivars that developed more quickly, producing more leaves on the main stem, tended to tiller less than cultivars that developed more slowly. In other words, cultivars that developed the fastest, requiring the fewest growing degree days to produce a new leaf on the main stem, tended to tiller less than cultivars that develop more slowly. Cultivars that developed more quickly also tended to require more P for tiller initiation at the critical T1 and T2 positions. This suggests that, in general, the more rapid the normal main stem development of a cultivar, the more P fertilizer is needed for full initiation of T1 + T2 tillers and that faster developing cultivars take up P more readily than slower developing cultivars. These results obtained are not typically seen in the field and the results were obtained from a closed system with intense rooting whereas in the field, P would not be in as close contact with the roots.

The study was also conducted to produce a genetic table to provide a detailed database of the nature of main stem and tiller development of these cultivars, along with their P response characteristics, for the possible subsequent studies to discover of the genetic markers for these traits, this can be found in the tables in the back of the paper.

Overall it was found that there was no one perfect cultivar that used less P fertilizer and produced a greater amount of tillers or relative yield and to definitively say one cultivar is better than others is impossible. When choosing a cultivar one should look at the traits that are important, for producers, looking at a cultivar that produces a T1 and T2 tillers and has a good yield is the most important factor.

LITERATURE CITED

Alessi J. and J.F. Power. 1980. Effects of banded and residual fertilizer phosphorus on dryland spring wheat in the Northern Plains. Soil Sci Soc Am J 44: 792–796.

Fanning, C. and J. Goos. 1992. Phosphorus: impact on small grain plant development (Great Plains). Better Crops with Plant Food Magazine. 76 (4):26-27.

Frank, K., D. Beegle, and J. Denning. 2012. Recommended chemical soil testing procedures for the North Central Region. North Central Reg. Res. Publ. no. 221 (revised). Missouri Agric. Exp. Stn. SB 1001. Columbia, MO. 221:6.1-6.2.

Goos, R. J. 1995. Tillering patterns in spring wheat and the need for phosphorus (North Dakota). Better Crops with Plant Food Magazine. 79 (3):10-11.

Goos, R. J., and B. E. Johnson. 1996. Fertilizers and the early growth of spring wheat-agronomic and research implications. In: J. L. Havlin (ed.) Great Plains soil fertility conference proceedings. 6:259-268. Kansas State University, Manhattan.

Goos, R. J. and B. E. Johnson. 1999. Performance of two nitrification inhibitors over a winter with exceptionally heavy snowfall. Agron. J. 91:1046-1049.

Goos, R.J. and B.E. Johnson. 2001. Response of spring wheat to phosphorus and sulphur starter fertilizers of differing acidification potential. J. Agric. Sci., Cambridge. 136:283-289.

Goos, R. J., B. E. Johnson, and R. W. Stack. 1994. *Penicillium bilaji* and phosphorus fertilization effects on the growth, development, yield and common root rot severity of spring wheat. Fert. Res. 39:97-103.

Goos, R. J., J. A. Schimelfenig, B. R. Bock, and B. E. Johnson. 1999. Fert. Res. of spring wheat to nitrogen fertilizers of differing nitrification rate. Agron. J. 91:287-293.

Havlin, J. L., J. D. Beaton, S. L. Tisdale, and W. L. Nelson. 2005. Soil fertility and fertilizers an introduction to nutrient management. Pearson Education, Inc. New Jersey.

Haun, J.R. 1973. Visual quantification of wheat development. Agron. J. 65:116-119.

Jewiss, O.R. 1972. Tillering in grasses-its significance and control. Brit. Grassland Soc. 27: 65-82.

Klepper, B., R.W. Rickman, and C.M. Peterson. 1982. Quantitative characterization of vegetative development in small cereal grains. Agron. J. 74:789-792.

Large, E.C. Growth stages in cereals illustration of the Feekes scale. Plant Path. 3:128-129.

Liao, M.T., P. Hocking, B. Dong, E. Delhaize, and P.R. Ryan. 2004. Screening for genotypic variation in phosphorus-uptake efficiency in cereals on Australian soils. Available online at: http://www.cropscience.org.au/icsc2004/poster/2/5/4/697_liaomt.htm. (Accessed June 21, 2016).

Liao, M.T., P.J. Hocking, B. Dong, E. Delhaize, A.E. Richardson, and P.R. Ryan. 2008. Variation in early phosphorus-uptake efficiency among wheat genotypes grown on two contrasting Australian soils. Aust. J. Agric. Res. 59: 157-166. https://doi.org/10.1071/AR06311. (Accessed June 21, 2016).

Lindsay, W.L. 1979. Chemical equilibria in soils. John Wiley and Sons. New York.

Mengel, K., and E. A. Kirkby. 2001. Principles of plant nutrition. Kluwer Academic Publishers. Netherlands.

Nriau, J. O., and P. B. Moore. 1984. Phosphate minerals. Springer-Verlag. Berlin Heidelberg.

Ozturk, L., S. Eker, B. Torun, and I. Cakmak. 2005. Variation in phosphorus efficiency among 73 bread and durum wheat genotypes grown in a phosphorus-deficient calcareous soil. Plant Soil 269: 69-80. DOI: 10.1007/s11104-004-0469-z. (Accessed June 21,2016).

Raven, P. H., R. F. Evert, and S. E. Eichhorn. 1986. Biology of plants. Worth Publishers, Inc. USA.

SAS Institute Inc. 2016. SAS® 9.4 Statements: Reference, Fifth Edition. Cary, NC: SAS Institute Inc.

Smith, J. V. 1981. Halogen and phosphorus storage in the earth. Nature. 289: 762-765

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Official soil series descriptions. https://soilseries.sc.egov.usda.gov/OSD_Docs/R/RENSHAW.html. (Accessed January 12, 2017).

Steele, R. G., J. H. Torrie, and D. A. Dickey. 1996. Principles and procedures of statistics: a biometrical approach. McGraw-Hill Companies, New York.

Sun, S. S., and R. W. Nesbitt. 1977. Chemical heterogeneity of the archean mantle, composition of the earth and mantle evolution. Earth Planet Sci. Lett. 35: 429-448

United States Geological Survey. 2016. a. Marketable phosphate rock and potash-crop year 2015. Mineral Industry Surveys. https://minerals.usgs.gov/minerals/pubs/commodity/phosphate_rock/mis-2015cy-phosp-potas.pdf. (Accessed August 17, 2016).

United States Geological Survey. 2016. b. Phosphate rock. Mineral commodity summaries. https://minerals.usgs.gov/minerals/pubs/commodity/phosphate_rock/mcs-2016-phosp.pdf. (Accessed August 17, 2016).

United States Department of Agriculture Genetic Resources Program. National Plant Germplasm System. 2016. https://npgsweb.arsgrin.gov/gringlobal/search.aspx. (Accessed August 17, 2016.).

Van Vuuren, D.P., A.F. Bouwman, and A.H.W. Beusen. 2010. Phosphorus demand for the 1970-2100 period: A scenario analysis of resource depletion. Global env. change. 20: 428-439. https://doi.org/10.1016/j.gloenvcha.2010.04.004. (Accessed June 23, 2016).

APPENDIX A: TABLES

Table A1. Soil test results for the Renshaw topsoil used in the 2015 and 2016 greenhouse hard red spring wheat screening study for nutrient influence on plant trait expression.

		---------- Year‡ ----------	
Test†	Units	2015	2016
NO_3-N	mg kg^{-1}	5	4
P	mg kg^{-1}	8	10
K	mg kg^{-1}	118	114
pH	--	6.9	7
EC	mmho cm^{-1}	0.12	0.11
SO_4-S	mg kg^{-1}	2	2
Zn	mg kg^{-1}	0.7	1.01
Fe	mg kg^{-1}	13.5	19.5
Mn	mg kg^{-1}	29.5	26.5
Cu	mg kg^{-1}	0.52	0.56

†Soil tests were conducted as described in Frank et. al. (2012).
‡ The year represents the year of the study. Soil samples were collected in 2011 and 2014. The 2011 sampled soil was used in 2015 and the 2014 sampled soil was used in 2016.

Table A2. Formulas for the nutrient solutions used in the 2015 and 2016 greenhouse hard red spring wheat screening study for phosphorous level influence on plant trait expression.

Material	Amount	Final volume	Rate	Provides	
	g	mL	mL pot^{-1}	pot^{-1}	pot^{-1}
Basal solution 1		1000	3		
$Ca(NO_3)_2 * 4 H_2O$	70.26			25 mg N	36 mg Ca
KNO_3	60.17			25 mg N	70 mg K
FeEDDHA	0.556			0.1 mg Fe	--
KCl	3.51			0.5 mg Cl	< 1 mg K
Basal solution 2		1000	3		
$Mg(SO_4) * 7 H_2O$	25.64			10 mg S	8 mg Mg
H_3BO_4	0.191			0.1 mg B	--
$ZnSO_4 * 7 H_2O$	1.47			1 mg Zn	< 1 mg S
$CuSO_4$	0.84			1 mg Cu	< 1 mg S
$MnSO_4 * H_2O$	1.76			1 mg Mn	< 1 mg S
1 M HCl	1 mL/L				
Topdress solution					
NH_4NO_3	47.62	1000	3	50 mg N	--
Treatment solutions					
NaH_2PO_4	1.29	200	3	5 mg P	--
NaH_2PO_4	2.58	200	3	10 mg P	--
NaH_2PO_4	5.16	200	3	20 mg P	--

Table A3. Historical hard red spring wheat cultivars released from 1910 to 1997 used in the 2015 greenhouse hard red spring wheat screening study for phosphorous level influence on plant trait expression.

Historical Cultivar	Origin	Year Released
AC Barrie	Agriculture and Agri-Food Canada, Swift Current, SK	1997
Alex	North Dakota State University	1981
Amidon	North Dakota State University	1988
Bonanza	DeKalb Agricultural Research, Inc., North Dakota	1972
Bounty 208	Cargill Inc., Colorado	1973
Butte	North Dakota State University	1977
Ceres	North Dakota State University	1926
Chris	University of Minnesota	1967
Conley	North Dakota State University	1955
Coteau	North Dakota State University	1978
Ellar	North Dakota State University	1974
Era	University of Minnesota	1971
Fortuna	North Dakota State University	1966
Gus	North Dakota State University	1989
Justin	North Dakota State University	1963
Kitt	University of Minnesota	1976
Lark	World Seeds, Inc., California	1971
Lee	University of Minnesota	1950
Len	North Dakota State University	1979
Manitou	Agriculture and Agri-Food Canada, Winnipeg, MB	1967
Marquis	Agriculture and Agri-Food Canada, Ottawa, ON	1910
Marshall	University of Minnesota	1985
Mida	North Dakota State University	1944
Olaf	North Dakota State University	1972
Oslo	Agripro Biosciences, Inc., Colorado	1981
Pembina	Agriculture and Agri-Food Canada, Winnipeg, MB	1963
Pilot	North Dakota State University	1939
Polk	University of Minnesota	1971
Prodax	Northrup, King & Co., Minnesota	1975
Red River 68	World Seeds Inc., California	1968
Regent	Agriculture and Agri-Food Canada, Winnipeg, MB	1940
Renown	Agriculture and Agri-Food Canada, Winnipeg, MB	1940
Rival	North Dakota State University	1939
Rushmore	South Dakota State University	1940
Selkirk	Agriculture and Agri-Food Canada, Winnipeg, MB	1953
Solar	Northrup, King & Co., Minnesota	1979
Stoa	North Dakota State University	1984
Thatcher	University of Minnesota	1935
Vesta	North Dakota State University	1942
Waldron	North Dakota State University	1969
Walera	Northrup, King & Co., Minnesota	1982
Wared	Washington State University	1974
Wheaton	University of Minnesota	1984
World Seeds 1809	World Seeds, Inc., California	1974
World Seeds 1812	World Seeds, Inc., California	1969
2369	North Dakota State University	1982
2375	North Dakota State University	1990

Table A4. Current and pending hard red spring wheat cultivars released from 2005-2016 used in the 2016 greenhouse hard red spring wheat screening study for phosphorous level influence on plant trait expression.

Current and pending cultivar	Origin	Year Released
Advance	South Dakota State University	2012
Barlow	North Dakota State University	2009
Bolles	University of Minnesota	2015
Brick	South Dakota State University	2009
†Butte	North Dakota State University	1977
Elgin-ND	North Dakota State University	2013
Faller	North Dakota State University	2007
Focus	South Dakota State University	2015
Forefront	South Dakota State University	2012
Glenn	North Dakota State University	2005
HRS 3361	Croplan, Winfield United, Minnesota	2013
HRS 3419	Croplan, Winfield United, Minnesota	2014
HRS 3504	Croplan, Winfield United, Minnesota	2015
HRS 3530	Croplan, Winfield United, Minnesota	2015
LCS Albany	Limagrain Cereal Seeds, Colorado	2008
LCS Breakaway	Limagrain Cereal Seeds, Colorado	2011
LCS Iguacu	Limagrain Cereal Seeds, Colorado	2014
LCS Powerplay	Limagrain Cereal Seeds, Colorado	2011
LCS Pro	Limagrain Cereal Seeds, Colorado	2015
Linkert	University of Minnesota	2013
†Marshall	University of Minnesota	1985
Mott	North Dakota State University	2009
MS Chevelle	Meridian Seeds LLC, North Dakota	2014
MS Stingray	Meridian Seeds LLC, North Dakota	2013
ND 820	North Dakota State University	‡
ND 825	North Dakota State University	‡
ND 907	North Dakota State University	‡
ND901CL	North Dakota State University	2008
Norden	University of Minnesota	2012
Prevail	South Dakota State University	2014
Prosper	North Dakota State University	2011
RB07	University of Minnesota	2007
Rollag	University of Minnesota	2011
Sabin	University of Minnesota	2009
Select	South Dakota State University	2010
Steele-ND	North Dakota State University	2009
TCG-Cornerstone	21st Century Genetics Corp, North Dakota	2016
TGC-Spitfire	21st Century Genetics Corp, North Dakota	2016
TCG-Wildfire	21st Century Genetics Corp, North Dakota	2016
Velva	North Dakota State University	2012
†World Seed 1812	World Seeds, Inc., California	1969
†2375	North Dakota State University	1990

†Historical cultivar added as a control

‡ Cultivar is not yet released but may be released soon

Table A5. Effect of cultivar and P rate on dry matter production, on historical cultivars, reached by increasing average dry matter production.

Cultivar	0	5	10	20	Average
	-------------------- mg P pot^{-1} --------------------				
	------------------------------- g pot^{-1} --------------------------------				
Era	0.9	1.3	1.6	1.7	1.4
Walera	0.9	1.2	1.6	1.9	1.4
Wared	0.8	1.2	1.6	2.0	1.4
Solar	0.9	1.4	1.6	1.9	1.4
Bonanza	0.9	1.4	1.7	1.9	1.5
Marshall	1.0	1.4	1.6	1.9	1.5
Wheaton	1.1	1.3	1.6	2.0	1.5
Kitt	1.1	1.4	1.6	2.0	1.5
Chris	1.1	1.6	1.7	2.1	1.6
Lark	1.2	1.5	1.8	2.1	1.6
Len	1.0	1.5	1.9	2.1	1.6
Bounty 208	1.2	1.4	1.7	2.3	1.6
Prodax	1.0	1.4	2.1	2.0	1.7
Olaf	1.1	1.5	1.9	2.2	1.7
Gus	1.1	1.4	1.9	2.2	1.7
World Seeds 1812	1.1	1.5	2.0	2.2	1.7
AC Barrie	1.2	1.5	2.0	2.1	1.7
Red River 68	1.1	1.5	1.9	2.3	1.7
Oslo	1.2	1.7	1.9	2.1	1.7
Thatcher	1.2	1.6	2.0	2.2	1.7
Stoa	1.1	1.6	2.0	2.4	1.8
Marquis	1.1	1.7	2.1	2.4	1.8
Conley	1.1	1.6	2.3	2.3	1.8
World Seeds 1809	1.1	1.7	2.2	2.3	1.8
Coteau	1.2	1.7	2.0	2.4	1.8
Fortuna	1.1	1.7	2.1	2.3	1.8
Manitou	1.2	1.7	2.0	2.4	1.8
2369	1.2	1.6	2.1	2.5	1.8
Sharp	1.3	1.6	2.1	2.4	1.9
Ellar	1.3	1.6	2.2	2.5	1.9
Amidon	1.1	1.8	2.2	2.5	1.9
Rushmore	1.2	1.7	2.3	2.4	1.9
Renown	1.2	1.8	2.3	2.4	1.9
Rival	1.2	1.9	2.3	2.4	1.9
Butte	1.2	1.7	2.3	2.5	1.9
Ceres	1.3	1.6	2.3	2.6	2.0
Alex	1.3	1.8	2.2	2.5	2.0

Table A5. Effect of cultivar and P rate on dry matter production, on historical cultivars, reached by increasing average dry matter production (continued).

