IMPACT OF AVAIL® AND JUMPSTART® ON YIELD AND PHOSPHORUS RESPONSE OF CORN AND WINTER WHEAT IN KANSAS

by

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Abstract

The increasing price of phosphorus (P) fertilizers has created interest among producers in ways to enhance the efficiency of applied P fertilizers. Research has long focused on increasing phosphorus efficiency through the use of fertilizer placement techniques (banding, strip applications, and in furrow placement with the seed). Recently, various products have been introduced and marketed claiming to increase efficiency of applied P or increase availability of native soil P. The objective of this study was to test the use of two such widely advertised products: Avail®, a long chain, organic polymer created to reduce the fixation of fertilizer P by aluminum and calcium, and JumpStart®, a seed inoculant containing a fungus (*Penicillium bailii*), which is said to increase the availability of fertilizer and native soil P to plant roots through the colonization of the root system and producing organic acid exudates.

This study was conducted at multiple locations across Kansas with corn (*Zea mays* L.) in 2008 and 2009 and winter wheat (*Triticum aestivum* L.) in 2009. Selected sites varied in soil test P, with a majority of the locations having a Mehlich III P test of < 20mg kg^{-1}, where a P response would be expected. Treatments consisting of P rates from 0 to 20 kg P ha^{-1} with and without the addition of Avail were applied at planting. At many locations, each of the fertilizer/Avail treatments were planted with and without Jumpstart seed treatment. Plant samples were collected at early and mid-season growth stages. Harvest data consisting of grain yield, grain moisture content at harvest, test weight or bushel weight and grain P content also were collected to measure treatment response. Plant samples for both trials failed to show consistent responses to the addition of either product. Excellent corn grain yields were obtained at seven of eight site years with location averages above 12,500 kg ha^{-1}. One location displayed a significant grain yield response to P in both 2008 and 2009. There were no significant responses to enhancement products where a response to P was seen.

At two of the five wheat trials, a significant tissue P response to the addition of P was seen. At one location with very low soil test, 6 mg kg^{-1}, P fertilization increased rate of maturity. No effect on growth or yield at either P responsive or unresponsive sites was seen in wheat due to the use of enhancement products.

A series of 20 single replications sites were conducted with the JumpStart product in cooperation with County Extension Agents as a part of wheat variety demonstrations. Analysis of this data showed a significant decrease in wheat yield with the addition of JumpStart in 2009.

Overall, this study showed a lower than expected frequency of response to applications of P fertilizer based on soil test and the KSU P fertilizer recommendations. It also showed no response across locations, years and crops to the use of P fertilizer enhancement products.

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Dedication

This is dedicated to my Grandfather, Ray, for introducing me to Agronomy and to my wife, Brooke, for all her love and support.

CHAPTER 1 - Phosphorus Fertility, a Literature Review

Introduction

Phosphorus (P) is one of 17 essential nutrients required for plant growth and development. Known functions of P in plant growth include energy storage/transfer with adenosine tri-phosphate and genetics with its role in ribonucleic acid (Ozanne 1980). Adequate levels of available P hasten crop maturity and cause a proliferation of plant roots, increasing the plants ability to acquire other required nutrients and water (Sweell and Ozanne 1970). Ample levels of P also increase straw strength in cereals, which improves harvest-ability, and increases the ability of legumes to fix nitrogen (Andrew and Robins 1969).

Prairie soils, like those found in Kansas, vary in soil P concentrations, and many are characteristically low in plant available P (Havlin et al. 2005). Natural grassland ecosystems evolved in the central plains that do not require large amounts of P. Many of these native prairies are still used for grazing and forage production and though testing extremely low in available P, < 3 mg kg^{-1}, little or no P fertilizer is recommended (Mengel and Martin unpublished data).

In many Kansas soils the native P supply is low enough to limit the growth of most crops, requiring the addition of P from fertilizer sources. In 2005, 48 percent of soil samples tested in Kansas showed a soil test P level below the critical level, where recommended P fertilizer rates drop to zero (Fixen 2006). Therefore, fertilizer additions of P are crucial to achieve maximum yields for Kansas producers. In 2007 Kansas consumption from all inorganic fertilizer sources exceeded 200,000 M tons of P_2O_5 (USDA-NASS 2009). With increasing crop grain yields and a new demand for crop residue by the bio-fuel industry, P fertilizer use should increase in the future.

The Kansas agriculture economy relies heavily on the production of grain and oilseed crops. The four primary crops include wheat (*Triticum aestivum* L.), corn (*Zea mays* L.), soybean (*Glycine Max* L.) and grain sorghum (*Sorghum bicolor* L.). In 2008, Kansas produced 12.4 million Mg of corn, 9.69 million Mg of wheat, 3.27 million Mg of soybean and 5.45 million Mg of grain sorghum, ranking 7th, 1st, 10^{th}, and 1st in United States production respectively (USDA-NASS 2009).

With the concentrated production of grain crops requiring large quantities of P fertilizer, fertilizer price can greatly influence profits and fertilizer management decisions. The prices of all fertilizers have been extremely volatile over the past five years. From April 2007 to April 2008, phosphate prices rose 93 percent (Huang et al. 2009). Additionally, over roughly the same time period the price of corn and wheat rose 100 percent and 83 percent respectively. These volatile fertilizer and grain prices have increased interest from producers in ways to enhance the efficiency of applied P. This chapter will discuss various topics about P fertilization including: historical P fertilizers, P reactions in soil, response of crops to P and P fertilizer efficiency and methods of for improving efficiency.

Historical Phosphorus Fertilizers and Efficiencies

Exactly when phosphorus fertilization began is not certain, however we do know that farmers have been adding manures and other organic material to land used for crop production for several thousand years. In the epic poem The Odyssey, attributed to Homer, the practice of manuring vineyards is mentioned as is the storing of manure for use on fields. Theophrastus in the 4th century B.C., recommended abundant manuring of thin soils while suggesting that rich soils be manured sparingly. Around this same time a canal system was built around Athens to transfer sewage from the city to gardens and olive groves in surrounding areas. Control structures were included to regulate flow and there is evidence that the city charged farmers for this fertilizer (Tisdale et al. 1985).

The history of P fertilizer began in 1810, when Liebig first suggested that dissolving bones in sulfuric acid made P more available to plants (Young and Davis 1980). Later in 1842 John Bennet Lawes was granted the first patent of a commercial phosphate fertilizer in England, blending sulfuric acid with pulverized rock phosphate (RP) to produce Ordinary Super Phosphate (OSP). During the second half of the 19th century, the mining of RP spread through Europe and into North America and Africa. In 1887 world production reached 1million M tons. With this expanded mining came large scale commercial production and use of OSP, the product originally invented by Lawes (Young and Davis 1980).

Fertilizer technology continued to evolve during the 20th century in the United States with the production and distribution of concentrated superphosphate (CSP) by the Tennessee Valley Authority (TVA) (Young and Davis 1980). CSP is a product of slightly diluted phosphoric acid produced by the electric furnace process and ground RP; the two are mixed in either batch or continues mixers (Bridger et al. 1945). The mixing process takes about two and one-half minuets, and is agitated until it's sufficiently dry. Commercial production of higher analysis triple super phosphate (TSP) began in the 1950s with large commercial production of wet-process phosphoric acid (Young and Davis 1980). TSP is made by acidulation of RP with wet-process phosphoric acid, with the process taking about 14 to 20 minuets. TSP became the main source of P because of its high analysis and inexpensive production and was the preferred source through the end of the 1950's.

The next evolutionary step was development of the ammoniated phosphate fertilizer. This fertilizer source became the preferred P fertilizer during the 1960's and 1970's when the TVA developed a practical and economical processes for granular diammonium phosphate (DAP) and a slightly modified procedure to produce monoammonium phosphate (MAP) (Young and Davis 1980). Diammonium phosphate is produced by feeding wet-process phosphoric acid into a preneutralizer and exposing it to anhydrous ammonia, producing a slurry with 16 to 20% water. The slurry is pumped into a rotary drum to granulate and expose to anhydrous ammonia again, the product is then dried with moderate heat and allowed to cool before being placed in storage (Young and Davis 1980). This is a gross simplification of the process and is only meant to give the reader a simple understanding. The TVA developed two comparatively minor modifications of the DAP process to allow production of MAP (Young and Hicks, 1967). These modifications adjust the ammonia/phosphate ratio in the preneutralizer or wet-process acid is added and distributed onto the granulator.

Ammonium polyphosphate (APP), another development by the TVA in the 1950s, has become an important liquid source of P for the fertilizer industry. In 1971 a simple, but very important TVA development allowed for the use of wet-process acid to produce ammonium polyphosphate liquids (Meline et al., 1972). This process, commonly known as the pipe reactor, combines superphosphoric acid with anhydrous ammonia under high pressure, creating a very rapid reaction. The resulting reaction product is then cooled (Young and Davis 1980). The liquid phosphate industry grew rapidly with this technology with about 2,800 plants producing APP in the USA by 1975. Today, fertilizer retailers can bring in these raw products via the railroad and produce APP on site.

As fertilizer technology progressed, available P content increased along with the phosphorus analysis or grade. The labeling of fertilizers is regulated by individual states and not by the federal government. The amount of P in fertilizers is expressed as percentage of P_2O_5 of the total volume. Fertilizer terminology defines available P as the sum of water-soluble and citrate-soluble P. The sum of available and citrate-insoluble P constitutes total P. Rock phosphates both early on and now generally have low amounts of available P. In fact there is no water-soluble P in most RP and the citrate solubility varies from five to 17% of total P. Higher analysis, non-ammoniated fertilizers like CSP or TSP have available P amounts of 97 to 100 percent total P with 85 and 87 percent being water-soluble P respectively. The ammoniated sources DAP, MAP and APP have P availabilities of 100 percent of total P, with greater than 95 percent being water-soluble. Studies by Seatz and Stanberry (1963), Terman (1971) and others have shown the affect of these higher analysis fertilizers on plant growth.

