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Macronutrient Content of Winter Annual Cereal Grains with Phosphorus Fertilization

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MACRONUTRIENT CONTENT OF WINTER ANNUAL CEREAL GRAINS WITH PHOSPHORUS FERTILIZATION

A Master's Thesis
Presented to
The Graduate College of
Missouri State University

In Partial Fulfillment
Of the Requirements for the Degree
Master of Science, Plant Science

By
Taylor Anne Young
May 2019

MACRONUTRIENT CONTENT OF WINTER ANNUAL CEREAL GRAINS WITH PHOSPHORUS FERTILIZATION

Agriculture

Missouri State University, May 2019

Master of Science

Taylor Anne Young

ABSTRACT

Missouri ranks third in the United States in cow-calf production, and much of the land these cattle graze has acidic soil that is low in plant available phosphorus (P). Proper soil fertility is important to ensure that these forages meet the nutritional requirements of cattle. Tall fescue (*Festuca arundinaceum* (Schreb.)), has been shown to respond to increased soil P levels with increased growth and leaf concentrations of P, calcium (Ca), magnesium (Mg), and potassium (K). It is unknown if winter annual cereals will respond similarly. The objective of this study is to examine cereal rye (*Secale cereal* L.), winter wheat (*Triticum aestivum* L.), and oat (*Avena sativa* L.), grown over winter for early spring forage production, and their response to different levels of P fertilization. In October of 2016 and 2017, the three species were planted at the Missouri State University Shealy Farm. Treatments of 0, 25, 50, and 100 lbs/acre P were applied in early winter. Forage was harvested the following spring, and nutrient concentrations were determined. In all species, P concentration in the leaf tissue increased with increasing P treatment levels. P fertilization caused an increase in Ca and Mg at the100 lb treatment, and an increase in leaf K at the 50 lb treatment in oat. In winter wheat, P fertilization increased Ca concentration at the 25 lb, and Mg at the 50 lb treatment. There was no effect of treatment of K concentration in winter wheat. There was no significant effect of treatment on leaf Ca, Mg, or K in cereal rye. These findings suggest that P fertilization can influence the nutrient concentrations of winter wheat and oat, but have no influence on nutrient concentration of cereal rye.

KEYWORDS: phosphorus, grazing, winter annual forages, grass tetany ratio, winter wheat, oat, cereal rye, beef cattle

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INTRODUCTION

Over half of the land area in Missouri is dedicated to forage production and more than two thirds of livestock feed is comprised of forages (Missouri Forage & Grassland Council). This is vital to livestock producers in the state of Missouri, which currently ranks 3rd in the United States in beef cattle numbers and has almost 2 million cattle total (USDA, 2018).

Typically, the most cost-effective way to provide feed to the cattle is through grazable forage. To accomplish this, it is important have a combination of forages with different seasonal growth patterns to provide adequate forage throughout as much of the year as possible. Missouri's climate is well suited to support multiple types of forages to graze throughout the year. Common cool season grasses in Missouri are tall fescue (*Festuca arundinacea*), orchardgrass (*Dactylis glomerata*), smooth bromegrass (*Bromus inermis*), perennial ryegrass (*Lolium perenne*), and Kentucky bluegrass (*Poa pratensis*) which support grazing from March until May and again from September to November before becoming dormant in the winter. Mixing these grasses with cool season legumes such as red or white clover can help extend the grazing season from fall into late winter (Ball et al., 2015). Warm season grasses commonly grown for forage in Missouri are bermudagrass (*Cynodon dactylon*), crabgrass (*Digitaria ciliaris*) and native grasses such as big bluestem (*Andropogon gerardi*), Eastern gamagrass (*Tripsacum dactyloides*), switchgrass (*Panicum virgatum*), and indiangrass (*Sorghastrum nutans*) (Gerrish and Roberts, 1999). These forages are popular to graze because they grow abundantly from approximately June through August, and compliment the time when most cool season are at low production during the hotter summer months (Ball, 2015).

Stockpiling forage to is a great way to extend the grazing season through the fall and into the winter months. Tall fescue is most commonly chosen as it provides a large stand of growth in the fall, and has a waxy coating to the leaves that that can help retain forage quality well after growth ends (Ball et al., 2008). Stockpiled tall fescue can have higher crude protein (CP) and total digestible nutrients (TDN) than hay often fed to beef cattle (Ball et al., 2008). While stockpiling forage is a good option, it may not be able to sustain the cattle throughout the entire winter.

When grazable forage begins to run low, many producers turn to hay and other stored feed sources to bridge the gap during these months. Hay production is popular in Missouri with 3,349,348 acres of forage mechanically harvested for livestock feed in 2018 (USDA, 2018). Stored feeding practices can have some negative consequences as they tend to concentrate animals and their manure and cause compaction in feeding areas. There is also more time and labor required in mechanically harvesting forages causing stored feed to be up to three times more expensive than having available pasture for livestock to graze (Ball et al., 2008). Haying will always reduce the quality of forage compared to being directly harvested by the animals, and harvesting just 10 days later than the optimal harvest stage can reduce TDN by 20% and protein by 40%.

Rainfall in Missouri is usually highest during the spring, and it is common to have a drought in the late summer, reducing forage production during this time (Ball et al., 2015). This can lead to a shortage of forage that is able to be harvested for hay production and stored for winter feeding. An alternative to feeding hay and other stored feed sources during these late winter months would be to plant winter annuals for livestock consumption.

Winter Annual Forage

Winter annual cereals offer grazing mid-January to mid- April. This period covers the time when stockpiled tall fescue and stored feed are running low and before the cool season forages begin spring growth. Winter annual cereal grains are popular for grain and forage production, and can provide year round benefits in production systems. Winter wheat (*Triticum aestivum*), oat (*Avena sativa*), and cereal rye (*Secale cereal*) provide high quality forage to graze during the winter months (Ball et al., 2015). Cereals can also offer cover to fields that are used to grow summer annual forages or crops (Thelen and Leep, 2002). Double cropping summer annual crops such as soybean with winter annual forage has been more profitable to land managers, providing an increased net return to the land, compared to growing summer crops with no winter land cover (Thelen and Leep, 2002).

When growing cereals for the sole purpose of grazing, a few adjustments should be considered, including planting date and rates, compared to when these species are planted for grain production alone. Many producers using the planting rate for grain recommendation when establishing cereals to graze, but higher seeding rates may be needing in some areas to help combat the potential of winterkill (Juskiw et al., 2015). Cereals should also be planted three to four weeks earlier than for grain production in order to maximize the grazable time on these forages, and it is common to apply 60 to 100 lbs/A nitrogen (N) fertilization at the time of planting (Ball et al., 2008). Winter wheat and cereal rye have been shown to produce 1/3 of their grazable forage in the fall, and 2/3 in the spring (Sprague, 1954). When planted for fall grazing, oat can produce large amounts of high quality, but often do not survive the cold temperatures in the winter (Ball et al., 2008). Based on these growth patterns, a producer has the option offer his livestock a quick grazing event in the fall before allowing the cereals to rest and grow through the winter and graze again in the spring. Grazing winter annuals in the fall before harvesting the plant for grain in the spring is a common practice of producers looking to maximize the potential of their plants in both their crop and livestock systems. For winter wheat and cereal rye, a fall gazing event increased grain production the following spring by 11 to 19%. In years with favorable rainfall and temperature, winter wheat grain yields were up to 50% greater after a fall grazing event compared to winter wheat not grazed in the fall (Sprague, 1954). While these cereals are ideal to graze based on their growing season, there is also the risk of mineral imbalances occurring.

Cattle Nutrition

Late-winter to early-spring is common for calving season in Missouri. Therefore, it is important to be able to tailor forage production to meet the nutritional needs of the cattle during this period. Highly nutritious forage should be available four to six weeks after the birth of cattle to meet the mothers' nutritional needs. This time period also allows the calves to use the forage for most of their growing (Ball et al., 2015). During the times of pregnancy and lactation, some minerals are needed in higher amounts, specifically magnesium (Mg) (Whitehead, 2000). The dietary Mg requirement for growing cattle is 0.10%, but for cattle during lactation, it is greater at 0.18-0.20% (Whitehead, 2000). Adequate amounts of Mg are important to cerebral spinal fluid which is essential for the transmission of signals from the brain throughout the body (Elliot, 2009b). Magnesium cannot be stored in the body, and it is continually leaving the body through milk production, urine, and fecal waste. Therefore, a constant supply of Mg in the diet is needed (Elliott, 2008). When an animal becomes deficient in Mg, a potentially fatal condition called grass tetany can occur.

Grass Tetany

Grass tetany, or hypomagnesemia, is a nutritional disorder caused by low blood Mg in the animal. It is a rapidly progressing condition and many producers do not realize it is an issue in their herd until they find dead cattle. However, there are some symptoms to watch for in times of the year when the risk of grass tetany is highest. Early symptoms are often low milk production and nervous habits in the cattle. If not treated at the early symptoms, the condition will progresses to where the animals may begin secluding themselves from the rest of the herd, have a loss of appetite, begin staggering and walking with a stiff gait, and their skin around the face and flanks may begin to twitch. These symptoms are caused by a lack of Mg in the cerebral spinal fluid causing the muscles to not work properly, and if left untreated the animal will die from suffocation (Elliott, 2009a).

The exact cause of grass tetany in cattle can be hard to diagnose. The most common is a deficiency of Mg from a lack in Mg in the diet. In more complex forms, it is induced by an abundance of K in the diet which limits the absorption of Mg in the rumen. This can be caused by cattle grassing pastures with excessive K fertilization or pastures that are naturally high in soil K. It is also important to have adequate amounts of P in the animal diet as P helps aid Mg absorption in the rumen (Elliott, 2009a). Grass tetany usually occurs in beef and dairy cattle after the consumption of lush spring forage. Many factors affect the susceptibility of cattle to grass tetany. Older cows are more susceptible than first- or second-calf heifers, and these cattle are most susceptible while nursing a calf (Mayland et al., 1976). Genetic variations, ability to absorb Mg, and amount of body fat can all increase an animals' susceptibility to developing grass tetany (Elliott, 2009a).

The risk of grass tetany occurs when the ratio K/(Ca+Mg) exceeds 2.2 in forage tissue (Kemp and ‘t Hart, 1957). Grass tetany potentials begin increasing in late February and into March in the short, new regrowth in annual ryegrass plants (Cherney et al., 1983). Grass tetany commonly occurs in cool season grasses, but there is also a potential for these mineral imbalances to occur in winter annual species that are used for early spring grazing (Stewart et al, 1981). In a study examining the grass tetany potential between cereal grains, winter wheat had the highest potential for grass tetany with its low Ca and high K values, and rye had the lowest potential (Mayland et al., 1976). Increasing soil temperatures have been shown to increase the plant available soil K content and have no effect on soil Ca and Mg levels, thus increasing the grass tetany ratio (Kemp and ‘t Hart, 1957). Karlen et al. (1978) found that higher soil moisture caused an increase in the grass tetany ratio of winter wheat due to depressed Ca and Mg levels, and an unchanged or slightly higher K contents. This study also noted that there was abundant Mg in the roots, but not in the shoots of the plants. Ohno and Grunes (1983) examined the interactions of Ca, Mg and K in their uptake and translocation in winter wheat. Their study found that higher plant available K reduced the shoot content of Mg by suppressing the translocation of the Mg from the root to the shoot.