Cultivar	0	5	10	20	Average
	-------------------- mg P pot-1 --------------------				
	------------------------------- g pot-1 -------------------------------				
Justin	1.3	1.9	2.2	2.5	2.0
Pembina	1.3	1.8	2.3	2.5	2.0
Lee	1.3	1.8	2.4	2.5	2.0
Polk	1.3	1.8	2.4	2.6	2.0
Regent	1.3	1.8	2.4	2.8	2.0
Pilot	1.4	1.8	2.4	2.7	2.1
Waldron	1.3	1.9	2.4	2.7	2.1
Vesta	1.4	2.1	2.5	2.6	2.1
2375	1.5	2.0	2.4	3.0	2.2
Selkirk	1.5	2.1	2.7	3.0	2.3
Average	1.2	1.6	2.1	2.3	1.8
Significance of F					
Cultivar	<.0001				
P rate	<.0001				
Cultivar x P rate	0.0002				
CV, %	9.4%				

LSD (0.05) for P rate 1.18

LSD (0.05) for cultivar and P*cultivar 0.23

Table A6. Effect of cultivar and P rate on dry matter relative yield, on historical cultivars, reached by increasing average relative yield.

	------------------- mg P pot^{-1} -------------------				
Cultivar	0	5	10	20	Average
	------------------------------ % ------------------------------				
Wared	40.9	57.9	80.2	100	59.7
Walera	46.8	64.2	82.2	100	64.4
Bounty 208	53.8	63.4	76.2	100	64.5
Stoa	45.7	67.5	80.8	100	64.7
2369	47.4	64.3	85.7	100	65.8
Regent	47.3	65.2	86.1	100	66.2
Gus	50.1	62.4	86.1	100	66.2
Marquis	44.9	68.8	85.2	100	66.3
Red River 68	51.2	67.2	83.1	100	67.1
Ceres	48.9	63.0	90.1	100	67.4
Ellar	51.4	64.4	86.8	100	67.5
Wheaton	54.6	66.2	81.9	100	67.5
2375	51.4	69.7	82.0	100	67.7
Waldron	48.3	70.5	86.2	100	68.3
Pilot	50.3	67.1	87.7	100	68.4
Amidon	46.1	71.2	87.9	100	68.4
Manitou	50.5	69.3	85.6	100	68.5
Solar	48.6	73.6	84.3	100	68.8
Len	48.7	71.0	87.7	100	69.1
Coteau	48.9	70.1	89.7	100	69.6
Kitt	54.7	71.4	83.5	100	69.8
Polk	50.3	68.3	91.2	100	69.9
Marshall	52.9	72.4	84.7	100	70.0
Sharp	54.1	68.3	88.1	100	70.2
AC Barrie	53.7	68.4	88.4	100	70.2
Conley	46.3	67.7	97.9	100	70.6
Butte	48.2	69.6	94.1	100	70.6
Olaf	50.9	72.1	88.9	100	70.7
World Seeds 1809	46.8	72.0	93.3	100	70.7
Alex	53.5	72.3	87.6	100	71.1
World Seeds 1812	51.1	71.0	91.4	100	71.2
Bonanza	49.3	75.1	90.1	100	71.5
Thatcher	53.4	73.4	88.7	100	71.8
Chris	54.4	75.5	85.7	100	71.8
Justin	51.4	76.8	87.7	100	72.0
Selkirk	52.0	71.7	92.7	100	72.1
Pembina	53.8	73.6	92.8	100	73.4

Table A6. Effect of cultivar and P rate on dry matter relative yield, on historical cultivars, reached by increasing average relative yield (continued).

	-------------------- mg P pot^{-1} --------------------				
Cultivar	0	5	10	20	Average
	---------------------------------- % --				
Fortuna	50.2	76.8	93.5	100	73.5
Era	51.9	75.3	93.4	100	73.5
Lark	57.9	75.4	87.5	100	73.6
Rushmore	50.7	73.5	96.6	100	73.6
Renown	50.0	74.2	98.1	100	74.1
Lee	54.0	72.5	97.1	100	74.6
Prodax	50.7	70.6	102.5	100	74.6
Rival	50.9	78.1	95.8	100	74.9
Vesta	52.8	78.9	94.3	100	75.4
Oslo	55.2	82.0	91.8	100	76.3
Average	50.6	70.5	88.8	100	70.0
Significance of F					
Cultivar	0.004				
P rate	<.0001				
Cultivar x P rate	0.99				
CV, %	13.0%				

LSD (0.05) for P rate 53.15

LSD (0.05) for cultivar and P*cultivar 14.60

Table A7. Effect of cultivar and P rate on main stem Haun stage, on historical cultivars, reached by increasing average main stem Haun stage.

	mg P pot^{-1}				
Cultivar	0	5	10	20	Average
	leaves plant^{-1}				
Renown	4.5	4.8	5.0	4.9	4.8
Wared	4.6	4.9	5.1	5.2	5.0
Regent	4.7	5.1	5.1	5.2	5.0
Era	4.9	5.2	5.1	5.2	5.1
Walera	4.8	5.1	5.2	5.3	5.1
Marquis	4.8	5.2	5.2	5.4	5.1
Chris	5.0	5.2	5.1	5.4	5.2
Conley	4.8	5.1	5.3	5.4	5.2
Solar	4.9	5.2	5.3	5.4	5.2
Coteau	4.9	5.2	5.2	5.4	5.2
Marshall	4.9	5.3	5.3	5.3	5.2
Red River 68	5.0	5.2	5.4	5.4	5.3
Bonanza	5.2	5.3	5.3	5.4	5.3
Lee	5.0	5.2	5.5	5.6	5.3
Rival	5.0	5.3	5.5	5.4	5.3
Selkirk	5.0	5.4	5.4	5.5	5.3
Sharp	5.0	5.3	5.5	5.5	5.3
Olaf	5.1	5.3	5.4	5.6	5.3
Vesta	5.0	5.4	5.5	5.5	5.3
Ceres	5.0	5.2	5.6	5.6	5.3
Prodax	5.1	5.4	5.5	5.4	5.3
Thatcher	5.0	5.3	5.5	5.6	5.4
Rushmore	5.1	5.3	5.5	5.6	5.4
Pilot	5.0	5.3	5.6	5.7	5.4
Pembina	5.2	5.4	5.5	5.5	5.4
2375	5.0	5.5	5.4	5.7	5.4
Fortuna	5.2	5.4	5.5	5.6	5.4
Kitt	5.3	5.5	5.5	5.6	5.5
World Seeds 1812	5.2	5.5	5.6	5.7	5.5
Justin	5.2	5.5	5.6	5.7	5.5
Len	5.2	5.5	5.6	5.6	5.5
Wheaton	5.3	5.5	5.6	5.7	5.5
Amidon	5.3	5.4	5.8	5.7	5.5
Ellar	5.4	5.7	5.8	5.6	5.6
Polk	5.5	5.6	5.8	5.6	5.6
AC Barrie	5.5	5.6	5.7	5.9	5.6
2369	5.5	5.8	5.7	5.7	5.7

Table A7. Effect of cultivar and P rate on main stem Haun stage, on historical cultivars, reached by increasing average main stem Haun stage (continued).

	-------------------- mg P pot^{-1} --------------------				
Cultivar	0	5	10	20	Average
	---------------------------- leaves $plant^{-1}$ ------------------------------				
Bounty 208	5.5	5.6	5.7	5.9	5.7
Waldron	5.5	5.8	5.8	5.9	5.8
Gus	5.6	5.8	5.8	5.9	5.8
Manitou	5.5	5.8	5.8	6.0	5.8
Lark	5.5	5.8	5.9	5.9	5.8
Stoa	5.5	5.8	5.9	6.0	5.8
Alex	5.8	5.8	5.8	5.8	5.8
World Seeds 1809	6.0	6.3	6.2	6.5	6.3
Oslo	5.9	6.4	6.4	6.6	6.3
Butte	6.2	6.5	6.5	6.5	6.4
Average	5.2	5.5	5.5	5.6	5.5
Significance of F					
Cultivar	<.0001				
P rate	<.0001				
Cultivar x P rate	0.54				
CV, %	3.0%				
LSD (0.05) for P rate	0.69				
LSD (0.05) for cultivar and P*cultivar		0.23			

Table A8. Effect of cultivar and P rate on T0 tiller initiation, on historical cultivars, reached by increasing average T0 tiller initiation.

	mg P pot^{-1}				
Cultivar	0	5	10	20	Average
	tillers plant^{-1}				
Butte	0.0	0.0	0.0	0.0	0.0
Stoa	0.0	0.0	0.0	0.0	0.0
Gus	0.0	0.0	0.0	0.0	0.0
World Seeds 1809	0.0	0.0	0.1	0.0	0.0
Rival	0.0	0.0	0.1	0.1	0.0
Conley	0.0	0.0	0.1	0.1	0.1
Pembina	0.0	0.0	0.1	0.1	0.1
Chris	0.1	0.0	0.1	0.1	0.1
2369	0.0	0.0	0.0	0.2	0.1
Waldron	0.0	0.0	0.1	0.2	0.1
Bonanza	0.0	0.0	0.2	0.1	0.1
Prodax	0.0	0.0	0.2	0.1	0.1
Bounty 208	0.0	0.0	0.1	0.3	0.1
Oslo	0.0	0.0	0.1	0.3	0.1
Lee	0.0	0.1	0.2	0.1	0.1
Wheaton	0.0	0.0	0.0	0.4	0.1
Manitou	0.0	0.0	0.3	0.2	0.1
Era	0.0	0.0	0.2	0.3	0.1
Solar	0.0	0.0	0.1	0.4	0.1
AC Barrie	0.0	0.1	0.3	0.2	0.1
Coteau	0.0	0.0	0.2	0.4	0.1
Ellar	0.0	0.0	0.1	0.5	0.1
Regent	0.0	0.0	0.2	0.4	0.1
Thatcher	0.0	0.1	0.1	0.4	0.2
Justin	0.0	0.0	0.1	0.6	0.2
Walera	0.0	0.1	0.1	0.5	0.2
Sharp	0.1	0.1	0.2	0.4	0.2
Len	0.0	0.1	0.1	0.6	0.2
2375	0.1	0.1	0.1	0.6	0.2
Red River 68	0.0	0.0	0.2	0.8	0.3
Alex	0.1	0.1	0.4	0.5	0.3
Olaf	0.0	0.1	0.4	0.7	0.3
Ceres	0.1	0.1	0.6	0.5	0.3
Pilot	0.1	0.2	0.3	0.7	0.3
Fortuna	0.0	0.1	0.5	0.6	0.3
Polk	0.0	0.1	0.3	0.9	0.3
Wared	0.0	0.2	0.4	0.7	0.3

Table A8. Effect of cultivar and P rate on T0 tiller initiation, on historical cultivars, reached by increasing average T0 tiller initiation (continued).

	-------------------- mg P pot^{-1} --------------------				
Cultivar	0	5	10	20	Average
	----------------------------- tillers plant^{-1} -------------------------------				
Marshall	0.1	0.1	0.3	0.8	0.3
Renown	0.0	0.4	0.3	0.6	0.3
Rushmore	0.1	0.3	0.3	0.7	0.3
Lark	0.1	0.3	0.3	0.8	0.3
Vesta	0.1	0.3	0.4	0.7	0.4
Selkirk	0.1	0.1	0.5	0.8	0.4
Kitt	0.1	0.1	0.7	0.7	0.4
Amidon	0.1	0.5	0.6	0.7	0.5
World Seeds 1812	0.2	0.4	0.8	0.8	0.6
Marquis	0.1	0.8	0.8	0.9	0.7
Average	0.0	0.1	0.2	0.4	0.2
Significance of F					
Cultivar	<.0001				
P rate	<.0001				
Cultivar x P rate	<.0001				
CV, %	90.0%				

LSD (0.05) for P rate 2.72

LSD (0.05) for cultivar and P*cultivar 0.25

Table A9. Effect of cultivar and P rate onT1 tiller initiation, on historical cultivars, reached by increasing average T1 tiller initiation.

Cultivar	0	5	10	20	Average
	-------------------- mg P pot^{-1} --------------------				
	----------------------------- tillers plant^{-1} ------------------------------				
World Seeds 1809	0.0	0.1	0.6	0.9	0.4
Stoa	0.0	0.7	1.0	1.0	0.7
2369	0.2	0.6	1.0	0.9	0.7
Polk	0.1	0.7	0.9	1.0	0.7
Lee	0.1	0.9	0.9	1.0	0.7
Prodax	0.1	0.7	1.0	1.0	0.7
Butte	0.3	0.7	0.8	1.0	0.7
Gus	0.2	0.8	0.9	1.0	0.7
Wared	0.2	0.8	1.0	1.0	0.7
Conley	0.3	0.9	1.0	1.0	0.8
Bonanza	0.1	1.0	1.0	1.0	0.8
Len	0.3	0.9	0.9	1.0	0.8
Fortuna	0.2	1.0	1.0	1.0	0.8
Oslo	0.4	1.0	0.9	0.9	0.8
Wheaton	0.3	0.9	1.0	1.0	0.8
Solar	0.2	1.0	1.0	1.0	0.8
Rival	0.4	0.9	1.0	1.0	0.8
Era	0.3	1.0	1.0	1.0	0.8
Ellar	0.3	1.0	1.0	1.0	0.8
Justin	0.3	1.0	1.0	1.0	0.8
Waldron	0.3	1.0	1.0	1.0	0.8
Walera	0.3	1.0	1.0	1.0	0.8
AC Barrie	0.3	1.0	1.0	1.0	0.8
Pilot	0.5	0.9	1.0	0.9	0.8
Rushmore	0.4	1.0	1.0	1.0	0.8
2375	0.4	0.9	1.0	1.0	0.8
Chris	0.5	1.0	0.9	1.0	0.9
Alex	0.6	0.8	1.0	1.0	0.9
Sharp	0.6	0.9	1.0	1.0	0.9
Marquis	0.5	1.0	1.0	1.0	0.9
Manitou	0.6	1.0	1.0	1.0	0.9
Bounty 208	0.6	0.9	1.0	1.0	0.9
Ceres	0.7	0.9	1.0	1.0	0.9
Olaf	0.6	1.0	1.0	1.0	0.9
Regent	0.8	0.9	1.0	1.0	0.9
Kitt	0.7	1.0	1.0	1.0	0.9
Amidon	0.7	1.0	1.0	1.0	0.9

Table A9. Effect of cultivar and P rate onT1 tiller initiation, on historical cultivars, reached by increasing average T1 tiller initiation (continued).

	-------------------- mg P pot-1 --------------------				
Cultivar	0	5	10	20	Average
	----------------------------- tillers plant-1 -------------------------------				
Vesta	0.8	1.0	1.0	1.0	0.9
Pembina	0.8	1.0	1.0	1.0	0.9
Lark	0.8	1.0	1.0	1.0	0.9
Coteau	0.8	1.0	1.0	1.0	0.9
Marshall	0.9	0.9	1.0	1.0	0.9
Red River 68	0.8	1.0	1.0	1.0	1.0
Thatcher	0.8	1.0	1.0	1.0	1.0
Renown	0.9	0.9	1.0	1.0	1.0
Selkirk	0.9	1.0	1.0	1.0	1.0
World Seeds 1812	0.9	1.0	1.0	1.0	1.0
Average	0.5	0.9	1.0	1.0	0.8
Significance of F					
Cultivar	<.0001				
P rate	<.0001				
Cultivar x P rate	<.0001				
CV, %	17.2%				

LSD (0.05) for P rate 1.01

LSD (0.05) for cultivar and P*cultivar 0.20

Table A10. Effect of cultivar and P rate on T2 tiller initiation, on historical cultivars, reached by increasing average T2 tiller initiation.

	mg P pot^{-1}				
Cultivar	0	5	10	20	Average
	tillers plant^{-1}				
Lee	0.0	0.0	0.4	0.5	0.2
2369	0.0	0.0	0.1	0.8	0.2
Gus	0.0	0.0	0.5	0.6	0.3
Polk	0.0	0.1	0.6	0.6	0.3
World Seeds 1809	0.0	0.2	0.3	0.8	0.3
Prodax	0.0	0.1	0.4	0.9	0.3
Wheaton	0.0	0.0	0.4	0.9	0.3
Stoa	0.0	0.1	0.3	1.0	0.4
Ellar	0.0	0.1	0.4	1.0	0.4
Amidon	0.0	0.0	0.6	1.0	0.4
Wared	0.0	0.1	0.7	0.9	0.4
Oslo	0.0	0.3	0.6	0.9	0.4
Rushmore	0.0	0.2	0.6	0.9	0.4
Waldron	0.0	0.1	0.7	1.0	0.4
Butte	0.0	0.3	0.6	0.9	0.4
Solar	0.0	0.0	0.8	1.0	0.4
2375	0.0	0.2	0.7	0.9	0.4
Fortuna	0.0	0.2	0.6	1.0	0.5
Bonanza	0.0	0.1	0.8	1.0	0.5
Len	0.0	0.1	0.8	1.0	0.5
Era	0.0	0.1	0.9	1.0	0.5
Bounty 208	0.0	0.1	0.9	0.9	0.5
Rival	0.1	0.3	0.7	0.9	0.5
Marshall	0.0	0.2	0.9	0.9	0.5
Marquis	0.0	0.3	0.9	0.9	0.5
Vesta	0.0	0.3	0.8	1.0	0.5
Conley	0.0	0.3	0.9	1.0	0.5
Red River 68	0.0	0.4	0.9	0.9	0.5
Alex	0.0	0.4	0.8	1.0	0.5
Regent	0.0	0.3	0.9	1.0	0.6
Walera	0.0	0.3	1.0	0.9	0.6
Kitt	0.0	0.4	0.9	1.0	0.6
AC Barrie	0.0	0.4	0.9	1.0	0.6
Ceres	0.1	0.3	0.9	1.0	0.6
Pembina	0.0	0.4	0.9	1.0	0.6
Justin	0.1	0.4	0.9	1.0	0.6
Lark	0.0	0.4	0.9	1.0	0.6

Table A10. Effect of cultivar and P rate on T2 tiller initiation, on historical cultivars, reached by increasing average T2 tiller initiation (continued).