An evaluation by Webb et al. (1961) of different P sources for corn supported these suppositions of P availability. They found that effectiveness of P sources could be attributed to the amount of water soluble P in the fertilizer source. Additionally they hypothesized that a difference in granule size may also contribute to effectiveness, with finer particles being more efficient, presumably by greater exposed surface area.

Non-ammoniated forms of P fertilizer from modern agriculture production in the US have all but disappeared. Products like MAP are easy and less expensive to produce than superphosphates, and the high analysis allows shipping more P per unit of product. The nitrogen portion although small also adds value to the final product. Furthermore, MAP may become the predominate source of ammoniated P fertilizer domestically, because the processing does not require a high grade phosphate ore (K. Pollizato, personal communication, 2009). However in the international market and currently on US commodity exchanges, DAP serves as the standard. Today, non-ammoniated P forms are not seen in production agriculture and may be more suited for specialty markets, with RP serving the organic farming community and TSP in the turf management industry.

Phosphorus in Soil

When fertilizer P is added to the soil, like all fertilizers and soil amendments, it faces a plethora of reactions affecting its' activity and fate (Sample et al. 1980). Phosphorus is also a unique nutrient in that it is never seen in elemental form and moves very little through the soil profile, unless added to extreme excess. When applied, there are countless reactions caused by chemical (mineralogy, organic matter, pH, interactions with other nutrients), physical (texture, aeration, temperature, moisture) and biological (crop residues, soil fauna) properties of the soil. Additionally, these reactions result in numerous fates and forms of P. Barber (1995) divides phosphorus into four common categories: (i) P as ions and compounds in the soil solution, (ii) P adsorbed on the surfaces of inorganic soil constituents, (iii) P minerals, and (iv) P as a component of soil organic matter. These categories can be described as pools that are sources of

P for plant growth. A reasonable understanding of these categories and the soil factors that control the fate of P allows one to make better fertility management decisions.

Soil Solution P is the fraction that is taken up by the plant. Soil solution is defined by Cameron (1911) as the natural nutrient medium from which plants absorb mineral constituents essential for development. This fraction will be covered more in depth later in this chapter.

Adsorbed P on the surface of inorganic constituents has been referred to as fixed P or more recently has been termed as labile P in the literature. Labile P consists of solution P compounds, $H_2PO_4^-$ and HPO_4^{-2}, that have left soil solution through chemical reactions and are retained on reactive surfaces in the solid phase of soil. It is unfortunate the term fixed P has been applied to sorbed P because these reactions can be reversible, and the P can return to the soil solution to replace P that has been taken up by plants. Mineral surfaces on which P adsorption occur depend on soil pH and in some cases soil mineralogy. In acidic soils, surfaces include Aluminum (Al) and Iron (Fe) oxide and hydroxide. These minerals have a net positive charge and attract the anionic P compounds readily. These reactions have been the focus of much research. A review by Wild (1950), stated that as early as 1866 Warington found that Al and Fe hydrous oxides retained large amounts of P from solution. At that time the mechanism of retention was not well known, but current understanding is that $H_2PO_4^-$ bonded through one Al-O-P bond is considered labile P, or retained P. Labile P is easily moved back into soil solution to maintain equilibrium when solution P is removed (Barber 1995). A second bond can form making desorption back into solution much less likely. This P is considered to be nonlabile or fixed.

Phosphorus concentration in relation to the potential sites for adsorption is important in determining the strength of bonds formed and number of bonds formed. In soils with large quantities of Al and Fe capable of binding with P, the binding strength is much stronger at low P concentrations, or at low levels of P additions. However in soils with relatively low Al and Fe concentrations, or when there are large additions of P, the binding strength is much lower. This influences the P buffering capacity of soils. Old, highly weathered soils containing large quantities of Al and Fe oxides and hydroxides require several times the quantity of P added to raise the soil test level one unit compared to younger, less highly weathered soils with lower Al and Fe contents (Sanchez and Uehara 1980)

In acid soils, adsorption can occur on the broken edges of clay minerals with $H_2PO_4^-$ replacing OH^- groups (Havlin et al. 2005). This reaction occurs most frequently in weathered, fine texture soils that contain kaolinite clay minerals. Some of these reactions can be managed by maintaining soil pH in a higher range, reducing available or active Al and Fe content (pH 5.5 to 6.5). However adsorption can occur above this optimal pH range on calcareous soils. Free CaCO3 can react with P and adsorption occurs. Cole et al. (1953) and Holford et al. (1974) have demonstrated how the Langmuir equation can describe P adsorption reactions with Ca. Studies by Griffin and Jurinak (1973, 1974) looked at these interactions and concluded that two reactions occur. The first reaction occurs that at low P concentrations when surface adsorption occurs. The second reaction occurs with the formation of CaP minerals. Most researchers have had little difficulty in demonstrating separate precipitation reactions between P solutions and CaCO3, even at relatively low concentrations (Sample et al. 1980). These adsorption reactions help identify fates of fertilizer P and understanding them well can help identify management strategies to minimize them.

The third category, P minerals, includes two classifications of primary and secondary minerals (Barber 1995), although this section will focus on primary minerals. Mineral forms of P move in the P cycle via precipitation and dissolution. Primary minerals such as apatite were formed as sedimentary rocks on ancient sea beds and are present in soils as a fraction of the parent material (McClellan and Gremillion 1980). Primary mineral forms of P are not a topic of discussion in current production research and will not be covered in depth in this chapter. However the content of these minerals is soils is known to vary and have an impact on P fertilizer response.

Organic matter (OM) accounts for nearly half of the P found in the A horizon of most soils (Barber 1995). Phosphorus content of OM varies from one to three percent, but is generally thought to have a C:N:P ratio of 100:10:1. This suggests that a productive soil with 2.0 g kg^{-1} OM content would contain approximately 200 kg organic P ha^{-1} in the top 15cm of the profile (Havlin et al. 2005). This organic P pool is made up of a variety of organic P compounds including inositol phosphates, often called phytins or phytic acids, which account for 10 to 50 percent of the total organic P (Mullen 2005). Phospholipids and nucleic acids can account for one to five percent of the total organic fraction with other organic compounds present only in trace amounts. A second important fraction of the organic P pool is be soil microbial biomass. This readily available pool actively cycles P by mineralization and immobilization.

Plant Uptake and Response

As discussed earlier, P plays a vital role in plant growth and development. A plant is supplied P primarily from the soil solution via mass-flow and diffusion (Barber 1980), however mass flow supplies very little P relative to P uptake causing a concentration gradient to form. Therefore, the primary method of supplying the plant root with P for uptake is diffusion, and factors affecting diffusion affect P uptake. Factors controlling diffusion are the concentration of P in the soil solution, volumetric moisture, tortuosity, or the length of the path P ions must follow to reach the root, the soil's buffering capacity, or ability to replenish P removed from the soil solution and temperature (Barber 1980).

Diffusion occurs through soil moisture, thus diffusive flux is directly related to the fractional volumetric moisture content (Barber 1980). As soil water content increases, the diffusion path becomes more direct, decreasing tortuosity. Three factors contribute to tortuosity's affect on diffusion. The first two are thickness of water films and the fineness of soil particles. Third, bulk density affects tortuosity of the diffusion paths by creating greater continuity of potential paths at ideal densities. The P buffering capacity of a soil can have a greater influence on diffusion than water content or tortuosity, and depends on how strongly P is adsorbed. Buffering capacity decreases as adsorbed P increases, there has been extensive work in this field to understand these processes (Bhat and Nye 1974a, Adepetu 1976).

The effect of temperature on diffusion can be calculated from the Stokes-Einstein equation $D=kT/6\pi r\eta$ (Barber 1980). Calculations by Barber (1980) provide data showing that increasing temperature would increase diffusion. Changes in temperature may change the amount of P found in solution as well as the amount of P on the solid phase that will equilibrate with solution P (Barber 1980). The effect of temperature on diffusion was evaluated indirectly from data on the effect of temperature on P in solution and on isotopically exchangeable P by Sutton, (1969) who observed increasing temperature increased isotopically exchangeable and solution P.

Phosphorus uptake by plants is governed by the roots and root system. A plant's age (Jungk and Barber 1975, and Edwards and Barber 1976), age of the root (Ferguson and Clarkson

1975, and Rovira and Bowen 1968), depth of roots (Mengel and Barber 1974) and root hairs (Bhat and Nye 1974) all can affect uptake. There is so much information and research on this subject that it's impractical to cover it all. A summary understanding would be that total P uptake is governed by both the length and diameter of the root system, and the chemical and physical soil environment.

There are two forms of P that plants are able to take up, $H_2PO_4^-$ or HPO_4^{-2}. Both forms exist in the soil solution; however the presence of these species is highly dependent on soil pH. At alkaline pHs, HPO_4^{-2} is more prevalent and in neutral to acidic soils $H_2PO_4^-$ is found in greater quantities. Uptake of HPO_4^{-2} is slower; therefore a neutral to acidic soil is preferable for plant uptake of P. Plants respond favorably to zones of high P fertility with a proliferation of roots (Ozanne 1980). Interestingly, this root proliferation in zones of high fertility can reduce the total amount of roots per unit of above ground growth. This could be the result of less energy being required to acquire P. Proliferated root growth can help to explain P's effect on plant vigor, especially at early stages of growth.

Knowing how plant and soil P interact, it is helpful for monitoring this interaction through the growing season. An effective tool to measure the response of plants to P is plant sampling. Past authors have recognized the relationship between nutrient concentration in plant tissue and plant growth. In a study on P sources, Webb et al (1961) found that measurement of P concentration in corn leaves at silking time was found to be a satisfactory method of evaluating effectiveness of applied fertilizers. In fact, in some of the experiments they concluded that observed differences in leaf P was a more critical evaluation of treatment affect than grain yield. Comparing nutrient concentrations can be problematic at times. Each crop has specific needs and takes in P at different rates. Differences also exist between hybrids of crop species.