There have been many studies examining ways to best reduce the grass tetany potential in various grass species. Liming acidic soils to achieve a higher pH has been shown to achieve a lower grass tetany ratio by increasing Ca and Mg and lowering K of stockpiled tall fescue (Hamilton et al., 2012). Applying poultry litter can be a cost saving way for producers to be able to add nutrients to their soil, especially N, phosphorus (P), and K. However, in stockpiled tall fescue, poultry litter applications increased the grass tetany ratio of the forage due to a combination of an increase in K in the forage as well as a decline in the Ca and Mg (McClain and Blevins, 2009). Asay and Mayland (1989) examined two cultivars of crested wheatgrass and were able to select breeding lines with higher Mg contents and reduced grass tetany potentials. Increasing Mg content in leaf tissue to reduce grass tetany potential may not be as simple as adding Mg fertilizer. In tall fescue, it was found that using a Mg fertilizer to increase tissue Mg concertation was only effective if the soil Bray I P was 26 lb/A or greater (Blevins et al 1996). This suggests that increasing Mg content in leaf tissue to reduce the incidence of grass tetany may be influenced by having higher soil P levels.

Phosphorus

Phosphorus is an essential element in plants and plays a key role in many plant functions including photosynthesis, energy production, nutrient uptake, and membranes such as phospholipid bilayers. Most Missouri soils rank low (<22 lb/A) in terms of plant available P for forage production. A study showed that 48% of Missouri cropland depends on P fertilizer to avoid profit losses, while 23% require P fertilizer for crop production (Nathan, 2011). When soil P levels are low, Mg content in tall fescue leaves decreases as the grass grows in the spring (Lock et al., 2002). Where P is adequate, Mg levels do not decrease with spring growth. This suggests that fertilizing with P increases the Mg levels in tall fescue leaves (Lock et al. 2002). Other studies have found P fertilization in Southwest Missouri to increase the macronutrient (Mg, Ca, K, and P) contents in tall fescue leaves in early spring. Specifically, 25 lb/A P was most effective at raising Mg levels and keeping the Mg level above the 0.20% requirement for beef cattle during lactation (McClain and Blevins, 2007). In the two years of this study, the plant available soil P increased 18-30 lb/A from the original 8 lb/A depending on treatment group (McClain and Blevins, 2007). By using P fertilization to increase soil levels to approximately 30 lb/A Bray I P rather than providing a Mg supplement, symptoms of grass tetany may be alleviated and calves could have average daily gains up to 10% more (Lock et al., 2004). When looking at winter wheat seedlings, it was observed that increasing P treatments increased leaf P incrementally, and increased Ca and Mg contents and reduced K contents in leaf tissue (Reinbott and Blevins, 1991).

Most recently, a hydroponic study was conducted to evaluate how P availability would affect the biomass and shoot macronutrients of winter wheat, oat, and cereal rye. Shoot biomass increased incrementally from 0 to 800 µM P treatments in solution in winter wheat, but only increased from 0 to 200 µM P treatments in oat and cereal rye. Shoot P increased incrementally with P availability in all species. In winter wheat, Ca and Mg decreased from 0 to 200 µM P, but increased from 200 to 800 µM P, and K only increased from 0 to 200 µM P. Similarly, in cereal rye, Mg content decreased from 0 to 200 µM P, and increased from 200 to 400 µM P. Calcium content of cereal rye increased from 200 to 400 µM P, and K from 0 to 200 µM P. In oat, Ca and Mg increased from 0 to 200 µM P, and there was no effect of P availability on K. All three species exhibited decreased grass tetany ratios. These decreases occurred between 200 and 400 µM P in winter wheat and cereal rye, and 0 and 200 µM P in oat (Henry et al., 2019). To further examine the effects of P availability on these winter annual species grown for forage, a field-based experiment is needed.

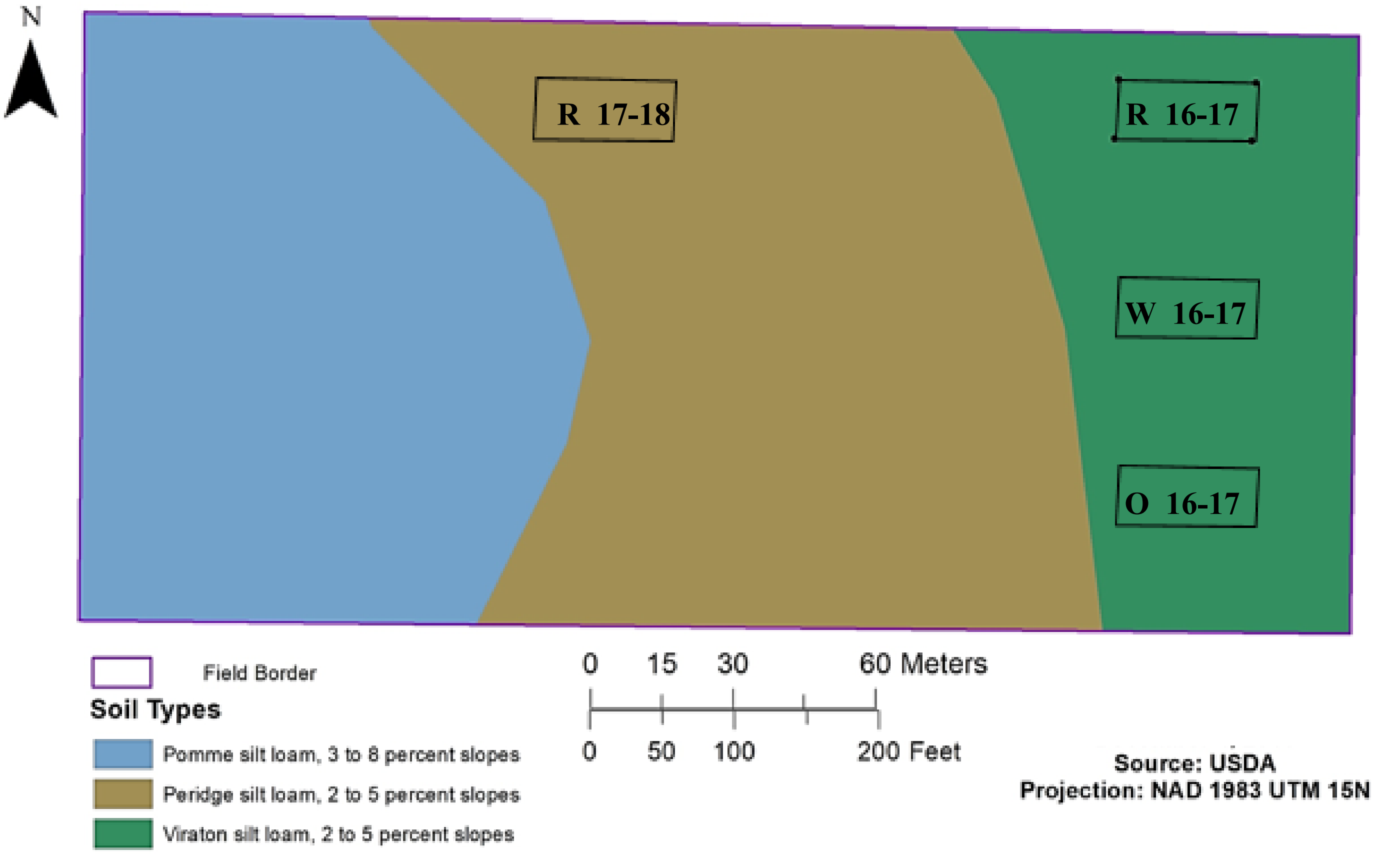
This field study will address the question: how will different levels of P fertilization affect leaf macronutrient content? The null hypothesis will be that adding different levels of P fertilization will have no effect on the leaf Ca, Mg, K, and P contents in winter wheat, oat, and cereal rye. The alternative will be that adding different levels of phosphorus fertilization will have a positive effect on the shoot Ca, Mg, K, and P contents in winter wheat, oat, and cereal rye.

MATERIALS AND METHODS

This two-year study was conducted at the Missouri State University Shealy Farm in Fair Grove, Missouri. The first year of the study was planted on a Viraton silt loam 2 to 5 percent slope (fine-loamy siliceous, active, mesic Oxyaqiuc Fragiudalfs). The second year of the study was on a Peridge silt loam 2 to 5 percent slope (Fine-silty, mixed, active, mesic Typic Paleudalfs) (Figure 1). A smother crop of sorghum Sudan grass was planted in the summers of 2016 and 2017 before each study year, and was cut and removed in August. The site was prepared each fall with a burn-down herbicide of 2% active ingredient glyphosate applied at 17 gallons/A before planting.

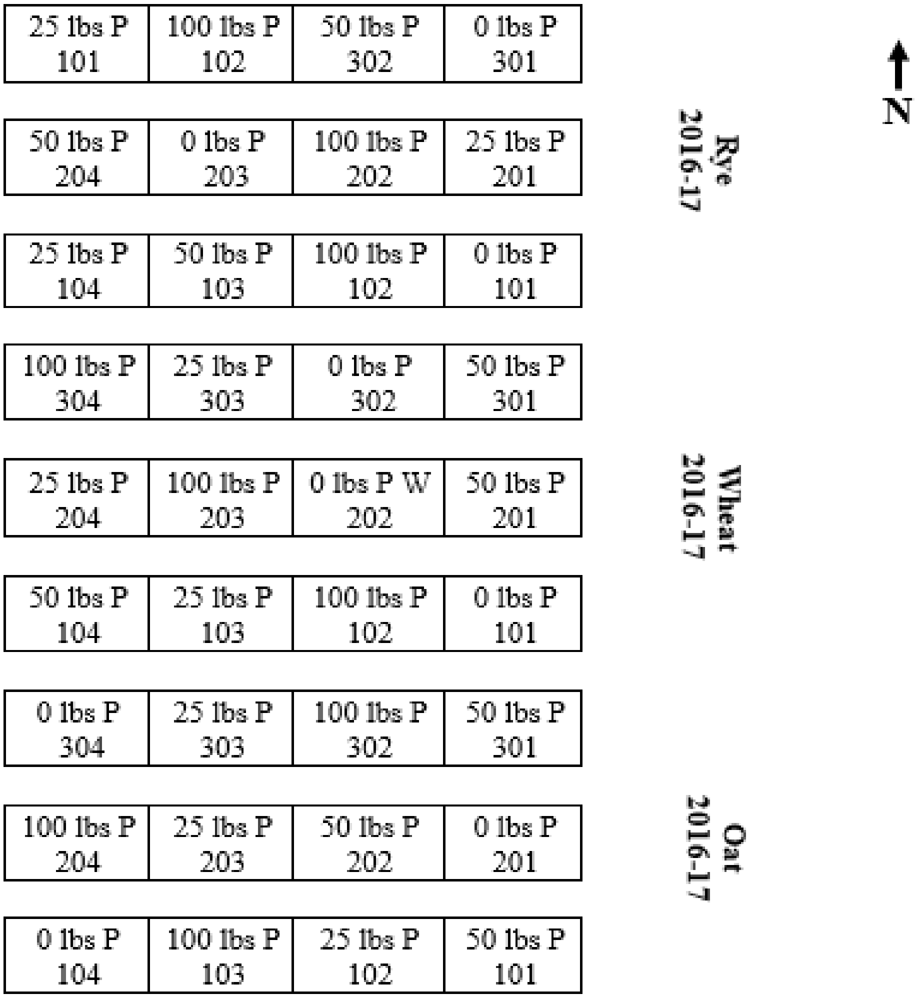
Planting and Treatments

Cereal rye (Elbon, KS), winter wheat (Kingrazer, MO), and oat (Bob, KS) were planted the third week of October in both 2016 and 2017. The three species were each planted to approximately one-third of a 9-acre field. Seeding rate for all species was 50 pounds of pure live seed/A. For each species, 10 ft by 20 ft plots with 5 ft alleys were laid out in three replicate blocks. Treatments within blocks were assigned at random. Treatments included 0, 25, 50 or 100 lbs of elemental P/A in the form of triple super phosphate (0-46-0) (Figures 2 and 3). Treatments were broadcast applied on December 21, 2016, and January 11, 2018. In March of the first year of the study, 50 lbs/A of N in the form of urea was applied across all treatments and all species. Nitrogen was not applied in year two because of wet conditions.