	-------------------- mg P pot-1 --------------------				
Cultivar	0	5	10	20	Average
	----------------------------- tillers plant-1 -------------------------------				
Coteau	0.0	0.4	0.9	1.0	0.6
Selkirk	0.0	0.5	0.9	1.0	0.6
Thatcher	0.0	0.4	1.0	1.0	0.6
Manitou	0.0	0.5	1.0	1.0	0.6
Sharp	0.0	0.6	1.0	1.0	0.6
Chris	0.2	0.6	0.9	1.0	0.7
Olaf	0.1	0.6	1.0	1.0	0.7
Pilot	0.1	0.8	1.0	0.9	0.7
World Seeds 1812	0.4	0.9	1.0	1.0	0.8
Renown	0.4	0.9	1.0	1.0	0.8
Average	0.0	0.3	0.8	0.9	0.5
Significance of F					
Cultivar	<.0001				
P rate	<.0001				
Cultivar x P rate	<.0001				
CV, %	35.1%				

LSD (0.05) for P rate 1.19

LSD (0.05) for cultivar and P*cultivar 0.24

Table A11. Effect of cultivar and P rate on T1 + T2 tiller initiation, on historical cultivars, reached by increasing average T1 + T2 tiller initiation.

	-------------------- mg P pot^{-1} --------------------				
Cultivar	0	5	10	20	Average
	----------------------------- tillers plant^{-1} -----------------------------				
World Seeds 1809	0.0	0.3	0.9	1.8	0.8
2369	0.2	0.6	1.1	1.8	0.9
Lee	0.1	0.9	1.3	1.5	0.9
Polk	0.1	0.8	1.5	1.6	1.0
Gus	0.2	0.8	1.4	1.6	1.0
Prodax	0.1	0.8	1.4	1.9	1.0
Stoa	0.0	0.8	1.3	2.0	1.0
Butte	0.3	0.9	1.4	1.9	1.1
Wheaton	0.3	0.9	1.4	1.9	1.1
Wared	0.2	0.8	1.7	1.9	1.2
Ellar	0.3	1.1	1.4	2.0	1.2
Oslo	0.4	1.3	1.5	1.8	1.2
Solar	0.2	1.0	1.8	2.0	1.2
Fortuna	0.2	1.2	1.6	2.0	1.3
Bonanza	0.1	1.1	1.8	2.0	1.3
Len	0.3	1.0	1.8	2.0	1.3
Waldron	0.3	1.1	1.7	2.0	1.3
Rushmore	0.4	1.2	1.6	1.9	1.3
2375	0.4	1.1	1.7	1.9	1.3
Era	0.3	1.1	1.9	2.0	1.3
Rival	0.5	1.1	1.7	1.9	1.3
Conley	0.3	1.1	1.9	2.0	1.3
Amidon	0.7	1.0	1.6	2.0	1.3
Bounty 208	0.6	1.1	1.9	1.9	1.4
Walera	0.3	1.3	2.0	1.9	1.4
Marquis	0.5	1.3	1.9	1.9	1.4
Alex	0.6	1.2	1.8	2.0	1.4
AC Barrie	0.3	1.4	1.9	2.0	1.4
Justin	0.4	1.4	1.9	2.0	1.4
Marshall	0.9	1.1	1.9	1.9	1.4
Vesta	0.8	1.3	1.8	2.0	1.5
Regent	0.8	1.2	1.9	2.0	1.5
Ceres	0.8	1.2	1.9	2.0	1.5
Red River 68	0.8	1.4	1.9	1.9	1.5
Kitt	0.7	1.4	1.9	2.0	1.5
Sharp	0.6	1.4	2.0	2.0	1.5
Pembina	0.8	1.4	1.9	2.0	1.5

Table A11. Effect of cultivar and P rate on T1 + T2 tiller initiation, on historical cultivars, reached by increasing average T1 + T2 tiller initiation (continued).

	-------------------- mg P pot-1 --------------------				
Cultivar	0	5	10	20	Average
	----------------------------- tillers plant-1 -------------------------------				
Chris	0.7	1.6	1.8	2.0	1.5
Manitou	0.6	1.5	2.0	2.0	1.5
Lark	0.8	1.4	1.9	2.0	1.5
Coteau	0.8	1.4	1.9	2.0	1.5
Pilot	0.6	1.7	2.0	1.9	1.6
Thatcher	0.8	1.4	2.0	2.0	1.6
Selkirk	0.9	1.5	1.9	2.0	1.6
Olaf	0.7	1.6	2.0	2.0	1.6
Renown	1.3	1.9	2.0	2.0	1.8
World Seeds 1812	1.4	1.9	2.0	2.0	1.8
Average	0.5	1.2	1.7	1.9	1.3
Significance of F					
Cultivar	<.0001				
P rate	<.0001				
Cultivar x P rate	<.0001				
CV, %	16.2%				

LSD (0.05) for P rate 1.68
LSD (0.05) for cultivar and P*cultivar 0.30

Table A12. Effect of cultivar and P rate on other tiller initiation, on historical cultivars, reached by increasing average other tiller initiation.

Cultivar	mg P pot^{-1} 0	5	10	20	Average
	tillers plant^{-1}				
Rival	0.0	0.0	0.0	0.0	0.0
Rushmore	0.0	0.0	0.0	0.0	0.0
Lee	0.0	0.0	0.0	0.0	0.0
Fortuna	0.0	0.0	0.0	0.0	0.0
Polk	0.0	0.0	0.0	0.0	0.0
Waldron	0.0	0.0	0.0	0.0	0.0
Bonanza	0.0	0.0	0.0	0.0	0.0
World Seeds 1809	0.0	0.0	0.0	0.0	0.0
Wared	0.0	0.0	0.0	0.0	0.0
Prodax	0.0	0.0	0.0	0.0	0.0
Butte	0.0	0.0	0.0	0.0	0.0
Len	0.0	0.0	0.0	0.0	0.0
Oslo	0.0	0.0	0.0	0.0	0.0
Wheaton	0.0	0.0	0.0	0.0	0.0
Stoa	0.0	0.0	0.0	0.0	0.0
2369	0.0	0.0	0.0	0.0	0.0
2375	0.0	0.0	0.0	0.0	0.0
Conley	0.0	0.0	0.0	0.1	0.0
Era	0.0	0.0	0.0	0.1	0.0
Regent	0.0	0.0	0.0	0.1	0.0
Walera	0.0	0.0	0.0	0.1	0.0
Gus	0.0	0.0	0.1	0.0	0.0
Chris	0.1	0.0	0.0	0.1	0.0
Ellar	0.0	0.0	0.1	0.1	0.0
Solar	0.0	0.0	0.0	0.1	0.0
Bounty 208	0.0	0.0	0.1	0.1	0.1
Selkirk	0.0	0.1	0.0	0.2	0.1
Pembina	0.0	0.0	0.1	0.2	0.1
Lark	0.0	0.0	0.0	0.3	0.1
Alex	0.0	0.0	0.0	0.3	0.1
Thatcher	0.0	0.0	0.0	0.3	0.1
Amidon	0.0	0.0	0.0	0.3	0.1
Coteau	0.0	0.0	0.1	0.2	0.1
AC Barrie	0.0	0.0	0.0	0.3	0.1
Ceres	0.0	0.0	0.0	0.3	0.1
Vesta	0.0	0.0	0.1	0.2	0.1
Manitou	0.0	0.0	0.1	0.3	0.1

Table A12. Effect of cultivar and P rate on other tiller initiation, on historical cultivars, reached by increasing average other tiller initiation (continued).

Cultivar	-------------------- mg P pot-1 -------------------- 0	5	10	20	Average
	----------------------------- tillers plant-1 -------------------------------				
Marshall	0.0	0.0	0.0	0.3	0.1
Sharp	0.0	0.0	0.0	0.3	0.1
Red River 68	0.0	0.0	0.1	0.3	0.1
Marquis	0.0	0.0	0.1	0.3	0.1
Pilot	0.0	0.1	0.1	0.3	0.1
Justin	0.0	0.1	0.1	0.3	0.1
Olaf	0.1	0.0	0.1	0.3	0.1
Kitt	0.0	0.0	0.0	0.7	0.2
World Seeds 1812	0.0	0.0	0.5	0.6	0.3
Renown	0.0	0.5	0.6	0.6	0.4
Average	0.0	0.0	0.1	0.2	0.1
Significance of F					
Cultivar	<.0001				
P rate	0.004				
Cultivar x P rate	<.0001				
CV, %	245.0%				

LSD (0.05) for P rate 0.49
LSD (0.05) for cultivar and P*cultivar 0.18

Table A13. Effect of cultivar and P rate on total tiller initiation, on historical cultivars, reached by increasing average total tiller initiation.

Cultivar	-------------------- mg P pot^{-1} --------------------				
	0	5	10	20	Average
	----------------------------- tillers plant^{-1} ------------------------------				
World Seeds 1809	0.0	0.3	1.0	1.8	0.8
2369	0.2	0.6	1.1	1.9	0.9
Lee	0.1	0.9	1.4	1.6	1.0
Gus	0.2	0.8	1.5	1.6	1.0
Stoa	0.0	0.8	1.3	2.0	1.0
Prodax	0.1	0.8	1.6	1.9	1.1
Butte	0.3	0.9	1.4	1.9	1.1
Wheaton	0.3	0.9	1.4	2.4	1.3
Oslo	0.4	1.3	1.6	2.0	1.3
Polk	0.1	0.8	1.8	2.5	1.3
Bonanza	0.1	1.1	1.9	2.1	1.3
Waldron	0.3	1.1	1.8	2.2	1.3
Rival	0.5	1.1	1.8	2.0	1.3
Ellar	0.3	1.1	1.6	2.6	1.4
Conley	0.3	1.1	1.9	2.2	1.4
Solar	0.2	1.0	1.8	2.6	1.4
Era	0.3	1.1	2.1	2.4	1.4
Len	0.3	1.1	1.9	2.6	1.5
Wared	0.2	1.0	2.1	2.6	1.5
2375	0.5	1.3	1.8	2.4	1.5
Bounty 208	0.6	1.1	2.1	2.3	1.5
Fortuna	0.2	1.3	2.1	2.6	1.6
Walera	0.3	1.3	2.1	2.5	1.6
AC Barrie	0.3	1.4	2.1	2.5	1.6
Chris	0.8	1.6	1.9	2.1	1.6
Rushmore	0.4	1.5	1.9	2.6	1.6
Pembina	0.8	1.4	2.0	2.3	1.6
Regent	0.8	1.2	2.1	2.4	1.6
Justin	0.4	1.5	2.1	2.8	1.7
Alex	0.7	1.3	2.1	2.8	1.7
Manitou	0.6	1.5	2.4	2.4	1.7
Coteau	0.8	1.4	2.2	2.6	1.7
Sharp	0.6	1.5	2.2	2.7	1.8
Thatcher	0.8	1.5	2.1	2.7	1.8
Red River 68	0.8	1.4	2.1	3.0	1.8
Marshall	0.9	1.2	2.2	3.0	1.8
Amidon	0.8	1.5	2.1	2.9	1.8

Table A13. Effect of cultivar and P rate on total tiller initiation, on historical cultivars, reached by increasing average total tiller initiation (continued).

	-------------------- mg P pot-1 --------------------				
Cultivar	0	5	10	20	Average
	----------------------------- tillers plant-1 ------------------------------				
Ceres	0.9	1.3	2.5	2.8	1.9
Vesta	0.8	1.6	2.4	2.9	1.9
Lark	0.8	1.7	2.2	3.1	1.9
Pilot	0.7	1.9	2.4	2.8	2.0
Olaf	0.8	1.8	2.4	3.0	2.0
Selkirk	1.0	1.7	2.4	3.0	2.0
Kitt	0.8	1.5	2.6	3.4	2.1
Marquis	0.6	2.1	2.8	3.2	2.2
Renown	1.3	2.8	2.9	3.3	2.6
World Seeds 1812	1.6	2.3	3.3	3.4	2.7
Average	0.5	1.3	2.0	2.5	1.6
Significance of F					
Cultivar	<.0001				
P rate	<.0001				
Cultivar x P rate	<.0001				
CV, %	18.6%				

LSD (0.05) for P rate 2.45

LSD (0.05) for cultivar and P*cultivar 0.41

Table A14. Effect of cultivar and P rate on P concentration in plant tissue, on historical cultivars, reached by increasing average plant tissue P concentration.

	mg P pot^{-1}				
Cultivar	0	5	10	20	Average
	%				
Renown	0.1	0.2	0.2	0.3	0.2
Lee	0.1	0.2	0.2	0.3	0.2
Pilot	0.1	0.2	0.2	0.3	0.2
Justin	0.1	0.2	0.2	0.3	0.2
Polk	0.1	0.2	0.2	0.3	0.2
Waldron	0.1	0.2	0.2	0.3	0.2
Rushmore	0.1	0.2	0.2	0.3	0.2
Selkirk	0.1	0.2	0.2	0.3	0.2
Stoa	0.1	0.2	0.2	0.3	0.2
Marquis	0.1	0.2	0.2	0.3	0.2
Amidon	0.2	0.2	0.2	0.3	0.2
Fortuna	0.1	0.2	0.2	0.3	0.2
Vesta	0.1	0.2	0.2	0.4	0.2
Rival	0.1	0.2	0.2	0.4	0.2
Sharp	0.1	0.2	0.2	0.4	0.2
Ceres	0.2	0.2	0.2	0.3	0.2
Coteau	0.1	0.2	0.2	0.3	0.2
Butte	0.1	0.2	0.2	0.3	0.2
2369	0.1	0.2	0.2	0.4	0.2
Conley	0.2	0.2	0.2	0.4	0.2
Ellar	0.2	0.2	0.3	0.3	0.2
2375	0.1	0.2	0.3	0.3	0.2
Regent	0.2	0.2	0.3	0.4	0.2
AC Barrie	0.1	0.2	0.2	0.4	0.2
Gus	0.1	0.2	0.3	0.4	0.2
World Seeds 1809	0.2	0.2	0.3	0.4	0.2
Olaf	0.2	0.2	0.3	0.4	0.2
Chris	0.2	0.2	0.2	0.4	0.2
Alex	0.2	0.2	0.3	0.4	0.3
Len	0.2	0.2	0.3	0.4	0.3
Pembina	0.2	0.2	0.3	0.4	0.3
Red River 68	0.2	0.2	0.3	0.4	0.3
Walera	0.1	0.2	0.3	0.4	0.3
World Seeds 1812	0.2	0.2	0.3	0.4	0.3
Wheaton	0.2	0.2	0.3	0.4	0.3
Bonanza	0.2	0.2	0.3	0.4	0.3
Wared	0.2	0.2	0.3	0.4	0.3

Table A14. Effect of cultivar and P rate on P concentration in plant tissue, on historical cultivars, reached by increasing average plant tissue P concentration (continued).