Improving P Fertilizer Efficiency

The goal of applying P or any nutrient fertilizer to a field is to reap a return on that investment. This return on investment begins when a producer develops their fertility philosophy. Throughout the Midwest, there are two such philosophies concerning P applications: Sufficiency or "feed the crop", and Build and Maintain or "feed the soil". The Kansas State University, Department of Agronomy has developed fertilizer recommendations for both approaches (Leikam et al. 2003). A common P fertility management practice is to apply P only once during a crop rotation sequence to the crop most likely to respond to the added fertility. This practice aims to increase economic returns by accomplishing increased efficiency of the fertilizer product applied. Thus far we have discussed the pieces of the P fertility puzzle; in this section we will review different approaches and methods of applications and ways to improve them.

Early work on placement identified how management choices could affect the most effective application method. Welch et al. (1966), in studying the efficiency of band versus broadcast, noted that the efficacy of the method was a result of initial soil P concentrations. Their findings indicated that band application resulted in greater yields at low soil P. However as the soil test increases, the difference between band and broadcast applications decreases. Anghinoni and Barber (1980) used simulation models for corn with two soil types demonstrated that differences in placement can be attributed to the fraction of soil that is fertilized. Their prediction equations found that for maximum P uptake, P fertilizer needs to be mixed with at least one-half the soil volume. Their model also indicated that as rate of P decreases so does the volume of soil to maintain maximum P availability. Work by Barber and Kovar (1985) expanded this model research to include 33 soils from across the US.

As seeding technology progressed, placing P at planting with the planter or drill has become a viable option. This placement method has variations often referred to as pop up or in furrow (fertilizer placed with the seed), dribble (fertilizer applied on the surface on or near the row) and 2×2 (fertilizer placed 6cm to the side of the row and 6 cm below the surface). There has been a large body of research conducted on starter placement. Mengel et al. (1988) studied the effect of starter on tillage systems and found statistical responses to “pop up.” Both liquid and granular sources of P can be used, however applying a liquid product is more common due to easier product handling.

More recently P fertilizer enhancement products have appeared. The idea of these products is to increase P availability and or uptake by preventing or reducing fixation (Engelstad and Terman 1980). Products could be placed in one of two categories, fertilizer coatings and seed inoculants, each category currently having a widely advertised product. In the past decade, a resurgence in fertilizer coating and specifically polymer coating research has occurred, although the idea of encapsulating fertilizers to control release has been present for 50 years. Oertli and Lunt (1962) studied the controlled release of a mixed N P K fertilizer. They stated that there is a distinct effect of thickness of the coating on the rate of release, with thicker coatings resulting in slower and more constant release. In additional studies they found there was a difference in release rate at different soil pH levels and soil temperatures. Much of their work reinforces the basic understanding of nutrient diffusion after they developed release curves at multiple temperatures. Dahnke et al. (1963) conducted experiments similar to Oertli and Lunt's (1962) thickness work. Dahnke et al. (1963) capsulated fertilizer and gave the capsules a specific number of pinholes for release. This work demonstrated that fewer pinholes resulted in a slower release rate, and release of P lagged considerably behind that of N and K. Dahnke et al. (1963) in the same study observed grass yield and nutrient recovery of Kentucky Bluegrass, and noted recovery of P by the grass was significantly lower when encapsulating. Work by Hall and Baker (1967) evaluated asphalt coatings on multiple P fertilizers including OSP, DAP, CaP sources and Magnesium ammonium phosphate in a growth chamber experiment. A reduction in P uptake was seen with coatings; however deficiency symptoms were never visible. In this study, the use of coatings did not contribute to more effective use of fertilizer P.

Recent work has refocused on polymer coatings in hopes of reducing fixation. A study by Malhi et al. (2002) looked at thicknesses of a polymer on MAP in greenhouse and field experiments. In greenhouse work, a response was seen with total P uptake with the addition of MAP over the control, and a thin coating and a mixed (coated and uncoated) blend improved P uptake relative to the uncoated fertilizer. These findings were supported by field trials in which five of seven locations saw a favorable response to a controlled release product relative to uncoated MAP (Malhi et al. 2002). An important point is made by the authors in that a balance needs to be meet in which a product must reduce short-term fixation, yet provide adequate release for P uptake during early growth. Work by Gordon (2005) has shown grain yield responses to a polymer coating in corn, which is currently being marketed as Avail (Specialty Fertilizer Products Leawood, KS). However, studies in North Caroline showed no yield advantage to the use of Avail with DAP as starter (Osmond et al. 2008).

A second methodology in enhancing P availability has been through biological means. Researches at the Agriculture Canada Research Station in Alberta isolated from soil a number of fungi and bacteria capable of solubilizing precipitated inorganic phosphates (Kucey 1983). Work by Asea et al. (1988) determined that *Penicillium bilaii* was able to solubilize native soil P as well as added RP. Out of this research, a commercial product was developed with *P. bilaii*, a fungus trade named PB-50 which was for in-furrow applications with canola and wheat (Gleddie et al. 1991). Later, *P. bilaii* was formulated into a dry powder inoculant and given the trade name Provide. Gleddie et al (1991) summarized that *P. bilaii* increased P availability and uptake as evidenced by positive yield responses. Work by Grant et al. (2002) concluded that *P. bilaii* appeared unable to mobilize sufficient P to enhance crop yield under the conditions of their study.

Fertilizer placement has been well researched and understood, but more recent P fertilizer enhancement products have produced mixed results.

Summary

The study of P fertility and fertilizers has advanced significantly since its inception over two centuries ago. Phosphorus fertilizers began as bones dissolved in acid and now have become global commodities. Researchers have studied in depth the numerous reactions and fates of P in soil. This research has developed a greater understanding of the P cycle in agriculture production. Producers today have the ability to acquire this vast amount of information and understand how their soils and cultural practices impact fertilizer availability and management strategies to improve efficiency. As crop yields increase and greater quantities of nutrients are removed, P specifically, continued research in this discipline will be needed to meet increasing demand.

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CHAPTER 2 - Phosphorus Fertilizer and Product Availability Enhancing Response in Corn

Abstract

The volatile price of phosphorus (P) fertilizers over the past few years has created interest among producers in ways to enhance the efficiency of applied P fertilizers. Research has long focused on increasing efficiency through various placement methods such as banding, in furrow, and with the seed. Recently, various products have been introduced and heavily marketed claiming to increase efficiency of applied P fertilizer or increase availability of native soil P. The objective of this study was to test the use of two such widely advertised products: Avail®, a long chain, organic polymer created to reduce the fixation of fertilizer P by aluminum and calcium, and JumpStart®, a seed inoculant containing a fungus (*Penicillium bailii*) which is said to increase the availability of fertilizer and native soil P to plant roots.

This study was conducted at five locations across Kansas with corn (*Zea mays* L.) during the 2008 and 2009 cropping seasons. Selected sites varied in soil test P, with a majority of the locations having a Mehlich III P test of less than 20mg kg^{-1}, where a P response is expected, and fertilizer is recommended. Treatments consisting of P rates from 0 to 20 kg P ha^{-1}, with and without the addition of Avail, were applied at planting. All but one location also contained treatments including JumpStart treated seed.

Plant samples were taken several times during the growing season to monitor treatment affects. Yield and grain properties data were collected at harvest to determine season response to treatments. Sampling data produced mixed results and did not provide strong evidence showing a consistent response to P, rate, or enhancement product. Harvest data showed excellent corn grain yields at seven of eight site years, with location averages greater than 12,500 kg ha^{-1}. One location displayed a significant response to added P in both years. There were no significant responses to enhancement products at the P responsive site. This multi-location, multi-year study failed to show a consistent response to the use of P fertilizer enhancement products.

Introduction

The volatile price of fertilizer during the last five years has created interest from producers and researches alike to revisit common P fertility questions concerning corn production. Such questions include concerns about fertilizer recommendations and the critical soil test value at which a P recommendation is made. Recommendations and critical levels vary from state to state and can be a source of pointed discussion. For Kansas State University (Leikam et al. 2003), current recommendations are given based on two basic philosophies, 'Nutrient Sufficiency' or feed the crop and 'Build and Maintain' or feed the soil. Both are based on Mehlich III or Bray P-1 soil tests with a critical P level for corn at 20 mg kg^{-1}. With both systems, soils testing below this threshold level call for a P fertilizer recommendation of a calculated amount. Soils testing from 20 to 30 mg kg-1 would lead to a recommendation only if you are following the Build and Maintain philosophy, with the recommendation being an amount equivalent to crop removal, to maintain the soil's ability to supply needed P to crops. Under the Nutrient Sufficiency system, no P fertilizer is recommended above the critical soil test level because no crop response is expected.

As a comparison, the University of Nebraska uses only the Nutrient Sufficiency system with a general cropping system critical level of 15 mg kg^{-1} for corn (Ferguson et al. 2000) citing the low probability of responses in soils testing greater than 15 mg kg^{-1}. Current Nebraska P fertilizer recommendations for corn production are calculated based on previous crop grown with continuous corn production having a critical level of 25 mg kg^{-1} and corn following soybean critical level of 17 mg kg^{-1} (Shapiro et al. 2008). Oklahoma State University (OSU) uses a P index approach, with index values ranging from 0 to 65+. An index value of 65 is the critical value for a majority of crops, including corn (Zhang et al. unknown). Recommendations from index values are based on percent sufficiency to reach maximum yield. The index value is two times the mg kg^{-1} value reported by a majority of labs. Therefore an index value of 20 (10 mg kg^{-1} P) gives a 45 percent sufficiency, meaning the soil is able to supply 45 percent of plant needed P while fertilizer must supple the remainder. Oklahoma State cites one of the benefits of building up P index values as P fertile soil increases land value (Zhang and Raun 2006).

P fertility management practices have been shown to increase P fertilizer efficiency. Practices such and banding, stripping or starter applications with or close proximity of the seed are well documented methods of increasing application year P efficiency (Welch et al. 1966, Barber and Kovar 1985, Mengel et al. 1988, Kaiser et al. 2004). However these solutions are not practical for all producers for various reasons. Deep band placement of P or any nutrient requires specific equipment that may be costly to purchase or rent and requires significant power to pull these implements. Producers, specifically those in no-tillage systems, may also find it undesirable to pull such equipment through their fields, disturbing residue cover and disrupting soil structure. Many producers do not have the ability to apply starter fertilizer, or can use only limited amounts of liquid materials, particularly on large scale planting equipment. Often broadcast fertilization becomes the preferred option. Inherent problems with broadcast applications are the low application year efficiency. Can enhancement products be a useful tool in these applications to achieve greater efficacy in the year of application? There is little published research pertaining to the use of these products in corn production, especially in no-till. Two of these products currently being advertised in publications such as the High Plains Journal and being sold in Kansas are Avail and JumpStart.