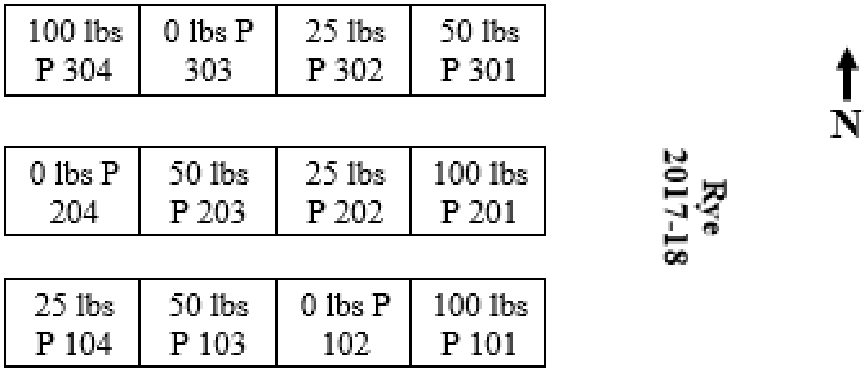
Source: USDA
Projection: NAD 1983 UTM 15N

Figure 1. Map of soils types of study site with approximate locations of species plots. R-Rye; W-Winter Wheat; O-Oat.



25 lbs P 101	100 lbs P 102	50 lbs P 302	0 lbs P 301
50 lbs P 204	0 lbs P 203	100 lbs P 202	25 lbs P 201
25 lbs P 104	50 lbs P 103	100 lbs P 102	0 lbs P 101
100 lbs P 304	25 lbs P 303	0 lbs P 302	50 lbs P 301
25 lbs P 204	100 lbs P 203	0 lbs P W 202	50 lbs P 201
50 lbs P 104	25 lbs P 103	100 lbs P 102	0 lbs P 101
0 lbs P 304	25 lbs P 303	100 lbs P 302	50 lbs P 301
100 lbs P 204	25 lbs P 203	50 lbs P 202	0 lbs P 201
0 lbs P 104	100 lbs P 103	25 lbs P 102	50 lbs P 101

Figure 2. Plot map for 2016-17 growing season.



100 lbs P 304	0 lbs P 303	25 lbs P 302	50 lbs P 301
0 lbs P 204	50 lbs P 203	25 lbs P 202	100 lbs P 201
25 lbs P 104	50 lbs P 103	0 lbs P 102	100 lbs P 101

Figure 3. Plot map for 2017-18 growing season.

Soils

One soil sample comprised of approximately 15 cores was taken to a six in. depth from each block prior to the application of treatments. Soil samples were again taken from each plot after shoot tissue harvest in each year of the study. Soil samples were analyzed by the University of Missouri soil testing laboratory (Columbia, MO, USA) for pHs, neutralizable acidity, percent organic matter, Bray I soil P, Bray II soil P, Ca, Mg, K, and cation exchange capacity.

Harvest

Each species was harvested when growth reached the boot stage (Figure 4). Winter wheat and cereal rye were harvested on April 11, 2017, and oat was harvested on April 18, 2017. Winter wheat and oat did not survive winter conditions in year two of the study. Rye plots were harvested on May 8, 2018. At each harvest, three one sq ft subsamples were collected from each plot of each block, except for the third block of rye in year one of the study where five subsamples were collected per plot.

Fresh weights were recorded, and samples were placed in a Cascade Tek temperature controlled forced air oven (Cascade Sciences, Hillsboro, Oregon, USA) to dry at 50 ˚C and dried to obtain dry weight.

Dried shoot samples were coarsely chopped using a food processor, and ground to pass through a 1 mm screen with a Cyclone Mill Sample Mill (UDY Corporation, Fort Collins, Colorado, USA). Ground samples were weighed to between 0.245 g and 0.255 g and digested in 5mL of trace grade nitric acid using a MARS 6 Microwave (CEM Corp., Matthews, North Carolina, USA). The MARS 6 Plant Tissue method was used (CEM Corp., Matthews, North Carolina, USA). This method included a 20-minute ramp time to 200 ˚C which was held for 10 minutes before samples were allowed to cool to 70 ˚C. After ventilation, samples were transferred to 20 mL clear polypropylene vials and diluted with DI H_2O to a final volume of 25 mL. Samples were then filtered using Q8 course, fast flowing, 11 cm filter paper (ThermoFisher Scientific, Waltham, Massachusetts, USA) and stored in 20 mL clear polypropylene vials.

Figure 4. Oat, winter wheat, and cereal rye at harvest in spring of 2017.

Nutrient Analysis

Phosphorus contents (% by weight) were determined colorimetrically (Murphy and Riley, 1962). Samples were diluted 1:20 (50 µL sample: 950 µL DI H_2O). Diluted samples (1 mL) were pipetted into glass test tubes, followed by an ascorbic acid working solution (4 mL), vortexed, and allowed to develop color for 20 minutes. An absorbance curve was developed using standard solutions of 0.00, 0.50, 1.00, 2.50, and 5.00 ppm P in DI H_2O. Samples were measured using a GENESYS™ 10S UV-Vis Spectrophotometer flow cell system (ThermoFischer Scientific, Waltham, Massachusetts, USA) set to read at 660 nm wavelength.

Contents (% by weights) of Ca, Mg, and K of digested samples were determined using Atomic Absorption/ Flame Emission Spectrophotometry (Agilent Technology, 200 Series AA, Santa Clara, California, USA). The analytical wavelengths were set at 766.5 nm (K), 285.2 nm (Mg), and 422.7 nm (Ca). All samples were diluted 1:20 using 0.105% lanthanum (La) (from La_2O_3). Standard solutions were made using a background 1% HNO_3 and 0.105% La. Standards were 1.00, 2.00, 3.00 and 4.00 ppm for Ca, 0.25, 0.50, 1.00, 1.50, and 2.00 ppm for Mg, and 0.25, 0.50, 1.00, and 2.00 ppm for K (Murphy and Riley, 1962).

Grass Tetany Ratio

Using the shoot tissue nutrient contents that were determined as described above, the grass tetany ratio was calculated K/(Ca+Mg) (Kemp and ‘t Hart, 1957).

Weather Data

Weather data including precipitation and maximum and minimum temperature for both growing seasons of the study, as well as the 30 year average, were collected from the NOAA weather station in Fair Grove, Missouri.

Statistical Analysis

This study was set up as a randomized complete block design. The model included species and fertilizer treatment as fixed factors, and block and year as random factors. This model was used to test for significance of P treatment effects, as well as interactions with year using PROC MIXED in SAS version 9.4 (SAS Institute, 2017). All effects and interactions were considered significant when means differed at $P < 0.05$. Means were separated using Tukey's pairwise comparison.

RESULTS

Weather Data

The monthly precipitation totals were 43% below the 30-year average in November, and approximately 80% below average in December and February of the 2016-17 growing season. For the months of October, January, March, April, and May, precipitation was above the 30 year average by 13, 67, 35, 200, and 60% respectively. For the 2017-18 growing season, the monthly precipitation was below the 30-year average by 25% in October and January, 87% in November, 46% in December, and 40% in April and May. Monthly precipitation was 200% above average in February and 6% in March (Figure 5).

Monthly minimum and maximum temperatures for the 2016-17 growing season were above the 30-year average in every month except December (Figure 6). The temperatures were below the 30 year average December through April of the 2017-18 growing season and above the 30-year average October, November, and May (Figure 7).

Dramatic changes in environmental conditions including prolonged drought right after planting, and extreme cold in January of 2018 in the second year of the study, led to stand failure for both oat and wheat. Therefore, only one year of data was collected for these species. Environmental growing conditions varied greatly across both years leading to a significant effect of year in rye, therefore each year of rye was analyzed separately.

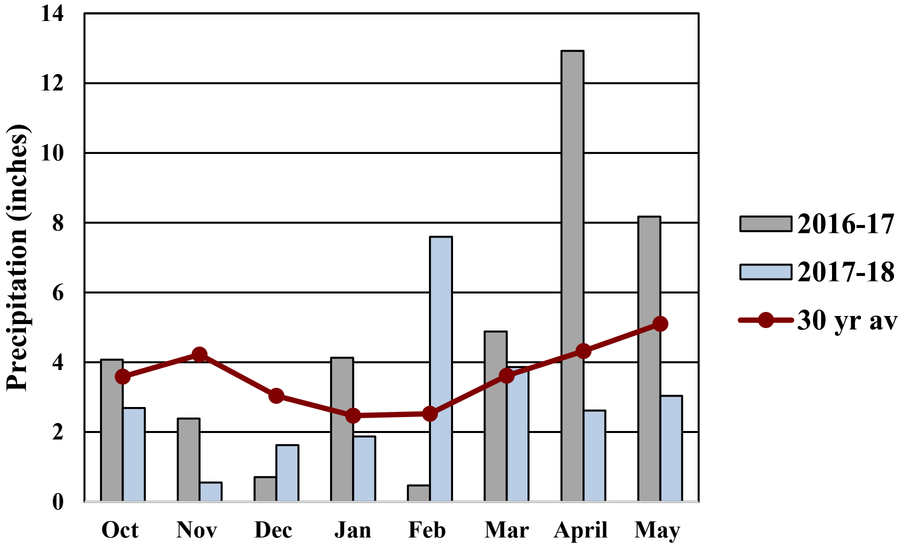


Figure 5. Monthly precipitation totals for the 2016-17 and 2017-19 growing seasons, and the 30-year monthly precipitation average for Fair Grove, Missouri.

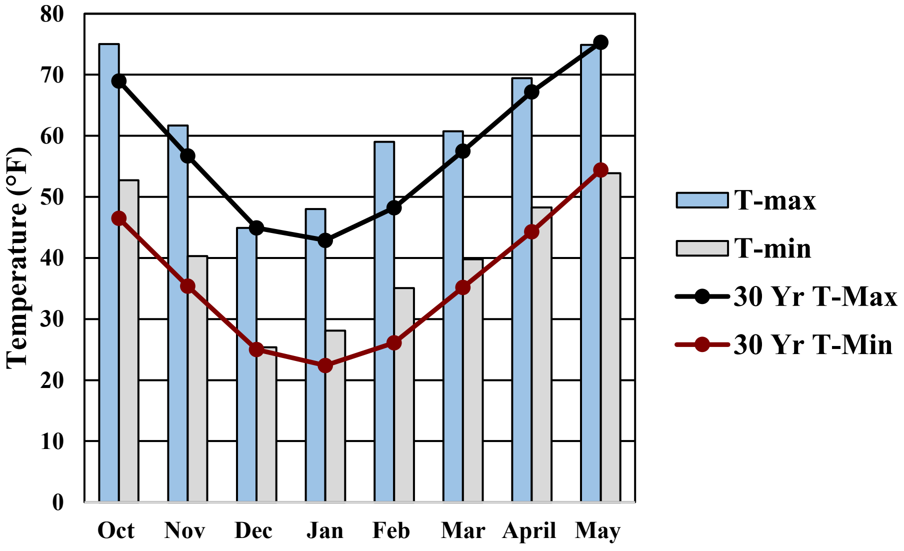


Figure 6. Monthly maximum (T-max) and minimum (T-min) temperatures for the 2016-17 growing season and the 30-year average maximum (30 Yr T-max) and minimum (30 Yr T-min) for Fair Grove, Missouri.