	-------------------- mg P pot-1 --------------------				
Cultivar	0	5	10	20	Average
	---------------------------------- % ------------------------------------				
Manitou	0.2	0.2	0.3	0.4	0.3
Bounty 208	0.2	0.2	0.3	0.4	0.3
Kitt	0.2	0.2	0.3	0.4	0.3
Solar	0.2	0.2	0.3	0.4	0.3
Lark	0.2	0.2	0.3	0.4	0.3
Era	0.2	0.2	0.3	0.4	0.3
Prodax	0.2	0.3	0.3	0.4	0.3
Thatcher	0.2	0.2	0.4	0.4	0.3
Oslo	0.2	0.2	0.3	0.4	0.3
Marshall	0.2	0.3	0.3	0.5	0.3
Average	0.2	0.2	0.3	0.4	0.2
Significance of F					
Cultivar	<.0001				
P rate	<.0001				
Cultivar x P rate	0.24				
CV, %	11.6%				

LSD (0.05) for P rate 0.12
LSD (0.05) for cultivar and P*cultivar 0.04

Table A15. Effect of cultivar and P rate on plant tissue P uptake, on historical cultivars, reached by increasing average plant tissue P uptake.

Cultivar	0	5	10	20	Average
	mg P pot^{-1}				
	mg pot^{-1}				
Walera	1.3	2.7	4.3	7.4	3.9
Renown	1.3	2.7	4.5	7.6	4.0
Era	1.6	2.9	4.6	7.2	4.1
Wared	1.5	2.5	4.5	7.7	4.1
Bonanza	1.5	3.1	4.6	7.4	4.1
Stoa	1.5	2.9	4.5	7.9	4.2
Solar	1.5	3.0	4.4	7.9	4.2
Wheaton	1.7	2.8	4.5	7.8	4.2
Marquis	1.5	3.0	4.7	7.8	4.2
AC Barrie	1.6	3.0	4.5	7.9	4.2
Fortuna	1.5	3.0	4.8	7.7	4.3
Chris	1.9	3.5	3.8	7.8	4.3
Gus	1.6	2.7	4.8	8.0	4.3
Rushmore	1.6	3.0	5.0	7.5	4.3
Olaf	1.7	3.0	4.9	7.7	4.3
Justin	1.7	3.0	4.7	8.0	4.4
Kitt	1.9	3.2	4.5	7.9	4.4
Amidon	1.7	3.1	4.8	8.0	4.4
Lee	1.7	3.0	4.9	8.0	4.4
Len	1.5	3.4	4.9	7.9	4.4
Coteau	1.7	3.1	4.9	8.1	4.5
Polk	1.6	3.0	5.2	8.2	4.5
Conley	1.6	3.0	5.3	8.2	4.5
Sharp	1.7	3.1	4.9	8.4	4.5
Marshall	1.6	3.5	4.3	8.9	4.5
World Seeds 1812	1.8	3.1	5.1	8.3	4.6
Pilot	1.8	2.9	5.3	8.3	4.6
Red River 68	1.8	3.4	4.8	8.5	4.6
2369	1.7	3.3	4.8	8.7	4.6
Rival	1.6	3.5	5.3	8.2	4.7
World Seeds 1809	1.7	3.3	5.3	8.4	4.7
Ellar	2.0	3.2	5.3	8.4	4.7
Bounty 208	1.9	3.0	5.0	8.9	4.7
Waldron	1.8	3.3	5.0	8.8	4.7
Lark	1.9	3.3	5.3	8.4	4.7
Ceres	1.9	3.0	5.5	8.8	4.8
Butte	1.7	3.4	5.7	8.6	4.8

Table A15. Effect of cultivar and P rate on plant tissue P uptake, on historical cultivars, reached by increasing average plant tissue P uptake (continued).

	-------------------- mg P pot-1 --------------------				
Cultivar	0	5	10	20	Average
	------------------------------- mg pot-1 ---------------------------------				
Prodax	2.0	3.6	5.3	8.5	4.9
Vesta	2.0	3.7	5.5	9.0	5.0
Regent	1.9	3.4	5.7	9.5	5.1
Thatcher	1.9	3.4	6.9	8.4	5.2
Alex	2.0	3.8	5.7	9.2	5.2
Oslo	2.1	4.0	5.6	9.0	5.2
Manitou	2.1	3.6	5.7	9.7	5.3
Selkirk	2.1	3.6	5.9	9.6	5.3
Pembina	2.2	3.8	6.0	9.3	5.3
2375	2.2	4.2	6.0	9.8	5.5
Average	1.8	3.2	5.1	8.3	4.6
Significance of F					
Cultivar	<.0001				
P rate	<.0001				
Cultivar x P rate	0.08				
CV, %	11.3%				

LSD (0.05) for P rate 2.52
LSD (0.05) for cultivar and P*cultivar 0.77

Table A16. Effect of cultivar and P rate on P uptake efficiency (PUE), on historical cultivars, reached by increasing average PUE.

Cultivar	mg P pot^{-1} 0	5	10	20	Average
	%				
Wared	--	20.1	29.3	30.9	26.8
Kitt	--	25.8	26.0	29.9	27.2
Wheaton	--	22.8	28.4	30.6	27.3
Era	--	25.5	30.0	28.0	27.8
Gus	--	22.3	32.1	31.8	28.7
AC Barrie	--	26.3	28.7	31.2	28.8
Walera	--	26.3	29.8	30.5	28.9
Justin	--	25.9	29.3	31.6	28.9
Olaf	--	25.6	31.7	30.0	29.1
Bounty 208	--	21.9	30.7	34.7	29.1
Pilot	--	21.3	35.0	32.4	29.5
Ellar	--	24.4	32.9	31.8	29.7
World Seeds 1812	--	24.9	32.3	32.1	29.8
Rushmore	--	26.6	34.0	29.5	30.0
Lee	--	26.5	32.5	31.5	30.1
Stoa	--	28.1	30.1	32.3	30.2
Ceres	--	20.8	36.3	34.4	30.5
Amidon	--	28.8	31.5	31.6	30.6
Coteau	--	28.6	31.4	32.0	30.7
Chris	--	31.1	31.7	29.3	30.7
Renown	--	28.1	32.5	31.7	30.8
Solar	--	30.8	29.7	32.0	30.8
Bonanza	--	32.2	30.8	29.8	30.9
Lark	--	27.4	33.2	32.3	31.0
Marquis	--	29.6	31.9	31.7	31.1
Sharp	--	27.7	31.9	33.8	31.1
Red River 68	--	30.6	29.9	33.2	31.2
Fortuna	--	31.3	33.5	31.2	32.0
Polk	--	28.1	35.5	32.7	32.1
Waldron	--	30.6	31.8	34.8	32.4
2369	--	31.7	30.9	34.9	32.5
Prodax	--	32.2	33.3	32.3	32.6
Conley	--	28.7	37.1	33.3	33.0
Marshall	--	38.0	27.8	36.5	34.1
Len	--	36.9	33.9	31.8	34.2
Vesta	--	33.3	34.3	35.0	34.2
World Seeds 1809	--	32.7	36.7	33.6	34.4

Table A16. Effect of cultivar and P rate on P uptake efficiency (PUE), on historical cultivars, reached by increasing average PUE (continued).

	-------------------- mg P pot-1 --------------------				
Cultivar	0	5	10	20	Average
	------------------------------------ % ------------------------------------				
Manitou	--	30.1	36.2	37.9	34.7
Pembina	--	31.4	37.4	35.4	34.8
Regent	--	29.4	38.1	37.9	35.1
Selkirk	--	30.4	37.7	37.8	35.3
Rival	--	37.1	37.0	33.0	35.7
Alex	--	35.4	36.7	35.7	35.9
Butte	--	33.8	39.8	34.4	36.0
Oslo	--	39.4	35.7	34.7	36.6
Thatcher	--	30.5	50.2	32.3	37.7
2375	--	40.0	37.8	38.0	38.6
Average	--	29.2	33.3	32.8	31.8
Significance of F					
Cultivar	0.0004				
P rate	0.23				
Cultivar x P rate	0.90				
CV, %	23.5%				

LSD (0.05) for P rate 28.3
LSD (0.05) for cultivar and P*cultivar 11.96

Table A17. The 2015 study overall average effect of P on the historical cultivars and selected response variables at rates of 0, 5, 10, and 20 mg P pot^{-1}.

Variable	Units	------- P rate†, mg pot^{-1} ------				Cultivar range ‡	Significance of F			CV %
		0	5	10	20		P rate	Cultivar	P*Cult.	
Dry matter	g pot^{-1}	1.2	1.6	2.1	2.3	1.4 - 2.3 (52)	**	**	**	9.4
Relative Yield	%	50.6	70.5	88.8	100	58.7 - 76.3 (23)	**	**	NS	13.0
Haun stage	leaves plant^{-1}	5.2	5.5	5.5	5.6	4.8 - 6.4 (30)	**	**	NS	3.0
T0	tillers plant^{-1}	0.0	0.1	0.2	0.4	0 - 0.7 (335)	**	**	**	90.0
T1	tillers plant^{-1}	0.5	0.9	1.0	1.0	0.4 -1.0 (67)	**	**	**	17.2
T2	tillers plant^{-1}	0.0	0.3	0.8	0.9	0.2 - 0.8 (124)	**	**	**	35.1
T1+T2	tillers plant^{-1}	0.5	1.2	1.7	1.9	0.8 - 1.8 (80)	**	**	**	16.2
Other tillers	tillers plant^{-1}	0.0	0.0	0.1	0.2	0 - 0.4 (880)	**	**	**	245.0
Total tillers	tillers plant^{-1}	0.5	1.3	2.0	2.5	0.8 -2.7 (215)	**	**	**	18.6
P concentration	%	0.2	0.2	0.3	0.4	0.2 - 0.3 (33)	**	**	NS	11.6
P uptake	mg pot^{-1}	1.8	3.2	5.1	8.3	3.9 - 5.5 (35)	**	**	+	11.3
PUE	%	--	29.2	33.3	32.8	26.8 - 38.6 (37)	**	NS	NS	23.5

†Averaged across cultivar

‡ Averaged across P rate. The values in parentheses represent the relative range as a percentage of the mean, see text

+, *, **, F-test significant at the 0.1, 0.05, and 0.01 level, respectively.

Table A18. Data used for correlation analysis on historical cultivars.

	-------------- Measurement at 20 mg P pot^{-1} ---------------							--- Measurement averaged across P rate ---				
Cultivar	DM	HS	T0	T1	T2	OT	TT	RY	P conc.	PU	PUE	T1T2
	g pot^{-1}	leaves plant^{-1}	--------------------- tillers plant^{-1}---------------------					%	%	mg pot^{-1}	%	tillers plant^{-1}
2369	2.5	5.7	0.2	0.9	0.8	0.0	1.9	65.8	0.2	4.6	32.5	0.9
2375	3.0	5.7	0.6	1.0	0.9	0.0	2.4	67.7	0.2	5.5	38.6	1.3
AC Barrie	2.1	5.9	0.2	1.0	1.0	0.3	2.5	70.2	0.2	4.2	28.8	1.4
Alex	2.5	5.8	0.5	1.0	1.0	0.3	2.8	71.1	0.3	5.2	35.9	1.4
Amidon	2.5	5.7	0.7	1.0	1.0	0.3	2.9	68.4	0.2	4.4	30.6	1.3
Bonanza	1.9	5.4	0.1	1.0	1.0	0.0	2.1	71.5	0.3	4.1	30.9	1.3
Bounty 208	2.3	5.9	0.3	1.0	0.9	0.1	2.3	64.5	0.3	4.7	29.1	1.4
Butte	2.5	6.5	0.0	1.0	0.9	0.0	1.9	70.6	0.2	4.8	36.0	1.1
Ceres	2.6	5.6	0.5	1.0	1.0	0.3	2.8	67.4	0.2	4.8	30.5	1.5
Chris	2.1	5.4	0.1	1.0	1.0	0.1	2.1	71.8	0.2	4.3	26.4	1.5
Conley	2.3	5.4	0.1	1.0	1.0	0.1	2.2	70.6	0.2	4.5	33.0	1.3
Coteau	2.4	5.4	0.4	1.0	1.0	0.2	2.6	69.6	0.2	4.5	30.7	1.5
Ellar	2.5	5.6	0.5	1.0	1.0	0.1	2.6	67.5	0.2	4.7	29.7	1.2
Era	1.7	5.2	0.3	1.0	1.0	0.1	2.4	73.5	0.3	4.1	27.8	1.3
Fortuna	2.3	5.6	0.6	1.0	1.0	0.0	2.6	73.5	0.2	4.3	32.0	1.3
Gus	2.2	5.9	0.0	1.0	0.6	0.0	1.6	66.2	0.2	4.3	28.7	1.0
Justin	2.5	5.7	0.6	1.0	1.0	0.3	2.8	72.0	0.2	4.4	28.9	1.4
Kitt	2.0	5.6	0.7	1.0	1.0	0.7	3.4	69.8	0.3	4.4	27.2	1.5
Lark	2.1	5.9	0.8	1.0	1.0	0.3	3.1	73.6	0.3	4.7	31.0	1.5
Lee	2.5	5.6	0.1	1.0	0.5	0.0	1.6	74.6	0.2	4.4	30.1	0.9
Len	2.1	5.6	0.6	1.0	1.0	0.0	2.6	69.1	0.3	4.4	34.2	1.3
Manitou	2.4	6.0	0.2	1.0	1.0	0.3	2.4	68.5	0.3	5.3	34.7	1.5
Marquis	2.4	5.4	0.9	1.0	0.9	0.3	3.2	66.3	0.2	4.2	31.1	1.4
Marshall	1.9	5.3	0.8	1.0	0.9	0.3	3.0	70.0	0.3	4.5	34.1	1.4
Olaf	2.2	5.6	0.7	1.0	1.0	0.3	3.0	70.7	0.2	4.3	29.1	1.6
Oslo	2.1	6.6	0.3	0.9	0.9	0.0	2.0	76.3	0.3	5.2	36.6	1.2
Pembina	2.5	5.5	0.1	1.0	1.0	0.2	2.3	73.4	0.3	5.3	34.8	1.5

Table A18. Data used for correlation analysis on historical cultivars (continued).

	-------------- Measurement at 20 mg P pot-1 ---------------							--- Measurement averaged across P rate ---				
Cultivar	DM	HS	T0	T1	T2	OT	TT	RY	P conc.	PU	PUE	T1T2
	g pot^{-1}	leaves $plant^{-1}$	--------------------- tillers $plant^{-1}$--------------------					%	%	mg pot^{-1}	%	tillers $plant^{-1}$
Pilot	2.7	5.7	0.7	0.9	0.9	0.3	2.8	68.4	0.2	4.6	29.5	1.6
Polk	2.6	5.6	0.9	1.0	0.6	0.0	2.5	69.9	0.2	4.5	32.1	1.0
Prodax	2.0	5.4	0.1	1.0	0.9	0.0	1.9	74.6	0.3	4.9	32.6	1.0
Red River 68	2.3	5.4	0.8	1.0	0.9	0.3	3.0	67.1	0.3	4.6	31.2	1.5
Regent	2.8	5.2	0.4	1.0	1.0	0.1	2.4	66.2	0.2	5.1	35.1	1.5
Renown	2.4	4.9	0.6	1.0	1.0	0.6	3.3	74.1	0.2	4.0	30.8	1.8
Rival	2.4	5.4	0.1	1.0	0.9	0.0	2.0	74.9	0.2	4.7	35.7	1.3
Rushmore	2.4	5.6	0.7	1.0	0.9	0.0	2.6	73.6	0.2	4.3	30.0	1.3
Selkirk	3.0	5.5	0.8	1.0	1.0	0.2	3.0	72.1	0.2	5.3	35.3	1.6
Sharp	2.4	5.5	0.4	1.0	1.0	0.3	2.7	70.2	0.2	4.5	31.1	1.5
Solar	1.9	5.4	0.4	1.0	1.0	0.1	2.6	68.8	0.3	4.2	30.8	1.2
Stoa	2.4	6.0	0.0	1.0	1.0	0.0	2.0	64.7	0.2	4.2	30.2	1.0
Thatcher	2.2	5.6	0.4	1.0	1.0	0.3	2.7	71.8	0.3	5.2	37.7	1.6
Vesta	2.6	5.5	0.7	1.0	1.0	0.2	2.9	75.4	0.2	5.0	34.2	1.5
Waldron	2.7	5.9	0.2	1.0	1.0	0.0	2.2	68.3	0.2	4.7	32.4	1.3
Walera	1.9	5.3	0.5	1.0	0.9	0.1	2.5	64.4	0.3	3.9	28.9	1.4

DM= dry matter, HS= main stem Haun stage, OT= other tillers, TT= total tillers, RY= relative yield, P conc.= P concentration, PU= P uptake, PUE= Phosphorus uptake efficiency, T1T2= T1 +T2 tillers

Table A19. Linear correlation coefficients (r) between dry matter production and main stem Haun stage at the highest rate of P, and selected response variables, for the historical cultivar study.