Avail is a product of Specialty Fertilizer Products (Specialty Fertilizer Products Leawood, KS) and is promoted as “a patented technology that surrounds phosphorus fertilizer in a water-soluble ‘shield;’ blocking the bonds of attraction of chemical elements in the soil to the phosphorus” (SFP 2009a). The material safety data sheet (MSDS) for Avail labels the active ingredient as maleic-itaconic copolymer that is said to sequester antagonistic metals in the soil. Use of Avail is covered in US patents 6,525,155 and 6,596,831. Information from these patents confirms that Avail is the sodium salt of long chain carbon compounds with a net negative charge.

The Avail patents cite greenhouse studies demonstrating the use of the product on P uptake by corn grown in flats (Sanders 2003a). Specialty Fertilizer Products provides additional research data on their website (SFP 2009b). Cited research includes a number of experiments conducted by researchers at Land Grant Universities. Essentially, all the cited work shows statistically greater grain yields when using avail with P fertilizers for corn.

Gordon (2005) studied the use of Avail with corn in Kansas over four years with monoammonium phosphate (MAP) at three rates of P. A summary of the results averaged over years indicated a yield response of 1130 kg ha^{-1} to Avail over the untreated MAP. Gordon also evaluated Avail in starter fertilizer applied 5 cm from the row and 5 cm below the soil surface.

The addition of Avail increased corn grain yield 817 kg ha^{-1} over untreated fertilizer (Gordon 2005). Such responses in grain yield should increase profitability.

A second enhancement product marketed to increase plant available P from fertilizer and residual soil P is JumpStart. JumpStart is a product of Novozymes Biologicals (Novozymes North America Inc. Franklinton, NC.) and is distinctly different from Avail. JumpStart is a seed inoculant with the active ingredient being the fungus *Penicillium bilaii*. According to the sales literature, JumpStart "colonizes plant roots and makes the bound mineral forms of less available soil phosphate immediately available for crop use" (Novozymes 2010a). The scientific literature has identified *P. bilaii*'s ability to solubilize precipitated inorganic phosphates (Kucey 1983). JumpStart is a product of Canada and no patent information is cited on the MSDS.

Research presented in their sales brochure (Novozymes 2010b) from on farm split-field trials from 2002-2007 in North Dakota, South Dakota, Minnesota, and Nebraska shows that JumpStart resulted in a six percent yield increase compared to non-inoculated seed. The product has been marketed as a number of formulations and product names including PB-50 and Provide, all using the same active ingredient, *P. bilaii*. Considerable research has been done with the product in Canada and Australia, but little university research is available from the Western Corn Belt region of the U.S.

The Objectives of this study are:

1. Corroborate the current Kansas State University P critical level by evaluating response to P fertilization at moderate to low soil P values
2. Test the response of corn to P fertilization with: Avail and JumpStart at different P fertilizer rates

Materials and Methods

Field trials were established in 2008 at three sites, the Agronomy North Farm in Riley County (ANF; 39°12’52’’N, 96°35’28”W), the Kansas River Valley Experiment Field in Shawnee County (KRV; 39°7’6”N, 95°55’33”W), and the North Central Agronomy Experiment Field in Republic County (NCE; 39°47’58”N, 97°50’20”). The study was replicated in 2009 at all three sites, with additional trials located at the East Central Agronomy Experiment Field in Franklin County (ECE; 38°32’33”N, 95°14’36”W) and a cooperator site in Shawnee County (HKS; 39°5’52”N, 95°49’26”W). Sites were identified based on low soil test P (Melich III <20 g kg^{-1}), where a response to P fertilizer would be expected (Leikam et al. 2003). Soils information including soil series, classification, and soil test levels for each site is given in Table 2.1.

In 2008, 14 treatments including two rates of P (9.8 kg ha^{-1} and 19.6 kg ha^{-1}), two application methods (broadcast and starter placed 5cm from the row by 5cm below the soil surface); and no product, Avail alone, JumpStart alone and Avail and JumpStart together were used. In 2009 the starter treatments were replaced with a lower rate of broadcast P (4.9 kg ha^{-1}) for logistical reasons. Treatments were replicated three or four times (depending on year and location) in a randomized complete block design.

2008

1. Control, no P
2. JumpStart, no P
3. 9.8 kg ha^{-1} P as Starter
4. 9.8 kg ha^{-1} P as Starter + JumpStart
5. 9.8 kg ha^{-1} P as Starter + Avail
6. 9.8 kg ha^{-1} P as Starter + JumpStart + Avail
7. 9.8 kg ha^{-1} P Broadcast
8. 9.8 kg ha^{-1} P Broadcast + JumpStart
9. 9.8 kg ha^{-1} P Broadcast + Avail
10. 9.8 kg ha^{-1} P Broadcast + JumpStart + Avail
11. 19.6 kg ha^{-1} P Broadcast
12. 19.6 kg ha^{-1} P Broadcast + JumpStart

13. 19.6 kg ha^{-1} P Broadcast + Avail
14. 19.6 kg ha^{-1} P Broadcast + JumpStart + Avail

2009

1. Control, no P
2. JumpStart, no P
3. 4.9 kg ha^{-1} P Broadcast
4. 4.9 kg ha^{-1} P Broadcast + JumpStart
5. 4.9 kg ha^{-1} P Broadcast + Avail
6. 4.9 kg ha^{-1} P Broadcast + JumpStart + Avail
7. 9.8 kg ha^{-1} P Broadcast
8. 9.8 kg ha^{-1} P Broadcast + JumpStart
9. 9.8 kg ha^{-1} P Broadcast + Avail
10. 9.8 kg ha^{-1} P Broadcast + JumpStart + Avail
11. 19.6 kg ha^{-1} P Broadcast
12. 19.6 kg ha^{-1} P Broadcast + JumpStart
13. 19.6 kg ha^{-1} P Broadcast + Avail
14. 19.6 kg ha^{-1} P Broadcast + JumpStart + Avail

Table 2.1 Description of soils (0-15cm) at P study sites in 2008 and 2009.

Location	Soil Series	Taxonomic Class	pH	O.M.	P	K
				g kg^{-1}	mg kg^{-1}	
ANF (2008)	Kahola silt loam	Fine-silty, mixed, superactive, mesic Cumulic Hapludolls	6.2	2.2	11.3	155
ANF (2009)	Reading silt loam	Fine-silty, mixed, superactive, mesic Pachic Argiudolls	7.7		13.0	
KRV (2008)	Eudora silt loam	Coarse-silty, mixed, superactive, mesic Fluventic Hapludolls	6.6	0.9	15.3	111
KRV (2009)			7.0		15.0	
NCE (2008)	Crete silt loam	Fine, smectitic, mesic Pachic Argiustolls	6.5	2.7	11.5	532
NCE (2009)			6.3	2.7	14.0	
ECE (2009)	Woodson silt loam	Fine, smectitic, thermic Abruptic Argiaquolls	6.0		11.0	
HKS (2009)	Rossville silt loam	Fine-silty, mixed, superactive, mesic Cumulic Hapludolls	6.9		12.5	

Common sources of P where used at all locations, including ammonium polyphosphate (APP) and monoamonium phosphate (MAP) for starter and broadcast treatments respectively. Fertilizers were purchased from local retailers, who impregnated MAP with Avail prior to purchase. Recommended concentrations of liquid Avail concentrate were added to APP fertilizer following label instructions. Broadcast P rates were balanced to a constant N rate of 13.62 kg N ha^{-1}, while starter rates were balanced at 9.08 kg N ha^{-1} with appropriate sources of N. Broadcast treatments were applied prior to planting; with the remaining recommended N applied either pre-plant or side dressed at appropriate growth stages depending on the site.

JumpStart seed treatments were applied at a rate of 57 g of product per 800,000 seeds with 2.8 L of water acting as a carrier (following label instructions). Seed was treated in a 0.099 m^3 concrete mixer, by spraying the appropriate amount of inoculant over the seed as it turned. In 2008, all locations were planted to the same commercially available hybrid, Pioneer 33M16, at seeding rates of 64 400, 79 200 and 84 200 seeds ha^{-1} for ANF, KRV and NCE respectively. In 2009, each site was planted to a different hybrid: ANF Dekalb 62-45 at 74 300 seeds ha^{-1}, KRV Dekalb 61-69 at 84 200 seeds ha^{-1}, NCE NC+ 45-82 at 84 200 seeds ha^{-1}, ECE Dekalb 50-44 at 59 400 seeds ha^{-1} and HKS Producers 7624 at 87 900 seeds ha^{-1}.

Tissue sampling and analysis

In 2008, whole plant and leaf tissue samples were taken three times during the growing season. Early season whole plant samples were taken at the at V-4 growth stage (four visible leaf collars). Fifteen randomly selected plants were cut at the soil surface and collected from the non-harvest border rows in each plot. At mid-season sampling at the R-1 growth stage (green silk), 15 randomly selected ear leaves (leaf at top ear shoot) were collected from the non-harvest boarder rows. Pre-harvest sampling at physiological maturity consisted of 10 randomly selected plants out of the non harvest rows, were cut at the soil surface, collected, ears removed, chopped, completely mixed, and quarter, with one quarter collected as a representative sample. In 2009 the pre harvest sampling was discontinued due to the high amount of labor required to sample. Early season plant samples were weighed before and after drying to determine dry biomass production as well as nutrient uptake. The 2008 pre harvest samples were treated in the same manner. All samples were dried at 60° C and ground to pass through a 0.5mm screen. Samples were analyzed for N, P and K with hydrogen peroxide and sulfuric acid by the KSU Soil Testing Lab.