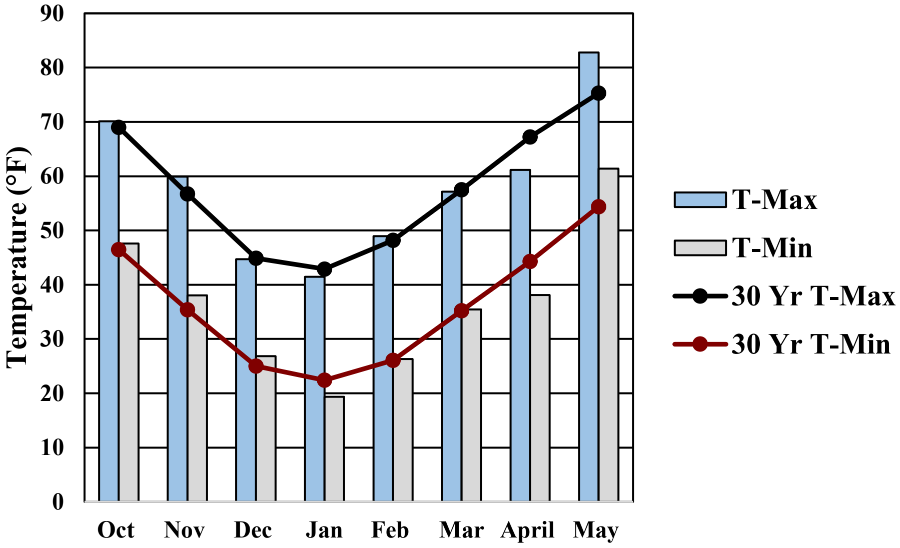


Figure 7. Monthly maximum (T-max) and minimum (T-min) temperatures for the 2017-18 growing season and the 30-year average maximum (30 Yr T-max) and minimum (30 Yr T-min) for Fair Grove, Missouri.

Yield

There was no effect of P treatment on yield on oat in 2016-17 (Figure 8). In winter wheat, P treatment only had an effect on yield in the 25 and 100 lb/A treatments (Figure 9). Yield was greater in the 25 lb/A treatments compared to other treatments in cereal rye in 2016-17, however the only effect on yield was in the 100 lb/A P treatment in 2017-18 (Figure 10).

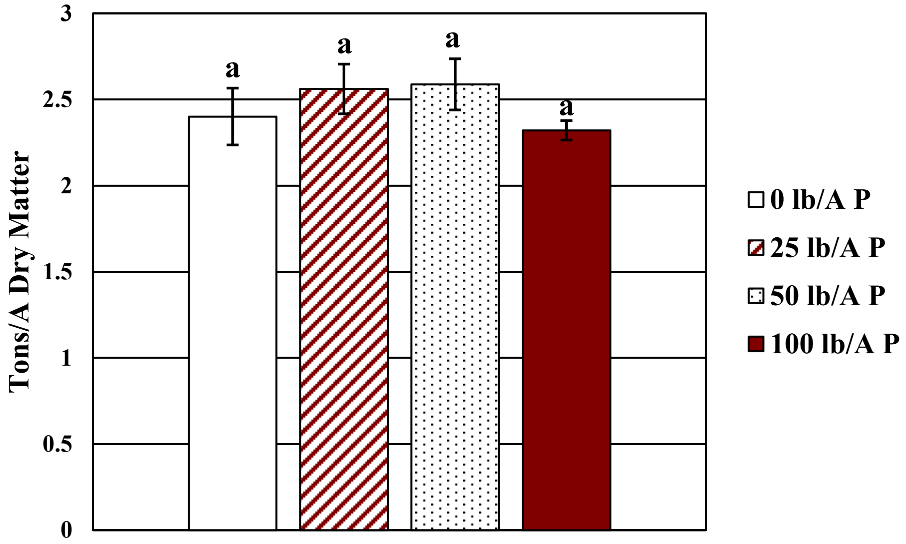


Figure 8. Dry matter yield of oat shoot tissue at harvest in spring 2017. Values are means ± SE, n=9. Values followed by the same letter are not significantly different (p< 0.05, Tukey's pairwise comparisons.

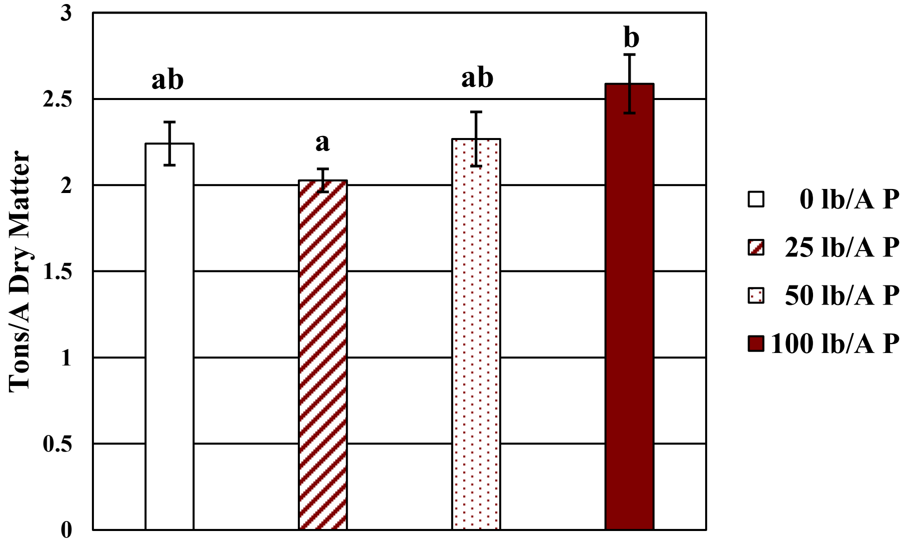


Figure 9. Dry matter tonnage of winter wheat shoot tissue at harvest in spring 2017. Values are means ± SE, n=9. Values followed by the same letter are not significantly different (p< 0.05, Tukey's pairwise comparisons

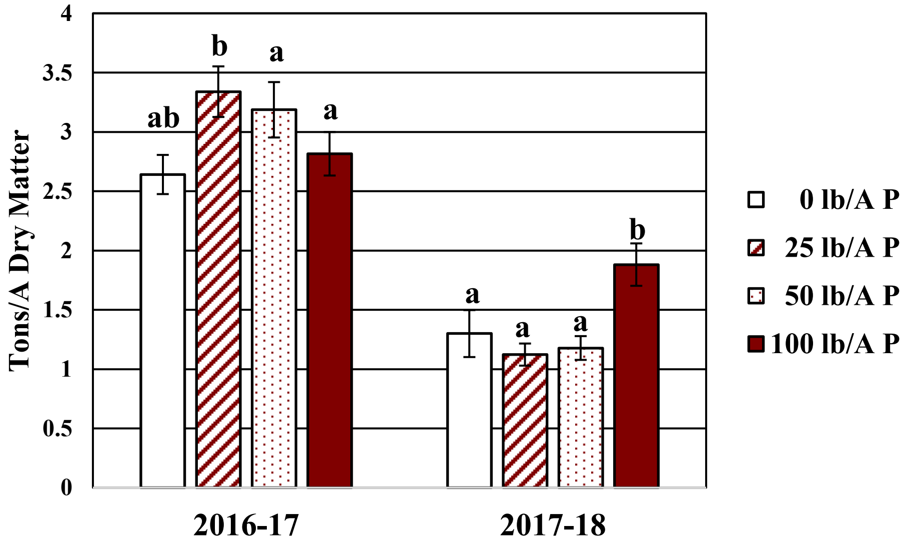


Figure 10. Dry matter tonnage of cereal rye shoot tissue at harvest spring 2017 and 2018. Values are means ± SE, n=9. Within year, values followed by the same letter are not significantly different (p< 0.05, Tukey's pairwise comparisons

Shoot Mineral Contents

In oat, phosphorus fertilization had a significant effect on shoot P content. Shoot P increased incrementally with P treatment with the greatest increase of 43% from 0 to 100 lb/A P fertilization (Figure 11). Shoot Ca and Mg were lower in the 50 lb/A P treatments compared to the 100 lb/A P treatments (Figures 12 and 13). However, shoot Ca and Mg of the 50 and 100 lb/A P treatments were not different from 0 and 25 lb/A P. Shoot K was greatest at the 50 lb/A P treatment compared to all other treatments (Figure 14). This resulted in a greater grass tetany ratio in the plants that received the 50 lb/A P treatment (Figure 15).

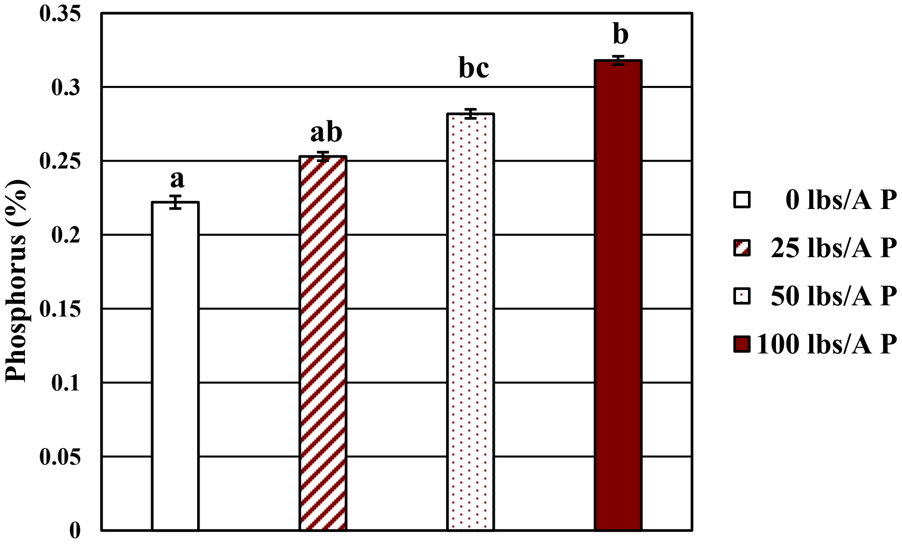


Figure 11. Phosphorus contents of dry oat shoot tissue at harvest in spring 2017. Values are means ± SE, n=9. Values followed by the same letter are not significantly different ($p< 0.05$, Tukey's pairwise comparisons).

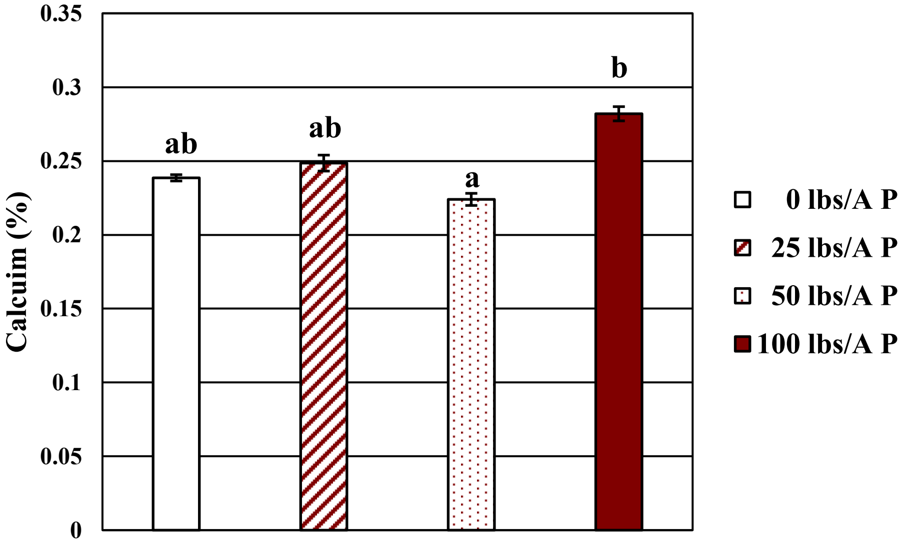


Figure 12. Calcium contents of dry oat shoot tissue at harvest in spring 2017. Values are means ± SE, n=9. Values followed by the same letter are not significantly different ($p < 0.05$, Tukey's pairwise comparisons).