Variable	P rate	Dry matter†	Haun stage†
	mg pot^{-1}	g pot^{-1}	leaves $plant^{-1}$
Dry matter	20	1	---
Haun stage	20	0.138	1
T0 tiller initiation	20	0.099	-0.353*
T1 tiller initiation	20	-0.016	-0.51**
T2 tiller initiation	20	-0.108	-0.181
Other tiller initiation	20	-0.067	-0.244
Total tiller initiation	20	0.007	-0.388**
Relative yield	0-10	-0.051	0.051
P concentration in plant tissue	0-20	-0.707**	0.109
Phosphorus uptake	0-20	0.578**	0.334*
Phosphorus uptake efficiency	5-20	0.456**	0.283
T1 + T2 tiller initiation	0-20	0.035	-0.392**

†Dry matter and main stem Haun stage at the highest rate of P, 20 mg pot^{-1}.
*, **, Correlation significant at the 0.05 and 0.01 level, respectively.

Table A20. Effect of cultivar and P rate on dry matter production, on current and pending cultivars, reached by increasing average dry matter production.

Cultivar	---- mg P pot^{-1} ---- 0	5	10	20	Average
	---- g pot^{-1} ----				
HRS-3419	1.2	1.6	1.7	1.7	1.5
Rollag	1.1	1.6	1.6	1.9	1.6
Marshall	1.3	1.6	1.6	1.9	1.6
Bolles	1.2	1.7	1.8	1.9	1.6
RB07	1.3	1.7	1.7	1.9	1.6
MS-Stingray	1.1	1.7	1.9	2.0	1.7
LCS-Albany	1.3	1.8	1.8	1.9	1.7
LCS-Powerplay	1.3	1.7	1.8	2.0	1.7
Linkert	1.3	1.7	1.9	2.0	1.7
HRS-3361	1.3	1.7	1.8	2.0	1.7
TCG-Wildfire	1.3	1.7	1.8	2.1	1.7
LCS-Iguacu	1.3	1.8	1.9	2.0	1.8
Advance	1.4	1.8	2.0	2.0	1.8
LCS-Breakaway	1.4	1.7	2.0	2.2	1.8
Steele-ND	1.4	1.8	2.0	2.1	1.8
Velva	1.4	1.9	2.0	2.0	1.9
2375	1.4	1.8	2.0	2.3	1.9
ND-825	1.5	1.9	2.0	2.1	1.9
Mott	1.5	1.9	2.0	2.1	1.9
HRS-3530	1.4	1.8	2.1	2.3	1.9
Barlow	1.4	1.9	2.1	2.2	1.9
MS-Chevelle	1.5	1.9	2.0	2.2	1.9
HRS-3504	1.5	1.9	2.0	2.2	1.9
Norden	1.5	1.9	2.0	2.2	1.9
WS 1812	1.5	1.9	2.1	2.2	1.9
Faller	1.5	1.9	2.1	2.3	1.9
TGC-Spitfire	1.3	1.9	2.1	2.4	1.9
Sabin	1.3	2.0	2.1	2.3	1.9
Prosper	1.4	1.9	2.1	2.3	1.9
TCG-Cornerstone	1.5	2.0	2.0	2.4	2.0
Forefront	1.6	2.0	2.0	2.3	2.0
ND901CL	1.5	2.0	2.2	2.4	2.0
Glenn	1.5	2.0	2.2	2.4	2.0
ND-820	1.6	1.9	2.2	2.4	2.0
ND-907	1.5	2.1	2.2	2.3	2.0
LCS-Pro	1.6	2.0	2.2	2.4	2.0
Butte	1.6	2.0	2.3	2.5	2.1

Table A20. Effect of cultivar and P rate on dry matter production, on current and pending cultivars, reached by increasing average dry matter production (continued).

	-------------------- mg P pot-1 --------------------				
Cultivar	0	5	10	20	Average
	------------------------------- g pot-1 ----------------------------------				
Elgin-ND	1.5	2.1	2.3	2.4	2.1
Focus	1.7	2.0	2.4	2.4	2.1
Select	1.6	2.2	2.5	2.5	2.2
Brick	1.7	2.1	2.4	2.6	2.2
Prevail	1.7	2.1	2.4	2.5	2.2
Average	1.4	1.9	2.0	2.2	1.9
Significance of F					
Cultivar	<.0001				
P rate	<.0001				
Cultivar x P rate	0.11				
CV, %	7.1%				

LSD (0.05) for P rate 1.10
LSD (0.05) for cultivar and P*cultivar 0.18

Table A21. Effect of cultivar and P rate on dry matter relative yield, on current and pending cultivars, reached by increasing average relative yield.

Cultivar	0	5	10	20	Average
	-------------------- mg P pot^{-1} --------------------				
	---------------------------------- % ----------------------------------				
2375	61.4	78.7	86.7	100.0	75.6
TGC-Spitfire	57.4	80.7	90.3	100.0	76.1
TCG-Wildfire	64.5	79.4	87.3	100.0	77.1
Rollag	60.2	85.5	85.5	100.0	77.1
Prosper	60.7	82.1	90.0	100.0	77.6
MS-Stingray	56.4	84.4	92.6	100.0	77.8
ND901CL	60.8	83.4	90.0	100.0	78.0
LCS-Breakaway	63.4	79.0	91.7	100.0	78.0
HRS-3530	62.6	80.6	91.6	100.0	78.3
Butte	63.4	79.6	92.2	100.0	78.4
Sabin	58.6	86.8	90.7	100.0	78.7
LCS-Powerplay	64.0	83.1	89.3	100.0	78.8
TCG-Cornerstone	65.3	84.5	87.1	100.0	79.0
Faller	65.1	81.6	91.5	100.0	79.4
Marshall	67.6	83.3	87.7	100.0	79.6
HRS-3361	65.7	84.9	89.1	100.0	79.9
Glenn	64.0	83.7	93.2	100.0	80.3
LCS-Pro	65.5	86.2	89.3	100.0	80.3
Bolles	63.5	86.9	91.0	100.0	80.5
HRS-3504	69.8	83.6	90.2	100.0	81.2
Elgin-ND	62.2	85.8	96.8	100.0	81.6
ND-820	68.6	81.9	94.9	100.0	81.8
MS-Chevelle	69.4	85.1	92.5	100.0	82.3
Steele-ND	67.4	83.7	96.5	100.0	82.5
LCS-Iguacu	63.5	87.9	96.5	100.0	82.6
RB07	67.6	89.0	91.6	100.0	82.7
Linkert	68.0	85.7	94.8	100.0	82.8
Brick	66.9	84.9	96.8	100.0	82.9
ND-825	70.5	87.3	91.4	100.0	83.1
Select	65.7	86.6	98.7	100.0	83.7
WS 1812	66.3	86.8	98.1	100.0	83.7
ND-907	68.0	89.5	93.7	100.0	83.8
Barlow	64.9	89.6	97.1	100.0	83.9
Forefront	70.5	90.8	90.8	100.0	84.0
Norden	70.2	87.6	94.3	100.0	84.1
Prevail	69.8	85.9	96.6	100.0	84.1
Focus	70.9	85.3	97.7	100.0	84.6

Table A21. Effect of cultivar and P rate on dry matter relative yield, on current and pending cultivars, reached by increasing average relative yield (continued).

	-------------------- mg P pot-1 --------------------				
Cultivar	0	5	10	20	Average
	----------------------------------- % -------------------------------------				
Mott	70.3	88.0	95.7	100.0	84.7
LCS-Albany	66.9	92.3	100.6	100.0	86.6
HRS-3419	72.0	94.1	98.1	100.0	88.1
Advance	70.9	93.6	100.9	100.0	88.5
Velva	73.0	97.2	102.4	100.0	90.9
Average	65.8	85.6	93.2	100.0	81.5
Significance of F					
Cultivar	0.01				
P rate	<.0001				
Cultivar x P rate	0.97				
CV, %	9.5%				

LSD (0.05) for P rate 25.98

LSD (0.05) for cultivar and P*cultivar 10.64

Table A22. Effect of cultivar and P rate on main stem Haun stage, on current and pending cultivars, reached by increasing average main stem Haun stage.

	mg P pot^{-1}				
Cultivar	0	5	10	20	Average
	leaves $plant^{-1}$				
MS-Stingray	4.7	4.9	5.1	5.1	5.0
Marshall	4.9	5.0	5.0	5.0	5.0
TCG-Wildfire	5.0	5.1	5.1	5.2	5.1
RB07	5.0	5.2	5.3	5.1	5.1
TGC-Spitfire	5.2	5.1	5.2	5.2	5.2
Velva	5.1	5.2	5.3	5.1	5.2
Rollag	5.3	5.3	5.2	5.3	5.3
WS 1812	5.1	5.4	5.4	5.3	5.3
HRS-3419	5.2	5.3	5.4	5.5	5.4
Bolles	5.3	5.4	5.4	5.4	5.4
Sabin	5.2	5.5	5.4	5.5	5.4
HRS-3530	5.4	5.5	5.4	5.4	5.4
2375	5.4	5.5	5.4	5.6	5.5
Linkert	5.5	5.5	5.6	5.5	5.5
HRS-3361	5.6	5.6	5.4	5.6	5.5
Glenn	5.6	5.6	5.5	5.5	5.6
LCS-Iguacu	5.4	5.8	5.5	5.6	5.6
TCG-Cornerstone	5.6	5.6	5.5	5.7	5.6
LCS-Powerplay	5.6	5.7	5.6	5.6	5.6
Mott	5.6	5.6	5.5	5.7	5.6
Prevail	5.7	5.7	5.6	5.5	5.7
LCS-Albany	5.3	5.6	6.1	5.7	5.7
ND-907	5.6	5.7	5.7	5.7	5.7
HRS-3504	5.6	5.8	5.7	5.7	5.7
Forefront	5.8	5.7	5.6	5.7	5.7
Advance	5.7	5.8	5.7	5.6	5.7
Norden	5.7	5.8	5.6	5.8	5.7
MS-Chevelle	5.5	5.9	5.9	5.7	5.7
ND-825	5.8	5.8	5.7	5.8	5.8
Steele-ND	5.8	5.7	5.7	5.8	5.8
Elgin-ND	5.7	5.9	5.6	6.0	5.8
Prosper	5.9	5.9	5.9	5.9	5.9
Faller	5.9	5.8	5.9	6.0	5.9
LCS-Pro	5.9	6.0	5.9	5.9	5.9
Focus	5.9	6.0	5.9	5.9	5.9
Barlow	5.9	5.9	6.0	6.0	6.0
ND901CL	6.0	6.1	6.1	6.1	6.0

Table A22. Effect of cultivar and P rate on main stem Haun stage, on current and pending cultivars, reached by increasing average main stem Haun stage (continued).

	-------------------- mg P pot-1 --------------------				
Cultivar	0	5	10	20	Average
	---------------------------- leaves plant-1 -----------------------------				
ND-820	6.2	6.4	6.2	6.3	6.3
Select	6.3	6.3	6.3	6.2	6.3
Brick	6.4	6.3	6.4	6.5	6.4
Butte	6.4	6.4	6.4	6.7	6.5
LCS-Breakaway	6.6	6.4	6.6	6.5	6.5
Average	5.6	5.7	5.7	5.7	5.7
Significance of F					
Cultivar	<.0001				
P rate	0.05				
Cultivar x P rate	0.06				
CV, %	2.9%				

LSD (0.05) for P rate 0.38
LSD (0.05) for cultivar and P*cultivar 0.23

Table A23. Effect of cultivar and P rate on T0 tiller initiation, on current and pending cultivars, reached by increasing average T0 tiller initiation.

	------------------- mg P pot^{-1} -------------------				
Cultivar	0	5	10	20	Average
	---------------------------- tillers plant^{-1} ----------------------------				
HRS-3419	0.0	0.0	0.0	0.0	0.0
Butte	0.0	0.0	0.0	0.0	0.0
ND901CL	0.0	0.0	0.1	0.0	0.0
Sabin	0.0	0.0	0.1	0.0	0.0
LCS-Powerplay	0.0	0.0	0.1	0.0	0.0
Faller	0.0	0.0	0.0	0.1	0.0
Prosper	0.0	0.1	0.0	0.1	0.0
Brick	0.1	0.0	0.0	0.1	0.0
LCS-Breakaway	0.0	0.0	0.1	0.1	0.0
TCG-Wildfire	0.0	0.0	0.0	0.1	0.0
2375	0.0	0.0	0.0	0.1	0.0
Mott	0.1	0.0	0.0	0.1	0.1
Advance	0.0	0.0	0.1	0.1	0.1
HRS-3530	0.0	0.0	0.0	0.2	0.1
ND-907	0.0	0.0	0.1	0.1	0.1
Forefront	0.0	0.0	0.1	0.1	0.1
Bolles	0.0	0.0	0.0	0.3	0.1
TCG-Cornerstone	0.1	0.0	0.1	0.1	0.1
ND-820	0.0	0.0	0.0	0.3	0.1
Norden	0.0	0.1	0.2	0.1	0.1
Velva	0.0	0.0	0.2	0.2	0.1
Rollag	0.0	0.1	0.1	0.2	0.1
LCS-Albany	0.2	0.0	0.1	0.1	0.1
LCS-Pro	0.0	0.0	0.0	0.4	0.1
ND-825	0.0	0.0	0.1	0.4	0.1
Barlow	0.0	0.0	0.1	0.4	0.1
Elgin-ND	0.0	0.0	0.3	0.3	0.1
Focus	0.0	0.1	0.3	0.1	0.1
HRS-3361	0.0	0.1	0.0	0.4	0.1
Steele-ND	0.0	0.0	0.2	0.4	0.2
HRS-3504	0.0	0.0	0.3	0.4	0.2
Glenn	0.0	0.1	0.2	0.5	0.2
Marshall	0.0	0.1	0.2	0.6	0.2
Select	0.0	0.2	0.4	0.3	0.2
TGC-Spitfire	0.0	0.1	0.3	0.6	0.2
MS-Stingray	0.0	0.1	0.3	0.6	0.2
RB07	0.1	0.3	0.3	0.3	0.3

Table A23. Effect of cultivar and P rate on T0 tiller initiation, on current and pending cultivars, reached by increasing average T0 tiller initiation (continued).

	-------------------- mg P pot-1 --------------------				
Cultivar	0	5	10	20	Average
	----------------------------- tillers plant-1 -------------------------------				
Linkert	0.0	0.2	0.4	0.6	0.3
Prevail	0.0	0.3	0.4	0.6	0.3
LCS-Iguacu	0.0	0.2	0.7	0.7	0.4
MS-Chevelle	0.4	0.5	0.4	0.9	0.6
WS 1812	0.4	0.3	0.9	0.9	0.6
Average	0.0	0.1	0.2	0.3	0.1
Significance of F					
Cultivar	<.0001				
P rate	<.0001				
Cultivar x P rate	<.0001				
CV, %	119.3%				

LSD (0.05) for P rate 0.25

LSD (0.05) for cultivar and P*cultivar 0.22

Table A24. Effect of cultivar and P rate on T1 tiller initiation, on current and pending cultivars, reached by increasing average T1 tiller initiation.

	-------------------- mg P pot^{-1} --------------------				
Cultivar	0	5	10	20	Average
	----------------------------- tillers plant^{-1} ------------------------------				
LCS-Breakaway	0.1	0.6	0.7	1.0	0.6
HRS-3530	0.1	0.5	0.9	1.0	0.6
Bolles	0.0	0.7	1.0	0.9	0.7
TCG-Wildfire	0.4	0.8	1.0	0.9	0.8
ND901CL	0.4	0.9	0.9	1.0	0.8
2375	0.4	0.9	0.9	1.0	0.8
Butte	0.4	0.9	1.0	1.0	0.8
Prosper	0.5	1.0	1.0	1.0	0.9
Barlow	0.6	1.0	1.0	1.0	0.9
Faller	0.6	1.0	1.0	1.0	0.9
LCS-Powerplay	0.8	0.9	0.9	1.0	0.9
Glenn	0.8	1.0	1.0	1.0	0.9
ND-820	0.8	1.0	1.0	1.0	0.9
Steele-ND	0.9	0.9	1.0	1.0	0.9
Sabin	0.8	1.0	1.0	1.0	0.9
LCS-Pro	0.8	1.0	1.0	1.0	0.9
TCG-Cornerstone	0.8	1.0	1.0	1.0	0.9
Elgin-ND	0.9	0.9	1.0	1.0	1.0
Mott	0.8	1.0	1.0	1.0	1.0
ND-825	0.8	1.0	1.0	1.0	1.0
ND-907	0.8	1.0	1.0	1.0	1.0
Prevail	0.9	0.9	1.0	1.0	1.0
Brick	0.9	1.0	0.9	1.0	1.0
Focus	0.9	1.0	1.0	1.0	1.0
Norden	0.9	1.0	1.0	1.0	1.0
HRS-3419	0.9	1.0	1.0	1.0	1.0
TGC-Spitfire	0.9	1.0	1.0	1.0	1.0
Advance	0.9	1.0	1.0	1.0	1.0
Linkert	0.9	1.0	1.0	1.0	1.0
RB07	1.0	0.9	1.0	1.0	1.0
HRS-3361	0.9	1.0	1.0	1.0	1.0
MS-Chevelle	1.0	1.0	1.0	0.9	1.0
MS-Stingray	0.9	1.0	1.0	1.0	1.0
Marshall	0.9	1.0	1.0	1.0	1.0
Velva	1.0	1.0	1.0	1.0	1.0
Forefront	1.0	1.0	1.0	1.0	1.0
Select	1.0	1.0	1.0	1.0	1.0

Table A24. Effect of cultivar and P rate on T1 tiller initiation, on current and pending cultivars, reached by increasing average T1 tiller initiation (continued).