Grain Yield and Analysis

Yield was determined by either hand-harvesting a 5.3 m length from the middle two rows of each plot at ANF, NCE, ECE, and HKS or machine harvesting the middle two rows for the 15.24 m length of the plot at KRV. After grain weights were recorded, a sub sample was taken to be analyzed for moisture content and test weight with a Dickey-john GAC® 2100 (Dickey-john Auburn, IL). Yields were adjusted to 155 g kg^{-1} moisture content. The sub sample was then dried, ground and analyzed for nutrient content. Grain analytical methods were identical to tissue methods given above.

Statistical Analysis

Data for plant tissue, grain, and grain properties were analyzed using the PROC MIXED procedure, with blocks as fixed random effects, in SAS (SAS, 2004). Significance of differences between treatments means were determined by pair-wise comparisons. Locations were analyzed separately and by year; treatments common between years and location where pooled together for an overall analysis and run in the same PROC MIXED procedure.

Results and Discussion

Early effects on plant growth and P uptake for 2008 and 2009 are shown in tables 2.2, 2.3, 2.4 and 2.5. In 2008 early sampling showed no effects on growth or P uptake due to P fertilization or P enhancing products at the Agronomy North Farm (Table 2.2). However P fertilization increased both the concentration in the plant and P uptake in early season samples at the North Central Experiment Field. The only effects of P products on early growth observed at the North Central Field was a significant decrease in P concentration in the plant due to the addition of the JumpStart seed treatments. There is no 2008 data for Kansas River Valley site because the samples were not dried properly before analysis.

Early season growth data from 2009 (Tables 2.3, 2.4 and 2.5) showed a significant increase in P up take due to increasing P application from low to high rates, a significant decrease in biomass with the addition of JumpStart as compared to no additives and a significant increase in plant P concentration with the addition of Avail to P fertilizer at the Agronomy North Farm. However, neither effect of additives on biomass production or P concentration resulted in an effect on P uptake per plant. At the Kansas River Valley site, P fertilizer significantly increased early-season biomass production compared to the unfertilized treatment (Table 2.3). The middle fertilizer rates increase P uptake per plant as compared to the low fertilizer rate. No effects of P product on any of the measured parameters were seen at this site.

Table 2.2 2008 early season (V-4) growth and P uptake at Agronomy North Farm and North Central Experiment Field

Trt.	P	Application	Enhancement	ANF			NCE		
num	kg ha^{-1}	Method	Product	Biomass	P conc.	P Uptake	Biomass	P conc.	P Uptake
				g	g kg^{-1}	mg plant^{-1}	g	g kg^{-1}	mg plant^{-1}
1	0		none	78.7	4.50	23.4	116.8	2.69	20.9
2	0		JumpStart	73.7	4.30	20.9	118.3	2.60	20.5
3	9.8	Starter	none	94.0	4.43	27.8	120.7	2.83	22.6
4	9.8	Starter	JumpStart	90.0	4.70	28.2	118.2	2.75	21.7
5	9.8	Starter	Avail	77.3	4.97	25.6	124.5	2.85	23.6
6	9.8	Starter	Avail+JS	78.7	5.06	26.7	119.7	2.80	22.4
7	9.8	Broadcast	none	85.7	5.02	29.1	124.0	3.11	25.8
8	9.8	Broadcast	JumpStart	79.0	5.23	27.6	121.1	2.63	21.3
9	9.8	Broadcast	Avail	84.7	4.83	27.1	115.2	2.87	22.0
10	9.8	Broadcast	Avail+JS	80.3	4.87	26.3	122.8	2.89	23.7
11	19.6	Broadcast	none	77.0	4.82	24.8	119.8	2.81	22.5
12	19.6	Broadcast	JumpStart	77.7	4.76	24.6	125.0	2.88	24.0
13	19.6	Broadcast	Avail	74.3	4.99	24.9	124.2	2.73	22.6
14	19.6	Broadcast	Avail+JS	80.3	5.21	27.9	127.4	2.85	24.2
SE				7.7	0.28	3.1	4.5	0.09	1.2
Treatment Pr > F				NS	NS	NS	NS	NS	0.050
Contrast									
Control vs. P				–	–	–	–	–	2.73 *
(1 vs. 3,7,11)									
Low vs. High P				–	–	–	–	–	(0.14)
(7,8,9,10 vs. 11,12,13,14)									
JumpStart vs. Control				–	–	–	–	–	0.47
(1 vs. 2)									
Broadcast vs. Starter				–	–	–	–	–	0.59
(7,8,9,10 vs. 3,4,5,6)									
JumpStart vs. No Product				–	–	–	–	–	(1.31)
(4,8,12, vs. 3,7,11)									
Avail vs. No Product				–	–	–	–	–	(0.87)
(5,9,13 vs. 3,7,11)									
Avail vs. JumpStart				–	–	–	–	–	0.44
(4,8,12 vs. 5,9,13)									
Combination vs. No Product				–	–	–	–	–	(0.19)
(6,10,14 vs. 3,7,11)									

* indicates significance < 0.05, ** indicates signifcance ≤ 0.01

– No contrast performed, ANOVA Pr > F non significant

Table 2.3 2009 early season (V-4) growth and P uptake at Agronomy North Farm and Kansas River Valley Experiment Field

Trt.	P	Enhancement	ANF			KRV		
num.	kg ha^{-1}	Product	Biomass	P conc.	P Uptake	Biomass	P conc.	P Uptake
			g	g kg^{-1}	mg plant^{-1}	g	g kg^{-1}	mg plant^{-1}
1	0	none	46.2	4.60	14.1	32.9	4.58	10.0
2	0	JumpStart	45.6	4.59	14.0	34.2	4.29	9.7
3	4.9	none	45.6	4.43	13.5	34.5	4.52	10.3
4	4.9	JumpStart	41.6	4.45	12.4	34.5	4.22	9.7
5	4.9	Avail	44.1	4.70	13.9	35.4	4.49	10.6
6	4.9	Avail+JS	47.4	4.54	14.4	36.2	4.63	11.1
7	9.8	none	47.8	4.28	13.6	36.0	5.00	12.0
8	9.8	JumpStart	43.9	4.79	14.0	34.7	4.92	11.4
9	9.8	Avail	44.6	4.77	14.2	35.7	4.69	11.2
10	9.8	Avail+JS	44.4	4.43	13.1	35.6	4.63	10.9
11	19.6	none	47.3	4.77	15.1	34.1	4.86	11.0
12	19.6	JumpStart	46.8	4.49	14.0	36.5	4.69	11.3
13	19.6	Avail	44.1	4.89	14.4	34.8	4.70	10.9
14	19.6	Avail+JS	45.3	4.52	13.6	34.4	4.91	11.2
SE			1.6	0.19	0.8	1.5	0.3	0.69
Treatment Pr > F			NS	NS	NS	NS	NS	NS
Contrast								
Control vs. P			–	–	–	–	–	–
(1 vs. 3,7,11)								
JumpStart vs. Control			–	–	–	–	–	–
(1 vs. 2)								
Low rate vs. High rate			–	–	–	–	–	–
(3,4,5,6 vs. 11,12,13,14)								
Low rate vs. Middle rate			–	–	–	–	–	–
(3,4,5,6 vs. 7,8,9,10)								
Middle rate vs. High rate			–	–	–	–	–	–
(7,8,9,10 vs. 11,12,13,14)								
JumpStart vs. No Product			–	–	–	–	–	–
(4,8,12, vs. 3,7,11)								
Avail vs. No Product			–	–	–	–	–	–
(5,9,13 vs. 3,7,11)								
Avail vs. JumpStart			–	–	–	–	–	–
(4,8,12 vs. 5,9,13)								
Combination vs. No Product			–	–	–	–	–	–
(6,10,14 vs. 3,7,11)								

– No contrast performed, ANOVA Pr > F non significant

Table 2.4 2009 early season (V-4) growth and P uptake at North Central Experiment Field and East Central Experiment Field

Trt.	P	Enhancement	NCE			ECE		
num.	kg ha^{-1}	Product	Biomass	P conc.	P Uptake	Biomass	P conc.	P Uptake
			g	g kg^{-1}	mg plant^{-1}	g	g kg^{-1}	mg plant^{-1}
1	0	none	39.9	3.11	8.33	45.9	4.31	13.0
2	0	JumpStart	38.2	3.22	8.19	42.6	3.87	11.0
3	4.9	none	39.8	3.21	8.52	44.8	4.33	12.9
4	4.9	JumpStart	42.1	3.45	9.71	45.9	4.31	13.2
5	4.9	Avail	40.5	3.11	8.37	46.0	4.20	13.0
6	4.9	Avail+JS	40.7	3.29	8.83	45.3	4.46	13.7
7	9.8	none	39.2	3.14	8.17	44.9	4.13	12.4
8	9.8	JumpStart	43.0	3.07	8.75	42.6	4.52	12.9
9	9.8	Avail	39.2	3.32	8.61	42.1	4.39	12.3
10	9.8	Avail+JS	38.6	3.61	9.26	49.3	4.49	14.7
11	19.6	none	40.3	3.50	9.37	45.4	4.41	13.2
12	19.6	JumpStart	39.1	3.50	9.08	42.9	4.28	12.2
13	19.6	Avail	40.6	3.18	8.57	44.6	4.27	12.6
14	19.6	Avail+JS	38.1	3.22	8.14	42.2	4.53	12.7
SE			1.6	0.21	0.55	2.8	0.31	1.16
Treatment Pr > F			NS	NS	NS	NS	NS	NS
Contrast								
Control vs. P			–	–	–	–	–	–
(1 vs. 3,7,11)								
JumpStart vs. Control			–	–	–	–	–	–
(1 vs. 2)								
Low rate vs. High rate			–	–	–	–	–	–
(3,4,5,6 vs. 11,12,13,14)								
Low rate vs. Middle rate			–	–	–	–	–	–
(3,4,5,6 vs. 7,8,9,10)								
Middle rate vs. High rate			–	–	–	–	–	–
(7,8,9,10 vs. 11,12,13,14)								
JumpStart vs. No Product			–	–	–	–	–	–
(4,8,12, vs. 3,7,11)								
Avail vs. No Product			–	–	–	–	–	–
(5,9,13 vs. 3,7,11)								
Avail vs. JumpStart			–	–	–	–	–	–
(4,8,12 vs. 5,9,13)								
Combination vs. No Product			–	–	–	–	–	–
(6,10,14 vs. 3,7,11)								
– No contrast performed, ANOVA Pr > F non significant								