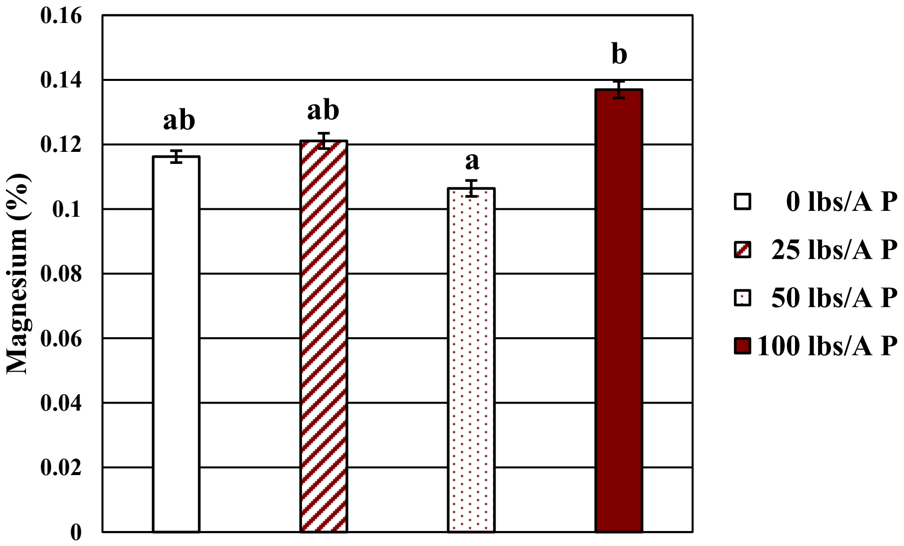


Figure 13. Magnesium contents of dry oat shoot tissue at harvest in spring 2017. Values are means ± SE, n=9. Values followed by the same letter are not significantly different ($p < 0.05$, Tukey's pairwise comparisons).

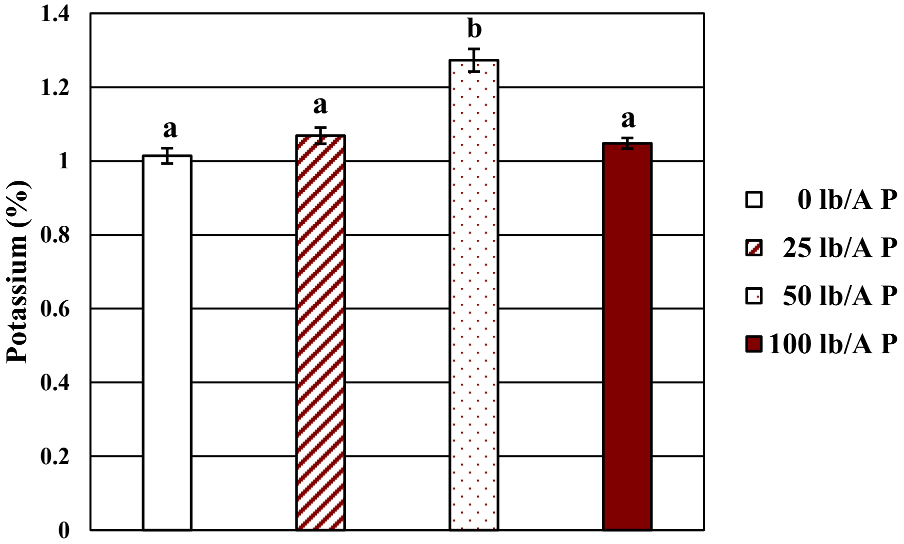


Figure 14. Potassium contents of dry oat shoot tissue at harvest in spring 2017. Values are means ± SE, n=9. Values followed by the same letter are not significantly different ($p< 0.05$, Tukey's pairwise comparisons).

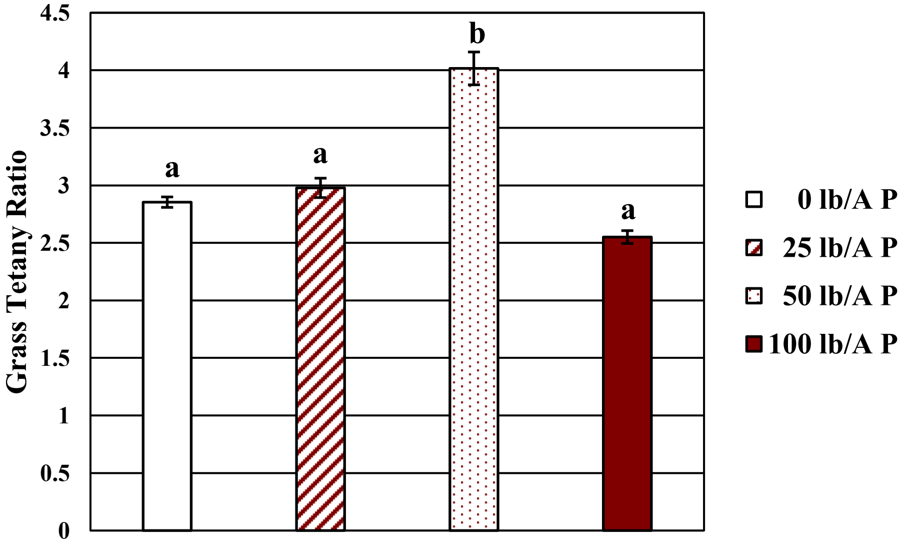


Figure 15. Grass tetany ratio of dry oat shoot tissue at harvest in spring 2017. Values are means ± SE, n=9. Values followed by the same letter are not significantly different ($p< 0.05$, Tukey's pairwise comparisons).

In winter wheat, P treatment affected shoot P content in an increasing manner. Overall, there was a 71% increase in shoot P content from 0 to 100 lb/A P (Figure 16). There was an increase in shoot Ca with P applications, increasing 35% from 0 to 25 lb/A P, and no additional increase in Ca with additional P in 50 or 100 lb/A P treatments (Figure 17). There was an effect of P treatment on shoot Mg content. Mg content increased from 0 to 50 lb/A P, however, there was no effects between other treatments (Figure 18). Phosphorus treatment had no effect on the K content in winter wheat (Figure 19). The grass tetany ratio was reduced in all winter wheat treatments where P was applied. (Figure 20).

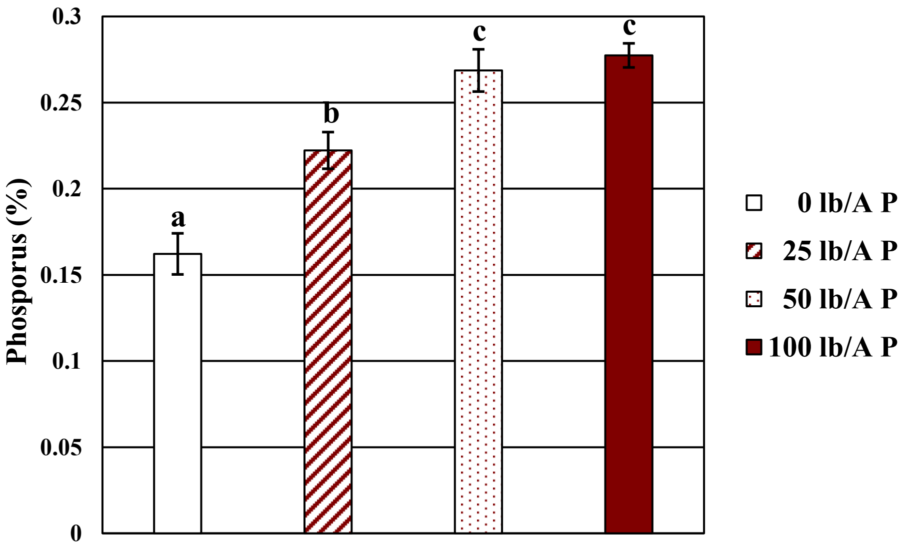


Figure 16. Phosphorus contents of dry winter shoot tissue at spring harvest. Values are means ± SE, n=9. Values followed by the same letter are not significantly different ($p< 0.05$, Tukey's pairwise comparisons).

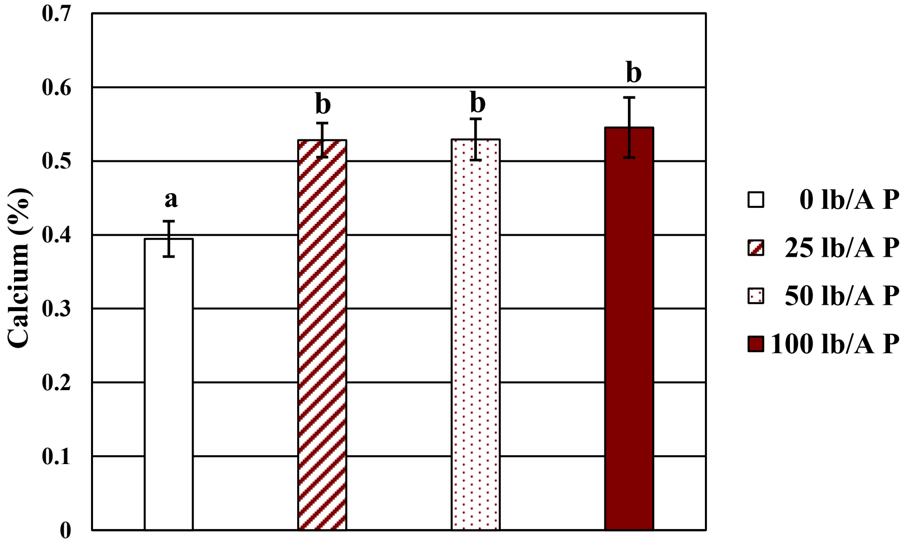


Figure 17. Calcium contents of dry winter wheat shoot tissue at harvest in spring 2017. Values are means ± SE, n=9. Values followed by the same letter are not significantly different ($p < 0.05$, Tukey's pairwise comparisons).

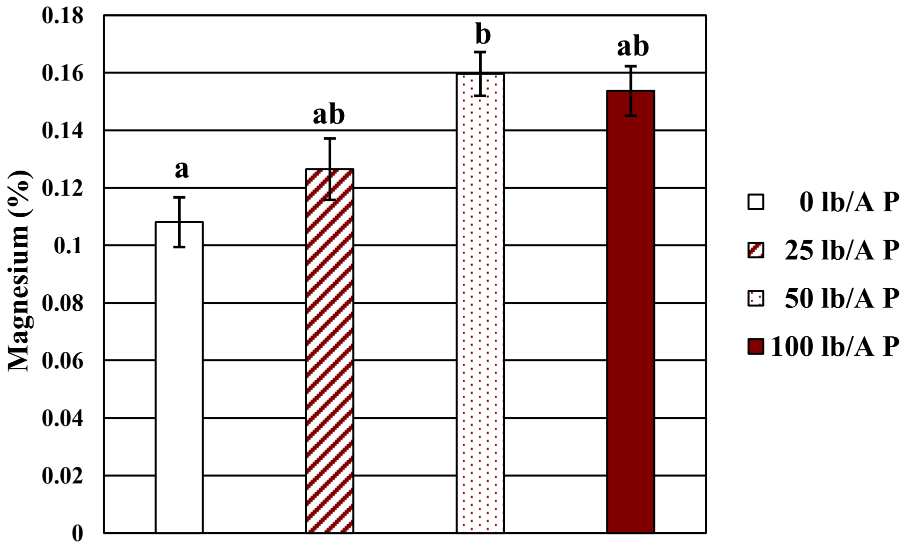


Figure 18. Magnesium contents of dry winter wheat shoot tissue at harvest in spring 2017. Values are means ± SE, n=9. Values followed by the same letter are not significantly different ($p < 0.05$, Tukey's pairwise comparisons).