	-------------------- mg P pot-1 --------------------				
Cultivar	0	5	10	20	Average
	----------------------------- tillers plant-1 ------------------------------				
Rollag	1.0	1.0	1.0	1.0	1.0
HRS-3504	1.0	1.0	1.0	1.0	1.0
LCS-Iguacu	1.0	1.0	1.0	1.0	1.0
WS 1812	1.0	1.0	1.0	1.0	1.0
LCS-Albany	1.0	1.0	1.0	1.0	1.0
Average	0.8	1.0	1.0	1.0	0.9
Significance of F					
Cultivar	<.0001				
P rate	<.0001				
Cultivar x P rate	<.0001				
CV, %	12.1%				

LSD (0.05) for P rate 0.37

LSD (0.05) for cultivar and P*cultivar 0.16

Table A25. Effect of cultivar and P rate on T2 tiller initiation, on current and pending cultivars, reached by increasing T2 tiller initiation.

Cultivar	mg P pot^{-1}				
	0	5	10	20	Average
	tillers plant^{-1}				
Bolles	0.0	0.1	0.3	0.1	0.1
LCS-Breakaway	0.0	0.0	0.3	0.3	0.1
TCG-Wildfire	0.0	0.1	0.4	0.7	0.3
2375	0.0	0.1	0.7	0.8	0.4
Barlow	0.0	0.3	0.6	0.9	0.4
ND-820	0.0	0.1	0.6	1.0	0.4
Steele-ND	0.0	0.3	0.6	0.8	0.4
ND-907	0.0	0.6	0.5	0.9	0.5
HRS-3530	0.0	0.5	0.4	1.0	0.5
Linkert	0.0	0.4	0.6	0.9	0.5
Brick	0.2	0.3	0.8	0.8	0.5
Prosper	0.0	0.4	0.8	1.0	0.5
Focus	0.1	0.4	0.8	0.9	0.5
Faller	0.0	0.3	0.9	1.0	0.6
Sabin	0.1	0.3	0.9	1.0	0.6
LCS-Pro	0.1	0.6	0.8	0.8	0.6
Butte	0.1	0.4	0.7	0.9	0.6
ND901CL	0.1	0.3	0.9	0.9	0.6
TCG-Cornerstone	0.0	0.4	0.9	1.0	0.6
HRS-3504	0.1	0.7	0.6	1.0	0.6
Elgin-ND	0.1	0.4	1.0	1.0	0.6
ND-825	0.0	0.6	0.8	1.0	0.6
Norden	0.1	0.4	1.0	1.0	0.6
LCS-Powerplay	0.1	0.6	0.8	1.0	0.6
Forefront	0.2	0.9	0.6	1.0	0.7
Select	0.1	0.6	0.9	1.0	0.7
Mott	0.4	0.6	0.8	0.9	0.7
MS-Chevelle	0.1	0.8	0.9	0.9	0.7
Velva	0.0	0.9	0.9	0.9	0.7
HRS-3361	0.1	0.7	1.0	1.0	0.7
Rollag	0.1	0.8	1.0	1.0	0.7
Advance	0.0	0.9	1.0	1.0	0.7
LCS-Iguacu	0.1	0.8	1.0	1.0	0.7
MS-Stingray	0.1	0.8	1.0	1.0	0.7
Glenn	0.1	0.9	0.9	1.0	0.8
Prevail	0.1	0.9	1.0	1.0	0.8
TGC-Spitfire	0.1	0.9	1.0	0.9	0.8

Table A25. Effect of cultivar and P rate on T2 tiller initiation, on current and pending cultivars, reached by increasing T2 tiller initiation (continued).

	-------------------- mg P pot-1 --------------------				
Cultivar	0	5	10	20	Average
	----------------------------- tillers plant-1 ------------------------------				
RB07	0.6	0.7	1.0	1.0	0.8
HRS-3419	0.4	1.0	1.0	1.0	0.9
Marshall	0.5	0.9	1.0	1.0	0.9
WS 1812	1.0	0.8	1.0	1.0	1.0
LCS-Albany	1.0	1.0	1.0	1.0	1.0
Average	0.1	0.6	0.8	0.9	0.6
Significance of F					
Cultivar	<.0001				
P rate	<.0001				
Cultivar x P rate	<.0001				
CV, %	33.2%				

LSD (0.05) for P rate 0.59
LSD (0.05) for cultivar and P*cultivar 0.28

Table A26. Effect of cultivar and P rate on T1 + T2 tiller initiation, on current and pending cultivars, reached by increasing average T1 + T2 tiller initiation.

	mg P pot^{-1}				
Cultivar	0	5	10	20	Average
	tillers plant^{-1}				
LCS-Breakaway	0.1	0.6	1.0	1.3	0.7
Bolles	0.0	0.8	1.3	1.0	0.8
TCG-Wildfire	0.4	0.9	1.4	1.6	1.1
HRS-3530	0.1	1.0	1.4	2.0	1.1
2375	0.4	1.1	1.6	1.8	1.2
Barlow	0.6	1.3	1.6	1.9	1.3
ND-820	0.8	1.1	1.6	2.0	1.4
Steele-ND	0.9	1.1	1.6	1.8	1.4
ND901CL	0.4	1.3	1.9	1.9	1.4
Butte	0.6	1.3	1.7	1.9	1.4
Prosper	0.5	1.4	1.8	2.0	1.4
ND-907	0.8	1.6	1.5	1.9	1.4
Faller	0.6	1.3	1.9	2.0	1.5
Brick	1.1	1.3	1.7	1.8	1.5
Linkert	0.9	1.4	1.6	1.9	1.5
Sabin	0.8	1.3	1.9	2.0	1.5
LCS-Pro	0.8	1.6	1.8	1.8	1.5
Focus	0.9	1.4	1.8	1.9	1.5
TCG-Cornerstone	0.8	1.4	1.9	2.0	1.5
LCS-Powerplay	0.8	1.6	1.8	2.0	1.5
Elgin-ND	0.9	1.3	2.0	2.0	1.6
ND-825	0.8	1.6	1.8	2.0	1.6
Norden	0.9	1.4	2.0	2.0	1.6
HRS-3504	1.1	1.7	1.6	2.0	1.6
Mott	1.2	1.6	1.8	1.9	1.6
Forefront	1.2	1.9	1.6	2.0	1.7
Select	1.1	1.6	1.9	2.0	1.7
MS-Chevelle	1.1	1.8	1.9	1.9	1.7
Glenn	0.9	1.9	1.9	2.0	1.7
Velva	1.0	1.9	1.9	1.9	1.7
HRS-3361	1.1	1.7	2.0	2.0	1.7
Prevail	1.0	1.8	2.0	2.0	1.7
Advance	0.9	1.9	2.0	2.0	1.7
Rollag	1.1	1.8	2.0	2.0	1.7
MS-Stingray	1.1	1.8	2.0	2.0	1.7
TGC-Spitfire	1.0	1.9	2.0	1.9	1.7
LCS-Iguacu	1.1	1.8	2.0	2.0	1.7

Table A26. Effect of cultivar and P rate on T1 + T2 tiller initiation, on current and pending cultivars, reached by increasing average T1 + T2 tiller initiation (continued).

	-------------------- mg P pot-1 --------------------				
Cultivar	0	5	10	20	Average
	----------------------------- tillers plant-1 -------------------------------				
RB07	1.6	1.6	2.0	2.0	1.8
HRS-3419	1.3	2.0	2.0	2.0	1.8
Marshall	1.4	1.9	2.0	2.0	1.8
WS 1812	2.0	1.8	2.0	2.0	2.0
LCS-Albany	2.0	2.0	1.9	2.0	2.0
Average	0.9	1.5	1.8	1.9	1.5
Significance of F					
Cultivar	<.0001				
P rate	<.0001				
Cultivar x P rate	<.0001				
CV, %	14.8%				

LSD (0.05) for P rate 0.79
LSD (0.05) for cultivar and P*cultivar 0.31

Table A27. Effect of cultivar and P rate on T3 tiller initiation, on current and pending cultivars, reached by increasing average T3 tiller initiation.

Cultivar	------------------- mg P pot^{-1} ------------------- 0	5	10	20	Average
	---------------------------- tillers plant^{-1} ----------------------------				
Barlow	0.0	0.0	0.0	0.0	0.0
Elgin-ND	0.0	0.0	0.0	0.0	0.0
Faller	0.0	0.0	0.0	0.0	0.0
Glenn	0.0	0.0	0.0	0.0	0.0
Mott	0.0	0.0	0.0	0.0	0.0
ND-820	0.0	0.0	0.0	0.0	0.0
ND-825	0.0	0.0	0.0	0.0	0.0
ND-907	0.0	0.0	0.0	0.0	0.0
Prosper	0.0	0.0	0.0	0.0	0.0
Steele-ND	0.0	0.0	0.0	0.0	0.0
Advance	0.0	0.0	0.0	0.0	0.0
Brick	0.0	0.0	0.0	0.0	0.0
Focus	0.0	0.0	0.0	0.0	0.0
Forefront	0.0	0.0	0.0	0.0	0.0
Prevail	0.0	0.0	0.0	0.0	0.0
Select	0.0	0.0	0.0	0.0	0.0
Bolles	0.0	0.0	0.0	0.0	0.0
Linkert	0.0	0.0	0.0	0.0	0.0
RB07	0.0	0.0	0.0	0.0	0.0
Sabin	0.0	0.0	0.0	0.0	0.0
HRS-3361	0.0	0.0	0.0	0.0	0.0
HRS-3504	0.0	0.0	0.0	0.0	0.0
HRS-3530	0.0	0.0	0.0	0.0	0.0
LCS-Pro	0.0	0.0	0.0	0.0	0.0
LCS-Powerplay	0.0	0.0	0.0	0.0	0.0
MS-Chevelle	0.0	0.0	0.0	0.0	0.0
TCG-Cornerstone	0.0	0.0	0.0	0.0	0.0
TGC-Spitfire	0.0	0.0	0.0	0.0	0.0
TCG-Wildfire	0.0	0.0	0.0	0.0	0.0
2375	0.0	0.0	0.0	0.0	0.0
Butte	0.0	0.0	0.0	0.0	0.0
Marshall	0.0	0.0	0.0	0.0	0.0
ND901CL	0.0	0.0	0.1	0.0	0.0
Velva	0.0	0.0	0.0	0.1	0.0
Norden	0.0	0.0	0.0	0.1	0.0
Rollag	0.0	0.0	0.0	0.1	0.0
HRS-3419	0.0	0.0	0.0	0.1	0.0

Table A27. Effect of cultivar and P rate on T3 tiller initiation, on current and pending cultivars, reached by increasing average T3 tiller initiation (continued).

	-------------------- mg P pot-1 --------------------				
Cultivar	0	5	10	20	Average
	----------------------------- tillers plant-1 ------------------------------				
MS-Stingray	0.0	0.0	0.1	0.0	0.0
LCS-Breakaway	0.0	0.0	0.3	0.0	0.1
LCS-Iguacu	0.0	0.1	0.1	0.1	0.1
WS 1812	0.0	0.1	0.2	0.1	0.1
LCS-Albany	0.0	0.7	0.9	0.9	0.6
Average	0.0	0.0	0.0	0.0	0.0
Significance of F					
Cultivar	<.0001				
P rate	0.001				
Cultivar x P rate	<.0001				
CV, %	241.1%				

LSD (0.05) for P rate 0.09
LSD (0.05) for cultivar and P*cultivar 0.08

Table A28. Effect of cultivar and P rate on T10 tiller initiation, on current and pending cultivars, reached by increasing average T10 tiller initiation.

Cultivar	mg P pot^{-1} 0	5	10	20	Average
	tillers plant^{-1}				
Faller	0.0	0.0	0.0	0.0	0.0
Glenn	0.0	0.0	0.0	0.0	0.0
Mott	0.0	0.0	0.0	0.0	0.0
ND-820	0.0	0.0	0.0	0.0	0.0
ND-825	0.0	0.0	0.0	0.0	0.0
ND-907	0.0	0.0	0.0	0.0	0.0
ND901CL	0.0	0.0	0.0	0.0	0.0
Prosper	0.0	0.0	0.0	0.0	0.0
Select	0.0	0.0	0.0	0.0	0.0
Linkert	0.0	0.0	0.0	0.0	0.0
Norden	0.0	0.0	0.0	0.0	0.0
HRS-3530	0.0	0.0	0.0	0.0	0.0
LCS-Breakaway	0.0	0.0	0.0	0.0	0.0
TCG-Wildfire	0.0	0.0	0.0	0.0	0.0
2375	0.0	0.0	0.0	0.0	0.0
Butte	0.0	0.0	0.0	0.0	0.0
Barlow	0.0	0.0	0.1	0.0	0.0
Elgin-ND	0.0	0.1	0.0	0.0	0.0
Steele-ND	0.0	0.0	0.0	0.1	0.0
Brick	0.0	0.0	0.1	0.0	0.0
Focus	0.1	0.0	0.0	0.0	0.0
Prevail	0.1	0.0	0.0	0.0	0.0
Bolles	0.0	0.0	0.1	0.0	0.0
Rollag	0.0	0.0	0.0	0.1	0.0
HRS-3361	0.0	0.0	0.0	0.1	0.0
HRS-3419	0.0	0.0	0.0	0.1	0.0
LCS-Pro	0.0	0.0	0.0	0.1	0.0
MS-Chevelle	0.0	0.0	0.1	0.0	0.0
Velva	0.0	0.0	0.1	0.1	0.0
Sabin	0.0	0.0	0.0	0.1	0.0
HRS-3504	0.0	0.0	0.0	0.1	0.0
LCS-Powerplay	0.0	0.0	0.1	0.1	0.1
TGC-Spitfire	0.0	0.0	0.0	0.2	0.1
LCS-Iguacu	0.0	0.0	0.1	0.2	0.1
TCG-Cornerstone	0.0	0.0	0.0	0.3	0.1
Forefront	0.0	0.0	0.1	0.3	0.1
RB07	0.0	0.0	0.1	0.3	0.1

Table A28. Effect of cultivar and P rate on T10 tiller initiation, on current and pending cultivars, reached by increasing average T10 tiller initiation (continued).

	-------------------- mg P pot-1 --------------------				
Cultivar	0	5	10	20	Average
	----------------------------- tillers plant-1 -------------------------------				
Advance	0.0	0.0	0.0	0.5	0.1
MS-Stingray	0.0	0.0	0.2	0.5	0.2
Marshall	0.0	0.0	0.2	0.7	0.2
WS 1812	0.0	0.2	0.6	0.6	0.3
LCS-Albany	0.4	0.9	0.9	1.0	0.8
Average	0.0	0.0	0.1	0.1	0.1
Significance of F					
Cultivar	<.0001				
P rate	0.001				
Cultivar x P rate	<.0001				
CV, %	172.5%				

LSD (0.05) for P rate 0.27

LSD (0.05) for cultivar and P*cultivar 0.14

Table A29. Effect of cultivar and P rate on other tiller initiation, on current and pending cultivars, reached by increasing average other tiller initiation.