Table 2.5 2009 early season (V-4) growth and P uptake at Hooks farm, Shawnee County

Trt.	P	Enhancement	HKS		
num.	kg ha^{-1}	Product	Biomass	P conc.	P Uptake
			g	g kg^{-1}	mg plant^{-1}
1	0	none	49.3	3.71	12.3
2	4.9	none	47.7	3.71	11.9
3	4.9	Avail	48.5	3.83	12.5
4	9.8	none	45.8	3.61	11.0
5	9.8	Avail	46.4	3.82	11.9
6	19.6	none	49.4	3.57	11.8
7	19.6	Avail	45.0	3.66	11.0
SE			3.89	0.16	1.30
Treatment Pr > F			NS	NS	NS
Contrast					
Control vs. P			–	–	–
(1 vs. 2,4,6)					
Low rate vs. High rate			–	–	–
(2,3 vs. 6,7)					
Low rate vs. Middle rate			–	–	–
(2,3 vs. 4,5)					
Middle rate vs. High rate			–	–	–
(4,5 vs. 6,7)					
Avail vs. No Product			–	–	–
(3,5,7 vs. 2,4,6)					
– No contrast performed, ANOVA Pr > F non significant					

There was no observed effect from the addition of P fertilizer, P rate, or the addition of enhancement products on early season growth, P concentration or P uptake at the Agronomy North Farm, Kansas River Valley Field, North Central Experiment Field, East Central Experiment Field or Hook Farm (Table 2.3, 2.4, 2.5) in2009.

The effects of P fertilization, fertilizer placement and the use of enhancement products on P concentration in the earleaf at mid-season 2008 are displayed in Table 2.6. Average tissue concentrations varied among locations with the Agronomy North Farm being the highest at 3.01 g P kg^{-1} followed by Kansas River Valley and North Central Experiment Field at 2.55 and 2.40 g P kg^{-1} respectively. There was no observed response from treatments at any of the locations in 2008, therefore no comparisons where conducted.

Table 2.6 2008 Mid-season plant sample results

Trt.	P	Application	Enhancement	ANF	NCE	KRV
num.	kg ha^{-1}	Method	Product	Ear leaf P (g kg^{-1})		
1	0		none	2.86	2.22	2.49
2	0		JumpStart	2.93	2.28	2.46
3	9.8	Starter	none	2.93	2.44	2.57
4	9.8	Starter	JumpStart	3.10	2.35	2.67
5	9.8	Starter	Avail	2.84	2.44	2.44
6	9.8	Starter	Avail+JS	3.12	2.35	2.69
7	9.8	Broadcast	none	2.88	2.42	2.34
8	9.8	Broadcast	JumpStart	2.99	2.36	2.34
9	9.8	Broadcast	Avail	3.17	2.59	2.34
10	9.8	Broadcast	Avail+JS	3.11	2.52	2.53
11	19.6	Broadcast	none	3.02	2.40	2.79
12	19.6	Broadcast	JumpStart	3.11	2.33	2.80
13	19.6	Broadcast	Avail	3.09	2.39	2.62
14	19.6	Broadcast	Avail+JS	3.05	2.55	2.64
SE				0.10	0.11	0.15
Treatment Pr > F				NS	NS	NS
Contrast						
Control vs. P				–	–	–
(1 vs. 3,7,11)						
Low vs. High P				–	–	–
(7,8,9,10 vs. 11,12,13,14)						
JumpStart vs. Control				–	–	–
(1 vs. 2)						
Broadcast vs. Starter				–	–	–
(7,8,9,10 vs. 3,4,5,6)						
JumpStart vs. No Product				–	–	–
(4,8,12, vs. 3,7,11)						
Avail vs. No Product				–	–	–
(5,9,13 vs. 3,7,11)						
Avail vs. JumpStart				–	–	–
(4,8,12 vs. 5,9,13)						
Combination vs. No Product				–	–	–
(6,10,14 vs. 3,7,11)						
– No contrast performed, ANOVA Pr > F non significant						

Table 2.7 2009 Mid-season plant sample results

Trt.	P	Enhancement	ANF	KRV	NCE	ECE	HKS
num.	kg ha^{-1}	Product	Ear leaf P (g kg^{-1})				
1	0	none	2.87	2.71	2.18	2.59	3.74
2	0	JumpStart	2.82	2.81	2.23	2.38	
3	4.9	none	2.47	2.52	2.07	2.70	3.75
4	4.9	JumpStart	2.82	2.73	2.42	2.70	
5	4.9	Avail	2.80	2.62	2.03	2.56	4.12
6	4.9	Avail+JS	2.95	2.76	2.09	2.63	
7	9.8	none	2.70	2.94	2.41	2.77	4.17
8	9.8	JumpStart	2.69	2.79	2.18	2.86	
9	9.8	Avail	2.67	2.89	2.15	2.64	4.23
10	9.8	Avail+JS	2.65	2.81	2.27	2.67	
11	19.6	none	2.97	2.64	2.32	2.63	4.11
12	19.6	JumpStart	3.36	2.93	2.50	2.76	
13	19.6	Avail	3.02	2.55	2.18	2.48	3.94
14	19.6	Avail+JS	2.77	2.55	2.47	2.61	
SE			0.18	0.12	0.16	0.15	0.14
Treatment Pr > F			NS	NS	NS	NS	NS
Contrast							
Control vs. P			–	–	–	–	–
(1 vs. 3,7,11)							
JumpStart vs. Control			–	–	–	–	NA
(1 vs. 2)							
Low rate vs. High rate			–	–	–	–	–
(3,4,5,6 vs. 11,12,13,14)							
Low rate vs. Middle rate			–	–	–	–	–
(3,4,5,6 vs. 7,8,9,10)							
Middle rate vs. High rate			–	–	–	–	–
(7,8,9,10 vs. 11,12,13,14)							
JumpStart vs. No Product			–	–	–	–	NA
(4,8,12, vs. 3,7,11)							
Avail vs. No Product			–	–	–	–	–
(5,9,13 vs. 3,7,11)							
Avail vs. JumpStart			–	–	–	–	NA
(4,8,12 vs. 5,9,13)							
Combination vs. No Product			–	–	–	–	NA
(6,10,14 vs. 3,7,11)							
– No contrast performed, ANOVA Pr > F non significant							

The effects of treatments on earleaf P in 2009 are summarized in Table 2.7. Locations ranged in P concentration with Hook Farms being the highest at 4.01 g kg^{-1} and the North Central Experiment Field being the lowest at 2.25 g kg^{-1}. This range in concentrations could be contributed to the different hybrids planted at each site. Overall, there was no response to P fertilizer or enhancement products at any location in 2009.

The results obtained from late season plant samples in 2008 are presented in Table 2.8. These samples were highly variable both within each and across location. This variability was the result of when we sampled, the later sampled locations were more mature and had dried down further. Late season samples did not indicate any effect on biomass production, P concentration or P uptake as a result of added P fertilizer, fertilizer placement or P enhancement product.

Table 2.8 Late season plant samples 2008

Trt.	P	Application	Enhancement	ANF			KRV			NCE		
num.	kg ha^{-1}	Method	Product	Biomass	P conc.	Uptake	Biomass	P conc.	Uptake	Biomass	P conc.	Uptake
				g	g kg^{-1}	mg plant^{-1}	g	g kg^{-1}	mg plant^{-1}	g	g kg^{-1}	mg plant^{-1}
1	0		none	3414	1.60	543	1766	1.03	191	3536	0.598	217
2	0		JumpStart	3394	1.46	497	1849	0.93	172	3681	0.632	237
3	9.8	Starter	none	3197	1.38	459	1349	0.93	125	3756	0.605	227
4	9.8	Starter	JumpStart	2918	1.33	389	1577	1.19	170	3553	0.654	232
5	9.8	Starter	Avail	3285	1.48	495	1606	0.92	150	3776	0.680	259
6	9.8	Starter	Avail+JS	3337	1.53	507	1814	1.10	207	3754	0.631	236
7	9.8	Broadcast	none	2760	1.41	385	1480	0.97	141	3672	0.610	226
8	9.8	Broadcast	JumpStart	3299	1.29	435	1430	1.03	144	3687	0.684	254
9	9.8	Broadcast	Avail	2902	1.68	490	1498	0.68	101	3607	0.623	226
10	9.8	Broadcast	Avail+JS	2787	1.46	400	1607	1.27	185	3837	0.690	263
11	19.6	Broadcast	none	3144	1.44	459	1778	1.05	187	3656	0.722	265
12	19.6	Broadcast	JumpStart	3321	1.47	482	1640	1.22	198	3632	0.825	305
13	19.6	Broadcast	Avail	3401	1.60	542	1763	1.09	197	3591	0.715	256
14	19.6	Broadcast	Avail+JS	3337	1.53	510	1928	1.11	218	3756	0.798	300
SE				221	0.16	63.8	218	0.21	41.3	172	0.082	35.8
Treatment Pr > F				NS	NS	NS	NS	NS	NS	NS	NS	NS
Contrast												
Control vs. P				–	–	–	–	–	–	–	–	–
(1 vs. 3,7,11)												
Low vs. High P				–	–	–	–	–	–	–	–	–
(7,8,9,10 vs. 11,12,13,14)												
JumpStart vs. Control				–	–	–	–	–	–	–	–	–
(1 vs. 2)												
Broadcast vs. Starter				–	–	–	–	–	–	–	–	–
(7,8,9,10 vs. 3,4,5,6)												
JumpStart vs. No Product				–	–	–	–	–	–	–	–	–
(4,8,12, vs. 3,7,11)												
Avail vs. No Product				–	–	–	–	–	–	–	–	–
(5,9,13 vs. 3,7,11)												
Avail vs. JumpStart				–	–	–	–	–	–	–	–	–
(4,8,12 vs. 5,9,13)												
Combination vs. No Product				–	–	–	–	–	–	–	–	–
(6,10,14 vs. 3,7,11)												

– No contrast performed, ANOVA Pr > F non significant

The effects of P fertilization and the use of P enhancement products on yield and grain properties in 2008 are presented in Tables 2.9, 2.10 and 2.11. Overall, yields were very good, with few responses to added P, P rate, placement or P enhancement products in 2008.