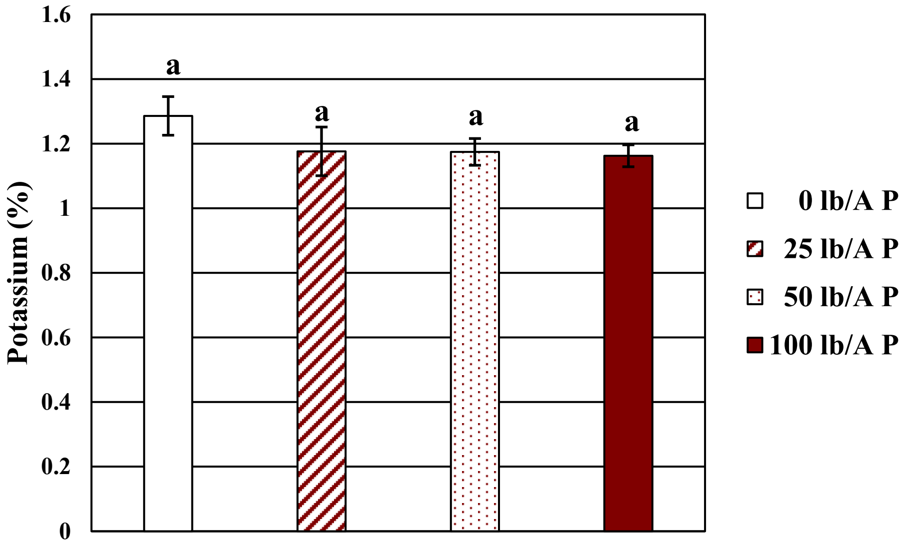


Figure 19. Potassium contents of dry winter wheat shoot tissue at harvest in spring 2017. Values are means ± SE, n=9. Values followed by the same letter are not significantly different ($p< 0.05$, Tukey's pairwise comparisons).

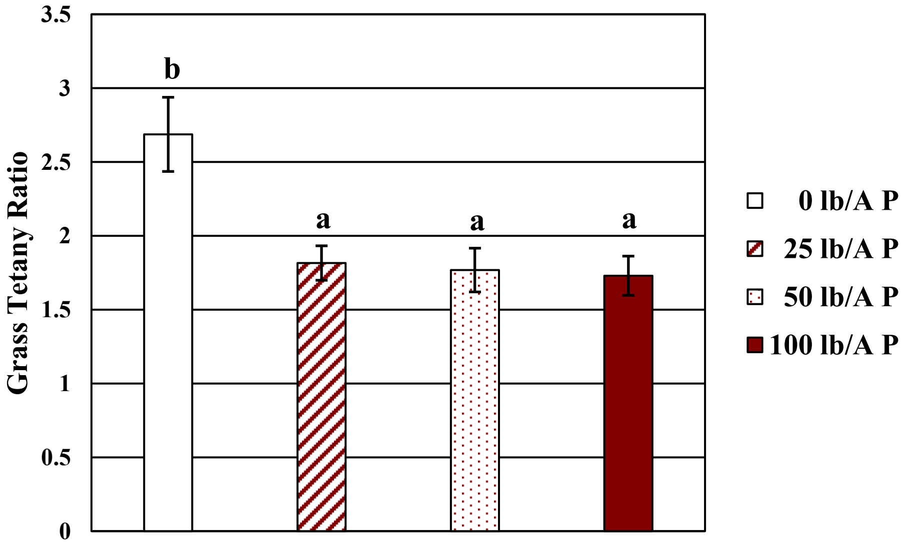


Figure 20. Grass tetany ratio of dry winter shoot tissue at harvest in spring 2017. Values are means ± SE, n=9. Values followed by the same letter are not significantly different ($p< 0.05$, Tukey's pairwise comparisons).

In cereal rye, shoot P content of cereal rye increased significantly with P treatment in both years. From 0 to 100 lbs/A P, there was an 82% and 78% increase in shoot P in 2016-17 and 2017-18, respectively (Figure 21). There was no statistically significant effect of P treatment on shoot Ca or Mg in cereal rye in either year of the study. However, average Ca content did increase from 0 to 100 lb/A P treatments in 2016-17 and from 0 to 50 lb/A P in 2017-18, but the measured increase was less than 0.1% (Figure 22). A non-significant stair-step increase in shoot Mg occurred from 0 to 100 lb/A P in 2016-17 of the study. In 2017-18, the largest increase occurred from 0 to 25 lb/A P (Figure 23). In 2016-17, K content remained the same from 0 to 25 lb/A P, but decreased from 25 to 50 lb/A P. There was no significant effect of P treatment on K content in 2017-18 (Figure 24). The grass tetany ratio was reduced by P treatments in 2016-17 from 25 to 50 lb/A P, but no effect of P was seen in 2017-18 (Figure 25).

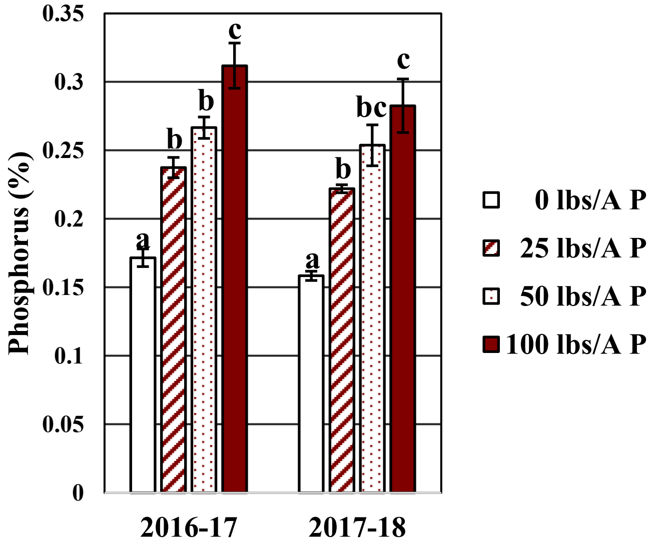


Figure 21. Phosphorus contents of dry cereal rye shoot tissue at spring harvest. Values are means ± SE, n=9. Within year, values followed by the same letter are not significantly different ($p < 0.05$, Tukey's pairwise comparisons).

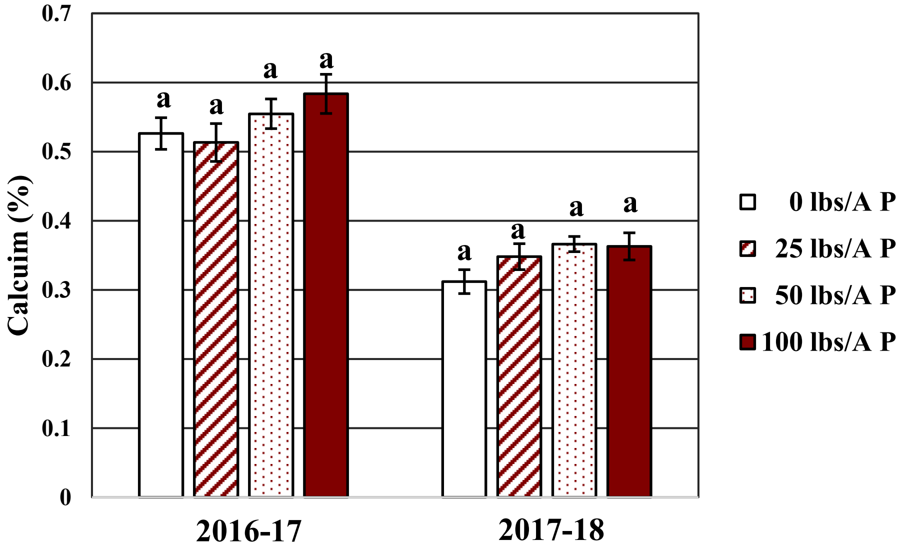


Figure 22. Calcium contents of dry cereal rye shoot tissue at harvest in spring 2017 and 2018. Values are means ± SE, n=9. Values within year followed by the same letter are not significantly different ($p < 0.05$, Tukey's pairwise comparisons).

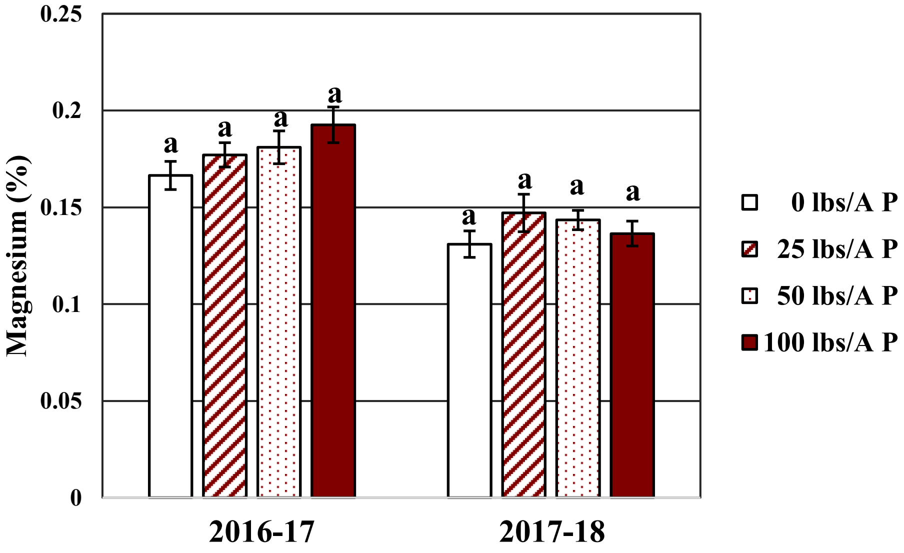


Figure 23. Magnesium contents of dry cereal rye shoot tissue at spring harvest. Values are means ± SE, n=9. Values within year followed by the same letter are not significantly different ($p < 0.05$, Tukey's pairwise comparisons).

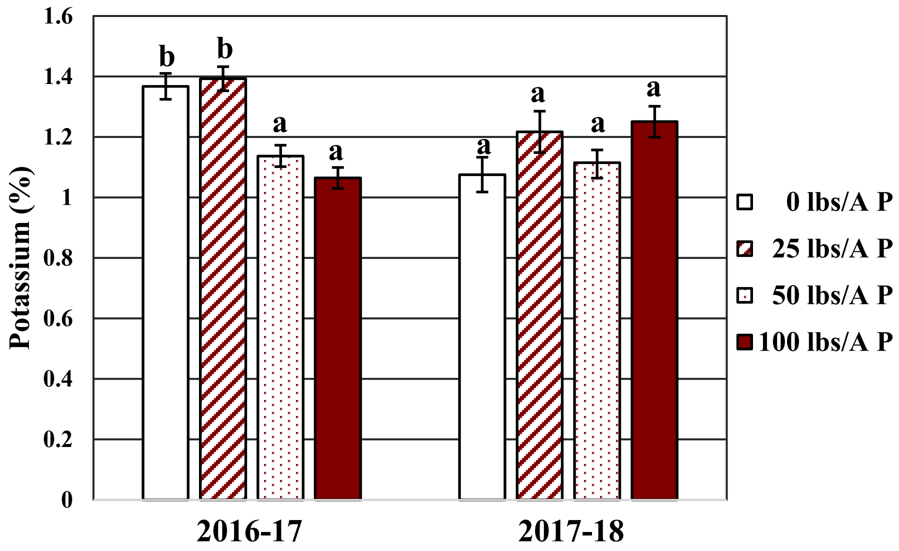


Figure 24. Potassium contents of dry cereal rye shoot tissue at harvest in spring 2017 and 2018. Values are means ± SE, n=9. Values within year followed by the same letter are not significantly different ($p < 0.05$, Tukey's pairwise comparisons).