Cultivar	-------------------- mg P pot^{-1} --------------------				
	0	5	10	20	Average
	----------------------------- tillers plant^{-1} ------------------------------				
Barlow	0.0	0.0	0.0	0.0	0.0
Elgin-ND	0.0	0.0	0.0	0.0	0.0
Faller	0.0	0.0	0.0	0.0	0.0
Glenn	0.0	0.0	0.0	0.0	0.0
Mott	0.0	0.0	0.0	0.0	0.0
ND-820	0.0	0.0	0.0	0.0	0.0
ND-825	0.0	0.0	0.0	0.0	0.0
ND-907	0.0	0.0	0.0	0.0	0.0
ND901CL	0.0	0.0	0.0	0.0	0.0
Prosper	0.0	0.0	0.0	0.0	0.0
Velva	0.0	0.0	0.0	0.0	0.0
Advance	0.0	0.0	0.0	0.0	0.0
Brick	0.0	0.0	0.0	0.0	0.0
Focus	0.0	0.0	0.0	0.0	0.0
Forefront	0.0	0.0	0.0	0.0	0.0
Prevail	0.0	0.0	0.0	0.0	0.0
Select	0.0	0.0	0.0	0.0	0.0
Bolles	0.0	0.0	0.0	0.0	0.0
Linkert	0.0	0.0	0.0	0.0	0.0
Norden	0.0	0.0	0.0	0.0	0.0
RB07	0.0	0.0	0.0	0.0	0.0
Rollag	0.0	0.0	0.0	0.0	0.0
Sabin	0.0	0.0	0.0	0.0	0.0
HRS-3361	0.0	0.0	0.0	0.0	0.0
HRS-3419	0.0	0.0	0.0	0.0	0.0
HRS-3504	0.0	0.0	0.0	0.0	0.0
HRS-3530	0.0	0.0	0.0	0.0	0.0
LCS-Breakaway	0.0	0.0	0.0	0.0	0.0
LCS-Iguacu	0.0	0.0	0.0	0.0	0.0
LCS-Pro	0.0	0.0	0.0	0.0	0.0
LCS-Powerplay	0.0	0.0	0.0	0.0	0.0
MS-Stingray	0.0	0.0	0.0	0.0	0.0
TCG-Cornerstone	0.0	0.0	0.0	0.0	0.0
TGC-Spitfire	0.0	0.0	0.0	0.0	0.0
TCG-Wildfire	0.0	0.0	0.0	0.0	0.0
2375	0.0	0.0	0.0	0.0	0.0
Butte	0.0	0.0	0.0	0.0	0.0

Table A29. Effect of cultivar and P rate on other tiller initiation, on current and pending cultivars, reached by increasing average other tiller initiation (continued).

	-------------------- mg P pot-1 --------------------				
Cultivar	0	5	10	20	Average
	------------------------------ tillers plant-1 -------------------------------				
Marshall	0.0	0.0	0.0	0.0	0.0
WS 1812	0.0	0.0	0.0	0.0	0.0
Steele-ND	0.0	0.1	0.0	0.0	0.0
MS-Chevelle	0.0	0.0	0.0	0.1	0.0
LCS-Albany	0.1	0.4	0.6	0.9	0.5
Average	0.0	0.0	0.0	0.0	0.0
Significance of F					
Cultivar	<.0001				
P rate	0.21				
Cultivar x P rate	<.0001				
CV, %	620.3%				

LSD (0.05) for P rate 0.13

LSD (0.05) for cultivar and P*cultivar 0.11

Table A30. Effect of cultivar and P rate on total tiller initiation, on current and pending cultivars, reached by increasing average total tiller initiation.

Cultivar	mg P pot^{-1} 0	5	10	20	Average
	tillers plant^{-1}				
LCS-Breakaway	0.1	0.6	1.3	1.3	0.8
Bolles	0.0	0.8	1.4	1.3	0.9
TCG-Wildfire	0.4	0.9	1.4	1.8	1.1
HRS-3530	0.1	1.0	1.4	2.2	1.2
2375	0.4	1.1	1.6	1.9	1.3
Butte	0.6	1.3	1.7	1.9	1.4
ND901CL	0.4	1.3	2.0	1.9	1.4
ND-820	0.8	1.1	1.6	2.3	1.4
Prosper	0.5	1.4	1.8	2.1	1.4
Barlow	0.6	1.3	1.8	2.3	1.5
Faller	0.6	1.3	1.9	2.1	1.5
ND-907	0.8	1.6	1.6	2.0	1.5
Brick	1.2	1.3	1.8	1.9	1.5
Sabin	0.8	1.3	1.9	2.1	1.5
Steele-ND	0.9	1.2	1.8	2.3	1.6
LCS-Pro	0.8	1.6	1.8	2.3	1.6
LCS-Powerplay	0.8	1.6	1.9	2.1	1.6
TCG-Cornerstone	0.9	1.4	1.9	2.3	1.6
Focus	1.0	1.5	2.1	2.0	1.6
Mott	1.3	1.6	1.8	2.1	1.7
ND-825	0.8	1.6	1.9	2.4	1.7
Norden	0.9	1.4	2.2	2.1	1.7
Elgin-ND	0.9	1.4	2.3	2.3	1.7
Linkert	0.9	1.6	2.0	2.6	1.8
Forefront	1.2	1.9	1.8	2.4	1.8
HRS-3504	1.1	1.7	1.9	2.6	1.8
Velva	1.0	1.9	2.2	2.2	1.8
HRS-3361	1.1	1.8	2.0	2.5	1.8
Rollag	1.1	1.9	2.1	2.3	1.8
HRS-3419	1.3	2.0	2.0	2.1	1.9
Select	1.1	1.8	2.3	2.3	1.9
Glenn	0.9	2.1	2.1	2.5	1.9
Advance	0.9	1.9	2.1	2.6	1.9
TGC-Spitfire	1.0	2.0	2.3	2.7	2.0
Prevail	1.1	2.1	2.4	2.6	2.1
RB07	1.6	1.9	2.4	2.6	2.1
MS-Stingray	1.1	1.9	2.6	3.1	2.1

Table A30. Effect of cultivar and P rate on total tiller initiation, on current and pending cultivars, reached by increasing average total tiller initiation (continued).

	-------------------- mg P pot-1 --------------------				
Cultivar	0	5	10	20	Average
	----------------------------- tillers plant-1 ------------------------------				
MS-Chevelle	1.4	2.3	2.4	2.8	2.2
LCS-Iguacu	1.1	2.1	2.8	2.9	2.3
Marshall	1.4	2.0	2.4	3.3	2.3
WS 1812	2.4	2.4	3.7	3.7	3.1
LCS-Albany	2.6	4.1	4.4	4.9	4.0
Average	1.0	1.6	2.1	2.4	1.8
Significance of F					
Cultivar	<.0001				
P rate	<.0001				
Cultivar x P rate	<.0001				
CV, %	18.0%				

LSD (0.05) for P rate 1.10
LSD (0.05) for cultivar and P*cultivar 0.44

Table A31. Effect of cultivar and P rate on P concentration in plant tissue, on current and pending cultivars, reached by increasing average plant tissue P concentration.

Cultivar	------------------- mg P pot^{-1} -------------------				
	0	5	10	20	Average
	---------------------------------- % ----------------------------------				
Prevail	0.2	0.2	0.3	0.4	0.3
Forefront	0.2	0.2	0.2	0.4	0.3
Butte	0.2	0.2	0.3	0.3	0.3
Select	0.2	0.2	0.3	0.4	0.3
HRS-3504	0.2	0.2	0.2	0.4	0.3
Brick	0.2	0.2	0.2	0.4	0.3
Elgin-ND	0.2	0.2	0.2	0.4	0.3
LCS-Pro	0.2	0.2	0.3	0.4	0.3
Focus	0.2	0.2	0.3	0.4	0.3
LCS-Albany	0.2	0.2	0.2	0.4	0.3
ND901CL	0.2	0.2	0.3	0.4	0.3
TGC-Spitfire	0.2	0.2	0.3	0.4	0.3
Sabin	0.2	0.2	0.3	0.4	0.3
ND-820	0.2	0.2	0.3	0.4	0.3
ND-907	0.2	0.2	0.3	0.4	0.3
Mott	0.2	0.2	0.3	0.4	0.3
Barlow	0.2	0.2	0.3	0.4	0.3
Glenn	0.2	0.2	0.3	0.4	0.3
Bolles	0.2	0.3	0.3	0.4	0.3
Faller	0.2	0.2	0.3	0.4	0.3
Advance	0.2	0.2	0.3	0.4	0.3
TCG-Cornerstone	0.2	0.2	0.3	0.4	0.3
TCG-Wildfire	0.2	0.2	0.3	0.4	0.3
Steele-ND	0.2	0.2	0.3	0.4	0.3
Norden	0.2	0.2	0.3	0.4	0.3
WS 1812	0.2	0.2	0.3	0.4	0.3
2375	0.2	0.3	0.3	0.4	0.3
LCS-Iguacu	0.2	0.2	0.3	0.4	0.3
Prosper	0.2	0.2	0.3	0.4	0.3
HRS-3361	0.2	0.2	0.3	0.4	0.3
MS-Stingray	0.2	0.2	0.3	0.4	0.3
Velva	0.2	0.2	0.3	0.4	0.3
LCS-Powerplay	0.2	0.2	0.3	0.4	0.3
ND-825	0.2	0.3	0.3	0.4	0.3
HRS-3530	0.2	0.3	0.3	0.4	0.3
HRS-3419	0.2	0.2	0.3	0.5	0.3
MS-Chevelle	0.2	0.3	0.3	0.4	0.3

Table A31. Effect of cultivar and P rate on P concentration in plant tissue, on current and pending cultivars, reached by increasing average plant tissue P concentration (continued).

	-------------------- mg P pot-1 --------------------				
Cultivar	0	5	10	20	Average
	---------------------------------- %			------------------------------------	
Marshall	0.2	0.3	0.3	0.4	0.3
Linkert	0.2	0.3	0.3	0.4	0.3
LCS-Breakaway	0.2	0.3	0.3	0.4	0.3
RB07	0.2	0.3	0.3	0.4	0.3
Rollag	0.2	0.3	0.4	0.4	0.3
Average	0.2	0.2	0.3	0.4	0.3
Significance of F					
Cultivar	<.0001				
P rate	<.0001				
Cultivar x P rate	0.01				
CV, %	10.2%				

LSD (0.05) for P rate 0.20
LSD (0.05) for cultivar and P*cultivar 0.04

Table A32. Effect of cultivar and P rate on plant tissue P uptake, on current and pending cultivars, reached by increasing average plant tissue P uptake.

	-------------------- mg P pot^{-1} --------------------				
Cultivar	0	5	10	20	Average
	------------------------------- mg pot^{-1} ---------------------------------				
LCS-Albany	2.2	3.8	4.1	7.7	4.5
Bolles	2.6	4.4	4.2	6.7	4.5
HRS-3419	2.1	3.6	4.7	7.6	4.5
Marshall	2.4	3.8	4.9	7.8	4.7
MS-Stingray	2.0	3.9	5.3	8.0	4.8
TCG-Wildfire	2.5	3.9	5.0	8.1	4.9
HRS-3361	2.5	4.0	4.6	8.3	4.9
HRS-3504	2.6	3.4	4.6	8.9	4.9
Forefront	2.9	4.1	4.7	7.9	4.9
LCS-Powerplay	2.6	3.9	5.2	8.1	4.9
Advance	2.5	3.9	4.9	8.4	4.9
LCS-Iguacu	2.5	4.1	5.0	8.4	5.0
Rollag	2.3	4.2	5.5	8.2	5.0
Steele-ND	2.7	4.0	5.3	8.3	5.1
RB07	2.7	4.3	5.5	8.0	5.1
Mott	2.8	4.3	5.1	8.3	5.1
Linkert	2.7	4.2	5.7	8.0	5.2
Barlow	2.6	4.1	5.7	8.3	5.2
Velva	2.5	4.4	5.8	8.2	5.2
Butte	2.7	4.1	5.8	8.3	5.2
2375	2.7	4.4	5.8	8.3	5.3
LCS-Pro	2.8	4.6	5.4	8.4	5.3
Norden	3.0	4.5	5.6	8.0	5.3
Faller	3.0	4.1	5.8	8.4	5.3
TGC-Spitfire	2.3	4.1	6.0	8.9	5.3
WS 1812	2.7	4.5	5.8	8.4	5.3
Sabin	2.5	4.5	5.4	8.9	5.4
TCG-Cornerstone	2.7	4.2	5.6	9.2	5.4
ND-825	3.2	4.8	5.2	8.5	5.4
ND901CL	2.6	4.4	5.7	9.0	5.4
Elgin-ND	2.7	4.5	5.6	8.9	5.4
Prevail	3.0	4.2	5.9	8.6	5.5
ND-820	3.0	4.4	5.6	8.9	5.5
Prosper	2.8	4.4	6.0	8.8	5.5
ND-907	2.8	4.5	5.4	9.3	5.5
Glenn	2.9	4.6	5.8	8.7	5.5
Select	2.8	4.6	6.2	8.7	5.5

Table A32. Effect of cultivar and P rate on plant tissue P uptake, on current and pending cultivars, reached by increasing average plant tissue P uptake (continued).

	-------------------- mg P pot-1 --------------------				
Cultivar	0	5	10	20	Average
	------------------------------- mg pot-1 ---------------------------------				
MS-Chevelle	3.1	4.6	6.0	8.5	5.6
Brick	3.0	4.4	5.8	9.1	5.6
LCS-Breakaway	2.7	4.5	6.4	8.7	5.6
HRS-3530	2.7	4.4	5.9	9.4	5.6
Focus	3.0	4.4	6.3	8.8	5.6
Average	2.7	4.2	5.4	8.4	5.2
Significance of F					
Cultivar	<.0001				
P rate	<.0001				
Cultivar x P rate	0.01				
CV, %	10.3%				

LSD (0.05) for P rate 2.73
LSD (0.05) for cultivar and P*cultivar 0.75

Table A33. Effect of cultivar and P rate on P uptake efficiency (PUE), on current and pending cultivars, reached by increasing average PUE.

	------------------- mg P pot^{-1} -------------------				
Cultivar	0	5	10	20	Average
	------------------------------ % ------------------------------				
Forefront	--	22.9	18.0	24.7	21.9
HRS-3504	--	16.5	20.1	31.2	22.6
Bolles	--	37.8	16.7	20.8	25.1
Faller	--	22.8	27.7	26.8	25.8
Marshall	--	26.8	24.6	26.6	26.0
LCS-Albany	--	31.8	19.0	27.7	26.1
Steele-ND	--	25.4	25.6	27.8	26.3
LCS-Powerplay	--	26.0	25.7	27.3	26.3
HRS-3361	--	29.6	21.0	28.6	26.4
ND-825	--	32.9	20.4	26.5	26.6
Advance	--	27.3	23.5	29.5	26.8
Norden	--	29.5	26.2	24.9	26.9
Prevail	--	24.2	29.0	27.9	27.0
HRS-3419	--	28.6	25.5	27.5	27.2
TCG-Wildfire	--	28.0	25.2	28.5	27.2
Mott	--	31.0	23.5	27.8	27.4
ND-820	--	27.4	26.3	29.5	27.7
MS-Chevelle	--	28.6	28.3	27.0	28.0
RB07	--	31.9	27.5	26.2	28.6
Brick	--	28.1	27.8	30.7	28.9
LCS-Pro	--	34.2	25.3	27.8	29.1
Linkert	--	31.0	29.9	26.5	29.1
LCS-Iguacu	--	32.9	25.0	29.5	29.2
Barlow	--	29.4	30.3	28.4	29.4
Butte	--	28.8	31.3	28.3	29.4
Focus	--	27.5	32.8	29.3	29.9
Glenn	--	33.4	29.1	28.7	30.4
TCG-Cornerstone	--	29.3	29.5	32.4	30.4
2375	--	34.5	30.6	28.3	31.1
ND-907	--	34.5	26.4	32.5	31.1
Prosper	--	32.8	31.7	29.9	31.4
WS 1812	--	37.1	31.0	28.7	32.2
Elgin-ND	--	37.0	29.7	31.4	32.7
ND901CL	--	36.3	30.7	31.8	32.9
HRS-3530	--	33.3	32.2	33.4	33.0
Rollag	--	37.5	31.9	29.7	33.0
Velva	--	37.9	33.2	28.5	33.2

Table A33. Effect of cultivar and P rate on P uptake efficiency (PUE), on current and pending cultivars, reached by increasing average PUE (continued).

	-------------------- mg P pot-1 --------------------				
Cultivar	0	5	10	20	Average
	---------------------------------- % --				
Select	--	36.0	34.8	29.6	33.4
MS-Stingray	--	37.8	32.9	29.9	33.5
Sabin	--	40.4	29.2	31.9	33.8
LCS-Breakaway	--	35.3	36.5	30.1	34.0
TGC-Spitfire	--	35.1	36.6	32.7	34.8
Average	--	31.2	27.7	28.7	29.2
Significance of F					
Cultivar	<.0001				
P rate	0.12				
Cultivar x P rate	0.62				
CV, %	24.2%				

LSD (0.05) for P rate 21.12

LSD (0.05) for cultivar and P*cultivar 11.34

Table A34. The 2016 study overall average effect of P on the current and pending cultivars and selected response variables at rates of 0, 5, 10, and 20 mg P pot^{-1}.