At the Agronomy North Farm in 2008 (Table 2.9), yields were above the 2008 east central regional dry land average of 6835 kg ha^{-1} (USDA 2009). There was no yield response to P fertilizer, P rate or P placement or P enhancement products. Looking at grain properties, there were no differences in grain P content, grain moisture at harvest and test weight across all comparisons.

At the Kansas River Valley Field, excellent yields were obtained in 2008 (Table 2.10) with the site average yielding 3200 kg ha^{-1} better than Shawnee County irrigated average (USDA 2009). However as at the Agronomy Farm location, there was no observed yield or grain property response to added P, P rate, placement or P enhancement products.

An excellent response to P fertilizer was seen at the North Central Experiment Field in 2008 for grain yield (Table 2.11). Yields were increased by 1330 kg ha^{-1} with the application of P fertilizer. However, there were no yield differences observed between P rate, placement method or enhancement products. Additionally, there was no observed effect on grain properties by P fertilizer, rate, fertilizer placement or enhancement products.

Table 2.9 Yield and grain property results from Agronomy North Farm, Riley County, 2008

Trt. num.	P kg ha^{-1}	Application Method	Enhancement Product	Yield kg ha-1	Moisture g kg-1	Test wt. kg hL-1	Grain P g kg-1
1	0		none	13000	227	65.8	3.50
2	0		JumpStart	11800	228	66.1	3.56
3	9.8	Starter	none	13000	218	67.9	3.44
4	9.8	Starter	JumpStart	13600	223	66.9	3.57
5	9.8	Starter	Avail	13500	224	66.5	3.49
6	9.8	Starter	Avail+JS	13200	220	67.5	3.49
7	9.8	Broadcast	none	11300	228	67.2	3.49
8	9.8	Broadcast	JumpStart	12500	226	67.1	3.39
9	9.8	Broadcast	Avail	13300	216	67.6	3.53
10	9.8	Broadcast	Avail+JS	13600	217	66.9	3.48
11	19.6	Broadcast	none	13200	219	67.7	3.42
12	19.6	Broadcast	JumpStart	12700	224	66.0	3.51
13	19.6	Broadcast	Avail	14200	218	66.7	3.59
14	19.6	Broadcast	Avail+JS	13300	219	66.9	3.59
SE				561	3.75	0.6	0.09
Treatment Pr > F				NS	NS	NS	NS
Contrast							
Control vs. P (1 vs. 3,7,11)				–	–	–	–
Low vs. High P (7,8,9,10 vs. 11,12,13,14)				–	–	–	–
JumpStart vs. Control (1 vs. 2)				–	–	–	–
Broadcast vs. Starter (7,8,9,10 vs. 3,4,5,6)				–	–	–	–
JumpStart vs. No Product (4,8,12, vs. 3,7,11)				–	–	–	–
Avail vs. No Product (5,9,13 vs. 3,7,11)				–	–	–	–
Avail vs. JumpStart (4,8,12 vs. 5,9,13)				–	–	–	–
Combination vs. No Product (6,10,14 vs. 3,7,11)				–	–	–	–

– No contrast performed, ANOVA Pr > F non significant

Table 2.10 Yield and grain property results from Kansas River Valley Field, Shawnee County, 2008

Trt. num.	P kg ha^{-1}	Application Method	Enhancement Product	Yield kg ha^{-1}	Moisture g kg^{-1}	Test wt. kg hL^{-1}	Grain P g kg^{-1}
1	0		none	14600	168	73.4	2.74
2	0		JumpStart	15600	169	74.0	2.90
3	9.8	Starter	none	12700	155	74.5	2.67
4	9.8	Starter	JumpStart	13300	160	73.5	2.80
5	9.8	Starter	Avail	14700	160	74.3	2.85
6	9.8	Starter	Avail+JS	14800	165	74.5	2.66
7	9.8	Broadcast	none	14000	161	72.9	2.59
8	9.8	Broadcast	JumpStart	13900	159	73.7	2.71
9	9.8	Broadcast	Avail	14200	156	74.0	2.67
10	9.8	Broadcast	Avail+JS	13900	161	73.2	2.90
11	19.6	Broadcast	none	15300	159	73.4	2.92
12	19.6	Broadcast	JumpStart	14600	162	73.6	2.87
13	19.6	Broadcast	Avail	15700	165	73.4	2.97
14	19.6	Broadcast	Avail+JS	14800	162	73.3	2.71
SE				947	4.84	0.37	0.15
Treatment Pr > F				NS	NS	NS	NS
Contrast							
Control vs. P				–	–	–	–
(1 vs. 3,7,11)							
Low vs. High P				–	–	–	–
(7,8,9,10 vs. 11,12,13,14)							
JumpStart vs. Control				–	–	–	–
(1 vs. 2)							
Broadcast vs. Starter				–	–	–	–
(7,8,9,10 vs. 3,4,5,6)							
JumpStart vs. No Product				–	–	–	–
(4,8,12, vs. 3,7,11)							
Avail vs. No Product				–	–	–	–
(5,9,13 vs. 3,7,11)							
Avail vs. JumpStart				–	–	–	–
(4,8,12 vs. 5,9,13)							
Combination vs. No Product				–	–	–	–
(6,10,14 vs. 3,7,11)							
– No contrast performed, ANOVA Pr > F non significant							

Table 2.11 Yield and grain property results from North Central Experiment Field, Republic County, 2008

Trt. num.	P kg ha^{-1}	Application Method	Enhancement Product	Yield kg ha^{-1}	Moisture g kg^{-1}	Test wt. kg hL^{-1}
1	0		none	13200	241	69.2
2	0		JumpStart	13500	234	68.6
3	9.8	Starter	none	14300	232	68.3
4	9.8	Starter	JumpStart	14000	230	67.9
5	9.8	Starter	Avail	14300	228	68.7
6	9.8	Starter	Avail+JS	14300	229	68.4
7	9.8	Broadcast	none	14500	234	68.1
8	9.8	Broadcast	JumpStart	13700	233	67.9
9	9.8	Broadcast	Avail	14900	231	68.3
10	9.8	Broadcast	Avail+JS	14000	231	68.0
11	19.6	Broadcast	none	14800	229	68.6
12	19.6	Broadcast	JumpStart	14300	234	68.4
13	19.6	Broadcast	Avail	14300	234	67.3
14	19.6	Broadcast	Avail+JS	15300	233	69.0
SE				407	3.2	0.4
Treatment Pr > F				0.0436	NS	NS
Contrast						
Control vs. P				1330**	–	–
(1 vs. 3,7,11)						
Low vs. High P				400	–	–
(7,8,9,10 vs. 11,12,13,14)						
JumpStart vs. Control				(300)	–	–
(1 vs. 2)						
Broadcast vs. Starter				50	–	–
(7,8,9,10 vs. 3,4,5,6)						
JumpStart vs. No Product				533	–	–
(4,8,12, vs. 3,7,11)						
Avail vs. No Product				33	–	–
(5,9,13 vs. 3,7,11)						
Avail vs. JumpStart				(500)	–	–
(4,8,12 vs. 5,9,13)						
Combination vs. No Product				0	–	–
(6,10,14 vs. 3,7,11)						
* indicates significance < 0.05, ** indicates signifcance ≤ 0.01						
– No contrast performed, ANOVA Pr > F non significant						

Harvest results from 2009 are presented in Table 2.12 through Table 2.16. As in 2008, the Agronomy Farm location in 2009 produced grain yields above 2008 regional dry land averages (USDA 2009) (Table 2.12) with no responses to P, P rate or P enhancement products. Looking at grain moisture at harvest, there was no response to P or P rate. However there were significant differences in grain moisture between Avail and JumpStart with JumpStart decreasing grain moisture. Using the enhancement products in combination resulted in a increase in grain moisture at harvest as compared to no product being used. There was no difference in test weight found due to P enhancement products, fertilizer P or P rates. Grain P content did show a significant increase in P concentration due to added P but no separation between rates. A positive response to Avail and a combination of products against no product was also seen in grain P concentration.

The Kansas River Valley Field location showed few differences in yield and grain properties as a result of treatment (Table 2.13). There were no effects on grain yield as a result of fertilizer P, P rate or enhancement products. For grain moisture, a significant decrease in moisture for the middle rate versus both the low and high rates of P was observed, but there is no response to added P or any enhancement product. For both test weight and grain P, there were no observed differences as a result of P, P rate or enhancement product.

The field trial located at the North Central Experiment Field in Republic County showed an excellent response to applied P fertilizer in 2009 (Table 2.14). There was a strong response to P fertilizer and significant differences between all P rates. At this location P increased the average yield by 1600 kg ha^{-1}. There was no response to either product but there was a significant negative response to the two products being used in combination. As for grain properties, there were no differences observed due to treatments in test weight. Grain P content showed the same response to P as yield with a significant increase in grain P concentration as compared to no fertilizer. Significant differences were observed between the low, medium and high rates with increasing rates resulting in increased P concentration. There was a negative response in grain P to the use of Avail in comparison to no product. Moisture content means are not displayed because the ears were artificially dried before shelling.

The East Central Experiment Field in Franklin County was the lowest yielding site in 2009 (Table 2.15) averaging 5700 kg ha^{-1}. Grain yield comparisons showed no response to P application as compared to control, P rate or enhancement products. For the grain properties, there were no significant effects of treatments on test weight or grain moisture at harvest. There was a strongly significant positive response to P fertilizer for grain P content, but no differentiation between rates. There also was a negative response to the combination of products compared to no product, but no significant responses to the individual products alone.

The final location in the 2009 trials was in central Shawnee County on the Hook Farm (Table 2.16). This site included only the three P rates with and without the use of the Avail P enhancement product on fertilizer. This location had excellent grain yields, averaging 14800 kg ha^{-1} but yield did not respond to P fertilizer, P rate, or the addition of Avail with the P fertilizer. Grain property responses also were limited, with no significant response in test weight and grain P concentrations as the result of treatment. Grain harvest was similar to that of the Republic County location in that ears were artificially dried before shelling, thus no moisture data is presented.