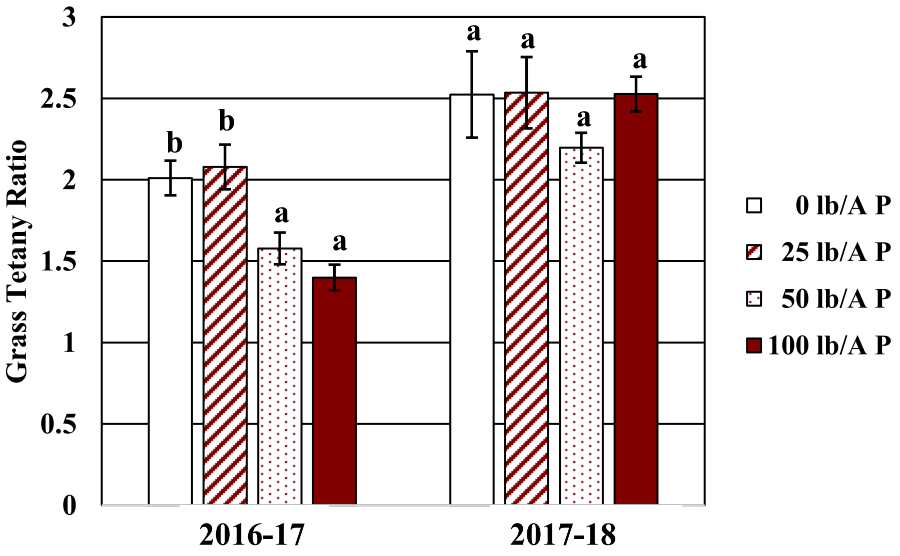


Figure 25. Grass tetany ratio of dry cereal rye shoot tissue at harvest in spring 2017 and 2018. Values are means ± SE, n=9. Values within year followed by the same letter are not significantly different ($p < 0.05$, Tukey's pairwise comparisons).

Soils

The initial soil test Bray I P content for the three oat blocks averaged 22 lb/A P by the 2017 harvest, Bray I P decreased approximately 10% in the 0, 25, and 50 lb/A P treatments, and increased 50% in the 100 lb/A P treatment. The initial Bray II P content was 85 lb/A. The Bray II P content decreased by 27% in the 0 lb/A P treatment and 12% in the 25 lb/A P treatment by the 2017 harvest. Additionally, the Bray II P content increased in the 50 and 100 lb/A P treatments by 8 and 33%, respectively (Figure 26).

For the winter wheat blocks, the initail Bray I P content of the soil was 24 lbs/A. In the 0 and 25 lb/A P treatments Bray I P decreased approximately 36 and 10%, respectivly. Bray I P was raised by 10 and 36% in the 50 and 100 lb/A P treatments, repectivly. Initail Bray II P was 113 lb/A. The 0 and 25 lb/A P treatments decresed by 12 and 26%, respectivly, by the 2017 harvest. The 50 and 100 lb/A treatments increaed the Bray II soil P by 4 and 10%, respectivly (Figure 27).

In the first year of cereal rye, the initial Bray I P content was 25 lb/A. In the 0 and 25 lb/A treatments, the Bray I P content was reduced by 48 and 20%, respectively. The 50 and 100 lbs/A P treatments increased the Bray I P by 28 and 60%, respectively. The initial Bray II P was 110 lb/A. In the 0 and 25 treatments groups, the Bray II soil P decreased by 43 and 25%, respectively. There was an increase in the Bray II soil P in the 50 and 100 lb/A groups by 19 and 63%, respectively (Figure 28).

In the second year of the study in cereal rye, the initial Bray I P content in the soil was 13 lbs/A. In the 0 lb/A P treatment, the Bray I P was lowered 8%. The 25, 50, and 100 lb/A P treatments increased the Bray I P content by 100, 108, and 215%, respectively. The initial Bray

II P was 46 lbs/A. Bray II P increased in the 0, 25, 50, and 100 lb/A P treatments by 120, 33, 61, and 163%, respectively (Figure 29).

Complete soil data for each sample taken can be found in the Appendix (page 43).

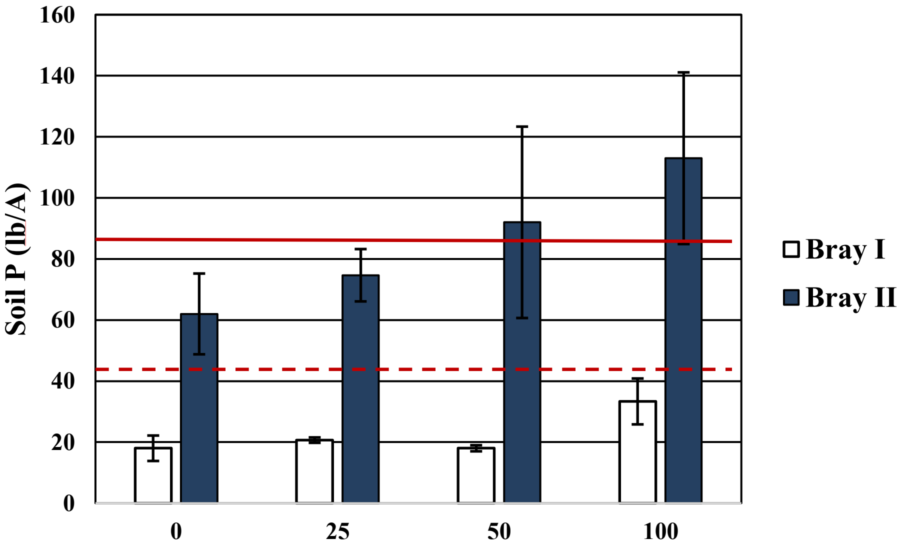


Figure 26. Soil Bray I and Bray II values by treatment in oat plots at harvest in 2017 and initial Bray I and Bray II values. The initial Bray I P and Bray II P values are represented by the dashed and solid lines respectively.

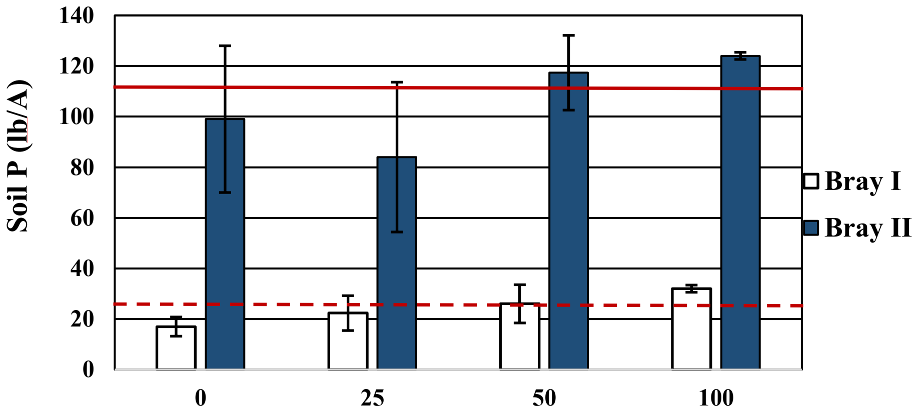


Figure 27. Soil Bray I and Bray II values by treatment in winter wheat plots at harvest in 2017 and initial Bray I and Bray II values. The initial Bray I P and Bray II P values are represented by the dashed and solid lines respectively.

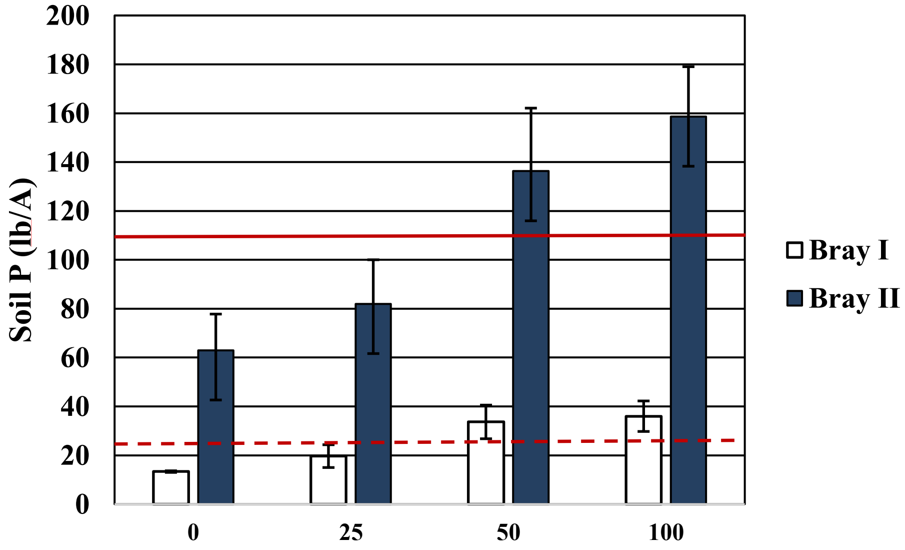


Figure 28. Soil Bray I and Bray II values by treatment in cereal rye plots at harvest in 2017 and initial Bray I and Bray II values. The initial Bray I P and Bray II P values are represented by the dashed and solid lines respectively.

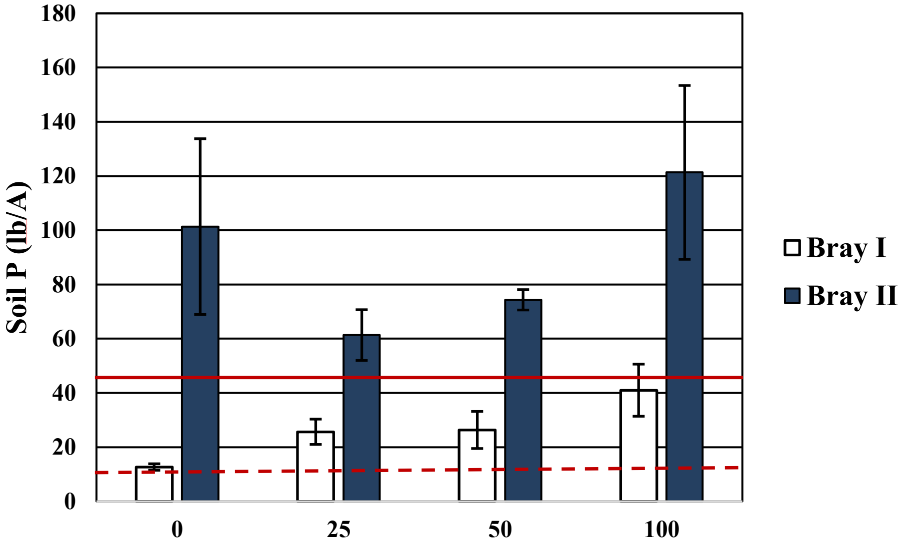


Figure 29. Soil Bray I and Bray II values by treatment in cereal rye plots at harvest in 2018 and initial Bray I and Bray II values. The initial Bray I P and Bray II P values are represented by the dashed and solid lines respectively.

DISCUSSION

Weather

The weather data displays only the monthly averages and does not show the severity of short-term weather events. In the 2017-18 growing season, the study site received approximately 1.5 inches of rain within three days of planting, but then received a total of 0.52 inches over the next two months (Figure 5). There were two periods in January of 2018 where low temperatures were in the single digits or negative temperatures for three- and four-day periods (Figure 7). The combination of these two events could be a possible explanation for the winter wheat and oat not surviving the second year of the study.