Variable	Units	------- P rate†, mg pot^{-1} -------				Cultivar	Significance of F			CV
		0	5	10	20	range ‡	P rate	Cultivar	P*Cult.	%
Dry matter	g pot^{-1}	1.4	1.9	2.0	2.2	1.5 - 2.2 (35)	**	**	NS	7.1
Relative Yield	%	65.8	85.6	93.2	100.0	75.6 - 90.9 (19)	**	**	NS	9.5
Haun stage	leaves plant^{-1}	5.6	5.7	5.7	5.7	5.0 - 6.5 (27)	*	**	+	2.9
T0	tillers plant^{-1}	0.0	0.1	0.2	0.3	0 - 0.6 (246)	**	**	**	119.3
T1	tillers plant^{-1}	0.8	1.0	1.0	1.0	0.6 - 1.0 (44)	**	**	**	12.1
T2	tillers plant^{-1}	0.1	0.6	0.8	0.9	0.1 – 1.0 (141)	**	**	**	33.2
T1+T2	tillers plant^{-1}	0.9	1.5	1.8	1.9	0.7 – 2.0 (82)	**	**	**	14.8
T3	tillers plant^{-1}	0.0	0.0	0.0	0.0	0 - 0.6 (1600)	**	**	**	241.1
T10	tillers plant^{-1}	0.0	0.0	0.1	0.1	0 - 0.8 (675)	**	**	**	172.5
Other tillers	tillers plant^{-1}	0.0	0.0	0.0	0.0	0 - 0.5 (2400)	NS	**	**	620.3
Total tillers	tillers plant^{-1}	1.0	1.6	2.1	2.4	0.8 - 4.0 (182)	**	**	**	18.0
P concentration	%	0.2	0.2	0.3	0.4	0.3 - 0.3 (26)	**	**	**	10.2
P uptake	mg pot^{-1}	2.7	4.2	5.4	8.4	4.5 - 5.2 (22)	**	**	**	10.3
PUE	%	--	31.2	27.7	28.7	21.9 - 34.8 (44)	NS	**	NS	24.2

†Averaged across cultivar

‡ Averaged across P rate. The values in parentheses represent the relative range as a percentage of the mean, see text

+, *, **, F-test significant at the 0.1, 0.05, and 0.01 level, respectively.

Table A35. Data used for correlation analysis on current and pending cultivars.

	------------------ Measurement at 20 mg P pot^{-1} ------------------									-- Measurement averaged across P rate --				
Cultivar	DM	HS	T0	T1	T2	T3	T10	OT	TT	RY	P conc.	PU	PUE	T1T2
	g pot^{-1}	leaves $plant^{-1}$	-------------------------- tillers $plant^{-1}$ --------------------------							%	%	mg pot^{-1}	%	tillers $plant^{-1}$
2375	2.3	5.6	0.1	1.0	0.8	0.0	0.0	0.0	1.9	75.6	0.3	2.3	5.6	0.1
Advance	2.0	5.6	0.1	1.0	1.0	0.0	0.5	0.0	2.6	88.5	0.3	2.0	5.6	0.1
Barlow	2.2	6.0	0.4	1.0	0.9	0.0	0.0	0.0	2.3	83.9	0.3	2.2	6.0	0.4
Bolles	1.9	5.4	0.3	0.9	0.1	0.0	0.0	0.0	1.3	80.5	0.3	1.9	5.4	0.3
Brick	2.6	6.5	0.1	1.0	0.8	0.0	0.0	0.0	1.9	82.9	0.3	2.6	6.5	0.1
Butte	2.5	6.7	0.0	1.0	0.9	0.0	0.0	0.0	1.9	78.4	0.3	2.5	6.7	0.0
Elgin-ND	2.4	6.0	0.3	1.0	1.0	0.0	0.0	0.0	2.3	81.6	0.3	2.4	6.0	0.3
Faller	2.3	6.0	0.1	1.0	1.0	0.0	0.0	0.0	2.1	79.4	0.3	2.3	6.0	0.1
Focus	2.4	5.9	0.1	1.0	0.9	0.0	0.0	0.0	2.0	84.6	0.3	2.4	5.9	0.1
Forefront	2.3	5.7	0.1	1.0	1.0	0.0	0.3	0.0	2.4	84.0	0.3	2.3	5.7	0.1
Glenn	2.4	5.5	0.5	1.0	1.0	0.0	0.0	0.0	2.5	80.3	0.3	2.4	5.5	0.5
HRS-3361	2.0	5.6	0.4	1.0	1.0	0.0	0.1	0.0	2.5	79.9	0.3	2.0	5.6	0.4
HRS-3419	1.7	5.5	0.0	1.0	1.0	0.1	0.1	0.0	2.1	88.1	0.3	1.7	5.5	0.0
HRS-3504	2.2	5.7	0.4	1.0	1.0	0.0	0.1	0.0	2.6	81.2	0.3	2.2	5.7	0.4
HRS-3530	2.3	5.4	0.2	1.0	1.0	0.0	0.0	0.0	2.2	78.3	0.3	2.3	5.4	0.2
LCS-Albany	1.9	5.7	0.1	1.0	1.0	0.9	1.0	0.9	4.9	84.0	0.3	1.9	5.7	0.1
LCS-Breakaway	2.2	6.5	0.1	1.0	0.3	0.0	0.0	0.0	1.3	78.0	0.3	2.2	6.5	0.1
LCS-Iguacu	2.0	5.6	0.7	1.0	1.0	0.1	0.2	0.0	2.9	82.6	0.3	2.0	5.6	0.7
LCS-Powerplay	2.0	5.6	0.0	1.0	1.0	0.0	0.1	0.0	2.1	78.8	0.3	2.0	5.6	0.0
LCS-Pro	2.4	5.9	0.4	1.0	0.8	0.0	0.1	0.0	2.3	80.3	0.3	2.4	5.9	0.4
Linkert	2.0	5.5	0.6	1.0	0.9	0.0	0.0	0.0	2.6	82.8	0.3	2.0	5.5	0.6
Marshall	1.9	5.0	0.6	1.0	1.0	0.0	0.7	0.0	3.3	79.6	0.3	1.9	5.0	0.6
Mott	2.1	5.7	0.1	1.0	0.9	0.0	0.0	0.0	2.1	84.7	0.3	2.1	5.7	0.1
MS-Chevelle	2.2	5.7	0.9	0.9	0.9	0.0	0.0	0.1	2.8	82.3	0.3	2.2	5.7	0.9
MS-Stingray	2.0	5.1	0.6	1.0	1.0	0.0	0.5	0.0	3.1	77.8	0.3	2.0	5.1	0.6

Table A35. Data used for correlation analysis on current and pending cultivars (continued).

	-------------------- Measurement at 20 mg P pot-1 ----------------- ---								-- Measurement averaged across P rate --				
Cultivar	DM	HS	T0	T1	T2	T3	T10	OT	TT	RY	P conc.	PU	PUE	T1T2
	g pot^{-1}	leaves plant^{-1}	------------------------------ tillers plant^{-1} ------------------------------							%	%	mg pot^{-1}	%	tillers plant^{-1}
ND-820	2.4	6.3	0.3	1.0	1.0	0.0	0.0	0.0	2.3	81.8	0.3	2.4	6.3	0.3
ND-825	2.1	5.8	0.4	1.0	1.0	0.0	0.0	0.0	2.4	83.1	0.3	2.1	5.8	0.4
ND901CL	2.4	6.1	0.0	1.0	0.9	0.0	0.0	0.0	1.9	78.0	0.3	2.4	6.1	0.0
ND-907	2.3	5.7	0.1	1.0	0.9	0.0	0.0	0.0	2.0	83.8	0.3	2.3	5.7	0.1
Norden	2.2	5.8	0.1	1.0	1.0	0.1	0.0	0.0	2.1	84.1	0.3	2.2	5.8	0.1
Prevail	2.5	5.5	0.6	1.0	1.0	0.0	0.0	0.0	2.6	84.1	0.3	2.5	5.5	0.6
Prosper	2.3	5.9	0.1	1.0	1.0	0.0	0.0	0.0	2.1	77.6	0.3	2.3	5.9	0.1
RB07	1.9	5.1	0.3	1.0	1.0	0.0	0.3	0.0	2.6	82.7	0.3	1.9	5.1	0.3
Rollag	1.9	5.3	0.2	1.0	1.0	0.1	0.1	0.0	2.3	77.1	0.3	1.9	5.3	0.2
Sabin	2.3	5.5	0.0	1.0	1.0	0.0	0.1	0.0	2.1	78.7	0.3	2.3	5.5	0.0
Select	2.5	6.2	0.3	1.0	1.0	0.0	0.0	0.0	2.3	83.7	0.3	2.5	6.2	0.3
Steele-ND	2.1	5.8	0.4	1.0	0.8	0.0	0.1	0.0	2.3	82.5	0.3	2.1	5.8	0.4
TCG-Cornerstone	2.4	5.7	0.1	1.0	1.0	0.0	0.3	0.0	2.3	79.0	0.3	2.4	5.7	0.1
TCG-Wildfire	2.1	5.2	0.1	0.9	0.7	0.0	0.0	0.0	1.8	77.1	0.3	2.1	5.2	0.1
TGC-Spitfire	2.4	5.2	0.6	1.0	0.9	0.0	0.2	0.0	2.7	76.1	0.3	2.4	5.2	0.6
Velva	2.0	5.1	0.2	1.0	0.9	0.1	0.1	0.0	2.2	90.9	0.3	2.0	5.1	0.2
WS 1812	2.2	5.3	0.9	1.0	1.0	0.1	0.6	0.0	3.7	83.7	0.3	2.2	5.3	0.9

DM= dry matter, HS= Haun stage, OT= other tillers, TT= total tillers, RY= relative yield, P conc. = P concentration, PU= P uptake, PUE= Phosphorus uptake efficiency, T1T2= T1 + T2 tillers

Table A36. Linear correlation coefficients (r) between dry matter production and main stem Haun stage at the highest rate of P, and selected response variables, current and pending cultivar study.

Variable	P rate	Dry matter†	Haun stage†
	mg pot^{-1}	g pot^{-1}	leaves $plant^{-1}$
Dry matter	20	1	----
Haun stage	20	0.604**	1
T0 tiller initiation	20	-0.092	-0.361*
T1 tiller initiation	20	0.15	0.176
T2 tiller initiation	20	0.08	-0.135
T3 tiller initiation	20	-0.266	-0.058
T10 tiller initiation	20	-0.404**	-0.404**
Other tiller initiation	20	-0.207	-0.006
Total tiller initiation	20	-0.27	-0.35**
Relative yield	0-10	-0.236	-0.012
P concentration in plant tissue	0-20	-0.657**	-0.441**
Phosphorus uptake	0-20	0.776**	0.464**
Phosphorus uptake efficiency	5-20	0.285	0.004
T1 + T2 tiller initiation	0-20	-0.22	-0.37*

†Dry matter and main stem Haun stage at the highest rate of P, 20 mg pot^{-1}.

*, **, correlation significant at the 0.05 and 0.01 level, respectively.

APPENDIX B: FIGURES

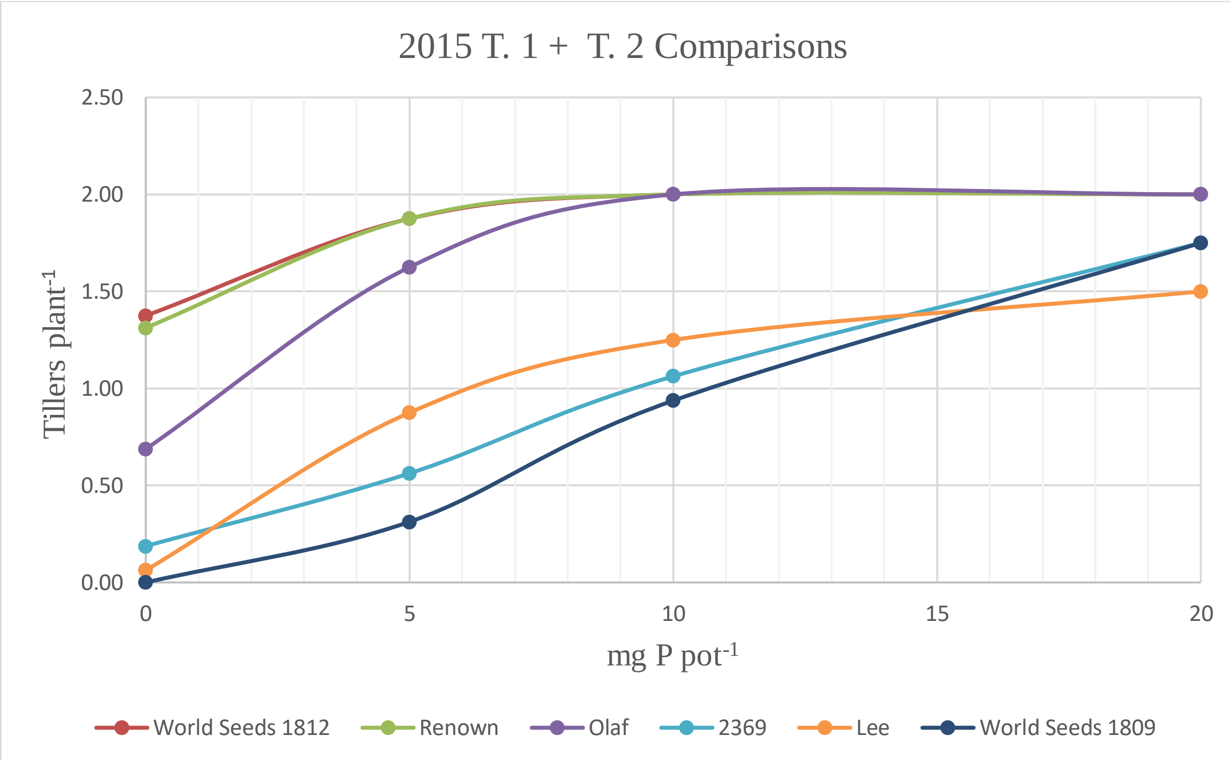

Figure B1. Effect of phosphorus rate on T1 + T2 tiller initiation by six historical wheat cultivars in 2015. LSD (0.05) for cultivar and P*cultivar, 0.30

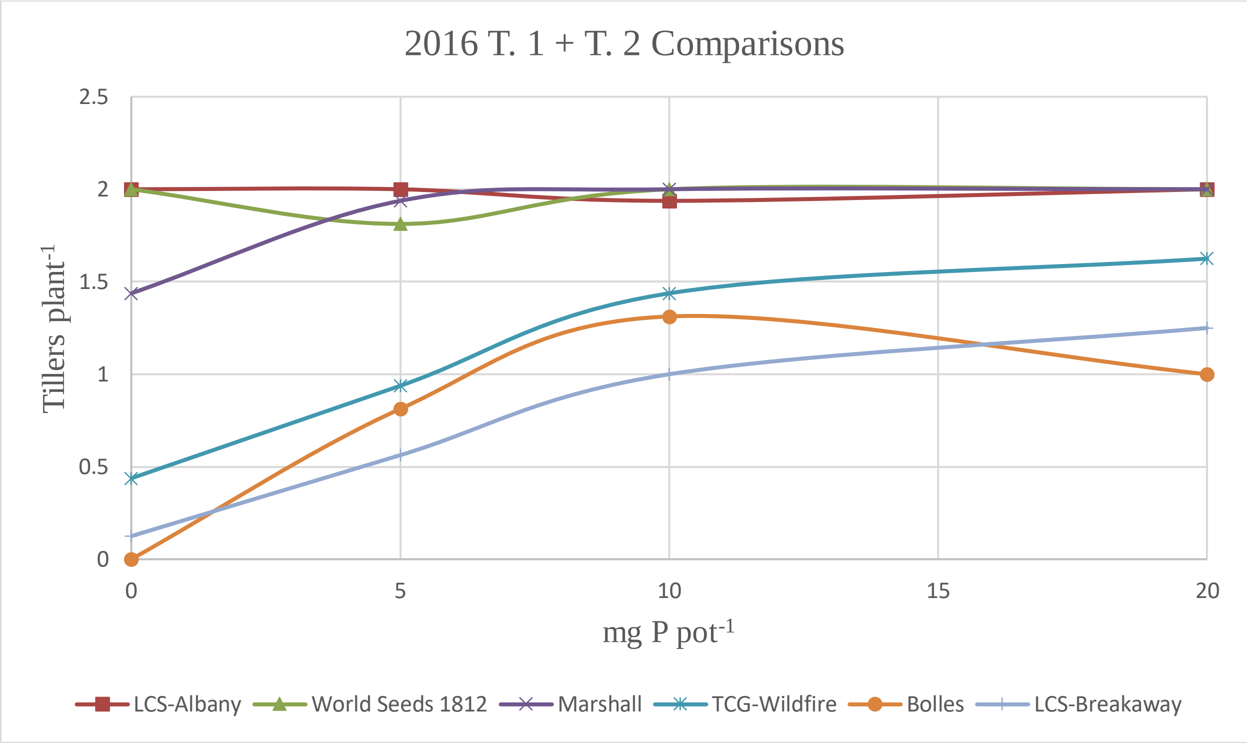

Figure B2. Effect of phosphorus rate on T1 + T2 tiller initiation by six current and pending wheat cultivars in 2016. LSD (0.05) for cultivar and P*cultivar, 0.31