Yield

A decrease in yield occurred at the 25 lb/A treatment in winter wheat (Figure 9). There was an effect of treatment on cereal rye in both years of the study. Yield increased in only the 25 lb/A treatment in 2016-17 while in 2017-18 yield increased in the 100 lb/A treatment. This difference could have been due to the different weather conditions in each year, or different beginning soil P levels (Figure 10). Similar to the hydroponic study of Henry et. al, (2019), yield of cereal rye increased with P treatments compared to the control in 2017-18.

Shoot Nutrient Contents

Increasing P treatment resulted in increased P content in shoot tissue in all species studied. This uptake of P is consistent with previous studies of winter annual cereal (Reinbott and Blevins, 1991; Henry et al., 2019). For all species, all treatments where P was applied raised the shoot tissue content of P to meet the nutritional requirement for P of lactating beef cattle (Figures 11, 16 and 21, respectively).

In oat, shoot Ca and Mg responded similarly to P fertilization treatment, with the only effect of treatment being a decrease in nutrient content at the 50 lb/A P (Figures 12 and 13, respectively). Where there was a decrease of Ca and Mg at the 50 lb/A P, there was an increase of K (Figure 14). This caused the grass tetany ratio to be highest at 50 lb/A P, and all treatment groups remained above the critical level of 2.2 (Figure 15). This differed from the Henry et al. hydroponic study where Ca and Mg increased with added P. Only the 100 lb/A P treatment was effective at raising the shoot Ca content to meet the animal nutritional requirement (Figure 12). For Mg, all treatment groups remained under 0.2% which is the recommended minimum requirement for lactating cattle (Figure 13). Based on the year of data in this study, oat would not be a good choice of forage for surviving the winter for spring grazing and trying to lower the grass tetany ratio.

In winter wheat, shoot Ca and Mg increased with increasing P treatment, while K decreased with increasing P treatment in wheat (Figures 17, 18, and 19, respectively). This combination caused a reduction in the grass tetany ratio. The control had a grass tetany ratio of 2.6 which is well about the critical level of 2.2, but in all treatment groups where P was applied the ratio was lowered to approximately 1.8 (Figure 20). These results show that P treatment might be effective in lowering the grass tetany ratio in winter wheat. All treatments were effective at keeping the shoot Ca content about the nutritional requirement of lactating beef cattle, but all groups were below the requirement of 0.2% for Mg (Figures 17 and 18, respectively). There was no additional effect of P treatment on nutrient contents or the grass tetany ratio past the 50 lb/A P treatment, therefore this may be the upper limit for seeing an effect of P treatment in winter wheat. Since there was only one year in this study, another year of the study should be completed. The response of shoot Ca and Mg to added P is similar to the findings of Henry et al., 2019, while the K response differs.

In cereal rye, there was no effect of P treatment on leaf Ca or Mg in either year of the study (Figures 22 and 23, respectively). There was a significant interaction of treatment and block on Ca content in year one. There was a decrease in K content in the 50 and 100 lb/A P treatments of the first year of the study which led to a reduction in the grass tetany ratio in these treatment groups in year one (Figures 24 and 25, respectively). In the second year of the study, the grass tetany ratio was higher than the previous year (2.5 in the 0, 25, and 100 lb/A P treatments) and was only reduced in the 50 lb/A P treatment due to a slightly lower K content, but still remained at a ratio of 2.2 (Figure 25). In both years, treatment was effective at keeping the shoot tissue Ca content above the recommended nutritional requirement for lactating beef a cattle (Figure 22). Only the 50 and 100 lb/A P treatments in the first year were able to meet the shoot tissue Mg content requirement for these animals (Figure 23). Overall, Ca and Mg contents were lower in the second year of the study while K remained similar to the first year which could have led to the higher grass tetany ratios in year two (Figures 22, 23, and 24, respectively). In both years, nutrient (Ca, Mg, and K) responses to added P differed from the findings of Henry et al., 2019. While this study was similar to the hydroponic study of Henry et al. 2019, they are difficult to compare as the control in Henry's study was a true zero plant available P scenario, this study's control was available P in the field without any added P fertilizer.

Soils

The field utilized for this for this study contains three different soil types. While both years of the study took place in the same field, each year was on a different soil type (Figure 1). The Peridge and Viraton soil series are both deep, well drained soils commonly found throughout pastureland in the Ozarks region of Missouri. While the two soil series are very similar in physical characteristics, soil test data (Figures 26, 27, 28, and 29) indicates differing levels of soil fertility across the field. The initial soil sampling of one soil sample per block failed to properly address the variability across each soil series. This variability was later revealed in the soil samples taken per plot at the end of each study year. Very little information about management practices at Shealy farm is known prior to Missouri State University acquiring the property. This could account for some of the variability in soil fertility across the site.

CONCLUSIONS

When compared to prior studies, the three annual cereal grains did not respond to P fertilization in the same ways as perennial tall fescue (McClain et al., 2007). Additionally, winter wheat, oat, and cereal rye all responded differentially to added P fertilization. Initial Bray I P soil test levels indicated approximately 22 lbs/A plant available P at this site. While this is considered "low" for P, in Missouri soils, this soil test level may not have been low enough to observe a response to P fertilizer when growing winter annual cereal grains. Depending on species and initial plant available soil P, adding P fertilizer may be effective at lowering the grass tetany ratio in winter annual cereals. Another year of data should be collected for winter wheat and oat, and the entire study should be replicated on a soil with a lower initial Bray I P level.

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APPENDIX

Complete Soil Test Data

Part 1. Pre-treatment soil test results for each block of each species fall 2016.

Block	pHs	N.A. meq/100g	%OM	P Bray I lb/A	P Bray II lb/A	Ca lb/A	Mg lb/A	K lb/A	CEC meq/100g
Wheat 1	6	1.5	3.3	20	115	3196	236	143	10.7
Wheat 2	5.6	2	3.9	18	91	3046	214	144	10.7
Wheat 3	5.9	1.5	3.5	24	116	2881	168	137	9.6
Oat 1	5.4	2.5	3	23	96	2261	186	129	9.1
Oat 2	5.9	1.5	2.9	22	120	2710	145	119	9
Oat 3	5.9	1.5	3.2	28	129	3113	162	125	10.1
Rye 1	6.2	1	3.7	19	126	3517	179	134	10.7
Rye 2	6	1	3.6	18	104	3303	163	129	10.1
Rye 3	6.2	1	3.6	24	156	3353	159	123	10.2

Part 2. Soil test results per plot for oat at harvest spring 2017.

Treatment	Plot	pHs	N.A. meq/100g	%OM	P Bray I lb/A	P Bray II lb/A	Ca lb/A	Mg lb/A	K lb/A	CEC meq/100g
50	Oat 101	5.6	2.5	1.9	16	53	2484	169	167	9.6
25	Oat 102	5.3	3	2	22	71	2360	146	97	9.6
100	Oat 103	5.4	2.5	2	20	62	2365	110	78	9
0	Oat 104	5.4	2.5	1.9	20	67	2192	109	83	8.5
0	Oat 201	6.1	1	2	10	37	2887	100	97	8.8
50	Oat 202	5.7	2	1.9	19	69	2665	118	95	9.3
25	Oat 203	5.6	2	1.8	21	91	2807	99	85	9.5
100	Oat 204	5.7	2	2.1	46	159	2564	96	82	8.9
50	Oat 301	6.1	1.5	2.3	19	154	3121	94	98	9.8
100	Oat 302	6.1	1.5	2	34	118	3372	95	91	10.4
25	Oat 303	6	1.5	2.2	19	62	3069	100	96	9.7
0	Oat 304	5.9	1.5	2.1	24	82	2921	96	104	9.3

Part 3. Soil test results per plot for wheat at harvest spring 2017.

Treatment	Plot	pHs	N.A. meq/100g	%OM	P Bray I lb/A	P Bray II lb/A	Ca lb/A	Mg lb/A	K lb/A	CEC meq/100g
0	Wheat 101	5.6	2	1.9	11	41	2149	104	93	7.9
100	Wheat 102	5.6	2	1.9	23	110	2820	134	97	9.7
25	Wheat 103	5.6	2	1.8	14	50	2574	141	98	9.1
50	Wheat 104	5.7	2	1.8	17	93	2521	99	87	8.8
50	Wheat 201	5.7	2	2.4	20	144	3046	146	102	10.4
0	Wheat 202	5.6	2.5	2.4	16	257	3177	185	109	11.4
100	Wheat 203	5.6	2.5	2.2	41	138	2849	133	89	10.3
25	Wheat 204	5.7	2.5	2.7	17	59	2709	113	93	9.9
50	Wheat 301	5.7	2	3.2	41	115	3069	142	95	10.4
0	Wheat 302	5.7	2	3.3	24	99	3322	147	107	11.1
25	Wheat 303	5.8	2	3.2	36	143	3540	144	86	11.6

Part 4. Soil test results per plot for rye at harvest spring 2017.

Treatment	Plot	pHs	N.A. meq/100g	%OM	P Bray I lb/A	P Bray II lb/A	Ca lb/A	Mg lb/A	K lb/A	CEC meq/100g
0	Rye 101	5.8	1.5	3.5	13	60	3119	120	88	9.9
100	Rye 102	5.8	1.5	3.3	48	181	4015	135	97	12.2
50	Rye 103	6	1.5	3.3	47	187	3777	132	93	11.6
25	Rye 104	6	1.5	4.3	29	117	3812	170	106	11.9
25	Rye 201	5.9	1.5	2.9	15	57	3101	115	96	9.9
100	Rye 202	6	1.5	2.5	27	118	3306	106	85	10.3
0	Rye 203	6.2	1	2.2	14	90	3744	96	86	10.9
50	Rye 204	5.9	1.5	3.9	30	103	3615	112	99	11.1
0	Rye 301	5.6	2.5	3.4	13	39	3119	126	93	10.9
50	Rye 302	5.9	1.5	2.6	24	119	3175	85	79	9.9
100	Rye 303	6.6	0.5	3.3	33	177	4244	115	98	11.7
25	Rye 304	5.7	2	3.5	15	72	3612	146	111	11.8

Part 5. Pre-treatment soil test results for each block of rye fall 2017.

Block	pHs	N.A. meq/100g	%O.M.	Bray I P lb/A	Bray II P lb/A	Ca lb/A	Mg lb/A	K lb/A	CEC meq/100g
Rye 1	5.6	2.5	2.7	11	39	3035	139	64	10.7
Rye 2	5.4	2.5	2.2	20	40	2378	91	47	8.9
Rye 3	5.2	3.5	2.8	9	60	2478	100	41	10.2

Part 6. Soil test results per plot for rye at harvest spring 2018.

Treatment	Plot	pHs	N.A. meq/100g	%O.M.	Bray I P lb/A	Bray II P lb/A	Ca lb/A	Mg lb/A	K lb/A	CEC meq/100g
100	Rye 101	5.3	3	3.3	60	185	2923	124	49	10.9
0	Rye 102	5.5	2.5	3.2	12	121	2721	109	43	9.8
50	Rye 103	5.4	2.5	2.8	40	81	2451	120	44	9.2
25	Rye 104	5.5	2.5	2.9	27	51	2858	118	54	10.2
100	Rye 201	5.7	2	2.6	34	96	2923	102	50	9.8
25	Rye 202	5.8	2	2.8	17	80	3038	107	51	10.1
50	Rye 203	5.5	2.5	2.4	19	68	2517	103	43	9.3
0	Rye 204	5.5	3	2.6	11	38	2520	95	46	9.8
50	Rye 301	5.5	2.5	2.6	20	74	2506	98	41	9.2
25	Rye 302	5.4	3	2.5	33	53	2421	98	41	9.5
0	Rye 303	5.4	3	2.6	15	145	2541	101	42	9.8
100	Rye 304	5.6	2.5	2.3	29	83	2558	97	49	9.4