Table 2.12 Yield and grain property results from Agronomy North Farm, Riley County, 2009

Trt. num.	P kg ha^{-1}	Enhancement Product	Yield kg ha^{-1}	Moisture g kg^{-1}	Test wt. kg hL^{-1}	Grain P g kg^{-1}
1	0	none	14600	188	73.8	3.46
2	0	JumpStart	15000	188	73.8	3.55
3	4.9	none	14800	188	73.6	3.34
4	4.9	JumpStart	13400	180	73.4	3.21
5	4.9	Avail	14800	192	73.3	3.33
6	4.9	Avail+JS	14000	181	74.5	3.53
7	9.8	none	14400	186	73.1	3.26
8	9.8	JumpStart	15100	187	73.1	3.33
9	9.8	Avail	14300	185	73.8	3.52
10	9.8	Avail+JS	13300	183	73.5	3.32
11	19.6	none	13300	182	73.8	3.11
12	19.6	JumpStart	13500	180	74.2	3.45
13	19.6	Avail	14600	188	73.7	3.49
14	19.6	Avail+JS	13500	178	74.0	3.33
SE			592	2.82	0.38	0.10
Treatment Pr > F			NS	0.0273	NS	0.05
Contrast						
Control vs. P (1 vs. 3,7,11)			–	(2.67)	–	(0.22) *
JumpStart vs. Control (1 vs. 2)			–	0.00	–	0.09
Low rate vs. High rate (3,4,5,6 vs. 11,12,13,14)			–	(3.19)	–	(0.01)
Low rate vs. Middle rate (3,4,5,6 vs. 7,8,9,10)			–	0.00	–	0.01
Middle rate vs. High rate (7,8,9,10 vs. 11,12,13,14)			–	(3.19)	–	(0.02)
JumpStart vs. No Product (4,8,12, vs. 3,7,11)			–	2.50	–	(0.09)
Avail vs. No Product (5,9,13 vs. 3,7,11)			–	(2.92)	–	(0.21) **
Avail vs. JumpStart (4,8,12 vs. 5,9,13)			–	(5.42) *	–	(0.11)
Combination vs. No Product (6,10,14 vs. 3,7,11)			–	4.50 *	–	(0.16) *

* indicates significance < 0.05, ** indicates signifcance ≤ 0.01

– No contrast performed, ANOVA Pr > F non significant

Table 2.13 Yield and grain property results from Kansas River Valley Experiment Field, Western Shawnee County, 2009

Trt. num.	P kg ha^{-1}	Enhancement Product	Yield kg ha^{-1}	Moisture g kg^{-1}	Test wt. kg hL^{-1}	Grain P g kg^{-1}
1	0	none	15400	158	72.3	2.44
2	0	JumpStart	15500	161	72.2	2.34
3	4.9	none	15200	153	72.3	2.42
4	4.9	JumpStart	15100	153	71.8	2.40
5	4.9	Avail	15000	158	72.1	2.42
6	4.9	Avail+JS	15700	156	71.7	2.58
7	9.8	none	15700	151	72.2	2.32
8	9.8	JumpStart	15200	148	71.9	2.52
9	9.8	Avail	15500	146	71.6	2.42
10	9.8	Avail+JS	16400	154	71.9	2.59
11	19.6	none	15500	161	72.2	2.73
12	19.6	JumpStart	15000	151	71.8	2.63
13	19.6	Avail	15600	159	70.6	2.46
14	19.6	Avail+JS	15500	155	72.2	2.56
SE			376	2.9	0.5	0.11
Treatment Pr > F			NS	0.009	NS	NS
Contrast						
Control vs. P			–	(3.08)	–	–
(1 vs. 3,7,11)						
JumpStart vs. Control			–	(2.75)	–	–
(1 vs. 2)						
Low rate vs. High rate			–	1.69	–	–
(3,4,5,6 vs. 11,12,13,14)						
Low rate vs. Middle rate			–	(5.25) *	–	–
(3,4,5,6 vs. 7,8,9,10)						
Middle rate vs. High rate			–	6.92 **	–	–
(7,8,9,10 vs. 11,12,13,14)						
JumpStart vs. No Product			–	3.92	–	–
(4,8,12, vs. 3,7,11)						
Avail vs. No Product			–	0.75	–	–
(5,9,13 vs. 3,7,11)						
Avail vs. JumpStart			–	(3.17)	–	–
(4,8,12 vs. 5,9,13)						
Combination vs. No Product			–	(0.25)	–	–
(6,10,14 vs. 3,7,11)						
* indicates significance < 0.05, ** indicates signifcance ≤ 0.01						
– No contrast performed, ANOVA Pr > F non significant						

Table 2.14 Yield and grain property results from North Central Kansas Experiment Field, Republic County, 2009

Trt. num.	P kg ha^{-1}	Enhancement Product	Yield kg ha^{-1}	Test wt. kg hL^{-1}	Grain P g kg^{-1}
1	0	none	12900	75.5	1.66
2	0	JumpStart	13200	72.4	1.76
3	4.9	none	14100	71.1	1.84
4	4.9	JumpStart	14100	75.2	1.76
5	4.9	Avail	13500	75.7	1.58
6	4.9	Avail+JS	12500	76.1	1.58
7	9.8	none	14400	75.5	1.79
8	9.8	JumpStart	14700	75.7	1.86
9	9.8	Avail	14000	75.3	1.78
10	9.8	Avail+JS	13800	75.1	1.85
11	19.6	none	15000	75.1	1.99
12	19.6	JumpStart	15300	70.5	1.97
13	19.6	Avail	15100	75.3	1.87
14	19.6	Avail+JS	15400	75.4	2.04
SE			441	2.0	0.08
Treatment Pr > F			<.0001	NS	0.001
Contrast					
Control vs. P			1600 **	–	0.21 *
(1 vs. 3,7,11)					
JumpStart vs. Control			(300)	–	(0.10)
(1 vs. 2)					
Low rate vs. High rate			1650 **	–	0.28 **
(3,4,5,6 vs. 11,12,13,14)					
Low rate vs. Middle rate			675 **	–	0.13 *
(3,4,5,6 vs. 7,8,9,10)					
Middle rate vs. High rate			975 **	–	0.15 **
(7,8,9,10 vs. 11,12,13,14)					
JumpStart vs. No Product			(200)	–	0.01
(4,8,12, vs. 3,7,11)					
Avail vs. No Product			300	–	(0.13) *
(5,9,13 vs. 3,7,11)					
Avail vs. JumpStart			500	–	0.12
(4,8,12 vs. 5,9,13)					
Combination vs. No Product			(600) *	–	0.05
(6,10,14 vs. 3,7,11)					

* indicates significance < 0.05, ** indicates signifcance ≤ 0.01

– No contrast performed, ANOVA Pr > F non significant

Table 2.15 Yield and grain property results from East Central Kansas Experiment Field; Franklin County, 2009

Trt. num.	P kg ha^{-1}	Enhancement Product	Yield kg ha^{-1}	Moisture g kg^{-1}	Test wt. kg hL^{-1}	Grain P g kg^{-1}
1	0	none	5220	140	69.5	2.26
2	0	JumpStart	6370	141	68.9	2.31
3	4.9	none	4550	139	69.8	2.78
4	4.9	JumpStart	5590	140	70.1	2.68
5	4.9	Avail	5220	141	70.8	2.69
6	4.9	Avail+JS	5780	138	70.3	2.62
7	9.8	none	5980	138	71.0	2.75
8	9.8	JumpStart	5540	137	69.8	2.83
9	9.8	Avail	6410	139	69.3	2.58
10	9.8	Avail+JS	5420	139	70.0	2.60
11	19.6	none	4770	141	69.9	2.84
12	19.6	JumpStart	5810	140	69.8	2.73
13	19.6	Avail	6890	141	69.4	2.78
14	19.6	Avail+JS	6310	140	70.1	2.69
SE			605	1.74	0.56	0.09
Treatment Pr > F			NS	NS	NS	<.0001
Contrast						
Control vs. P			–	–	–	0.45 **
(1 vs. 3,7,11)						
JumpStart vs. Control			–	–	–	(0.05)
(1 vs. 2)						
Low rate vs. High rate			–	–	–	0.07
(3,4,5,6 vs. 11,12,13,14)						
Low rate vs. Middle rate			–	–	–	(0.01)
(3,4,5,6 vs. 7,8,9,10)						
Middle rate vs. High rate			–	–	–	0.07
(7,8,9,10 vs. 11,12,13,14)						
JumpStart vs. No Product			–	–	–	0.04
(4,8,12, vs. 3,7,11)						
Avail vs. No Product			–	–	–	0.11
(5,9,13 vs. 3,7,11)						
Avail vs. JumpStart			–	–	–	0.06
(4,8,12 vs. 5,9,13)						
Combination vs. No Product			–	–	–	0.15 *
(6,10,14 vs. 3,7,11)						
* indicates significance < 0.05, ** indicates signifcance ≤ 0.01						
– No contrast performed, ANOVA Pr > F non significant						

Table 2.16 Yield and grain property results from Hook's Farm, Central Shawnee County, 2009

Trt. num.	P $kg\ ha^{-1}$	Enhancement Product	Yield $kg\ ha^{-1}$	Test wt. $kg\ hL^{-1}$	Grain P $g\ kg^{-1}$
1	0	none	15600	73.6	3.03
2	4.9	none	15300	73.9	2.85
3	4.9	Avail	14800	74.5	2.82
4	9.8	none	14100	74.1	3.02
5	9.8	Avail	14000	73.9	3.08
6	19.6	none	15000	74.1	3.02
7	19.6	Avail	14900	74.4	2.95
SE			649	0.63	0.10
Treatment Pr > F			NS	NS	NS
Contrast					
Control vs. P			–	–	–
(1 vs. 2,4,6)					
Low rate vs. High rate			–	–	–
(2,3 vs. 6,7)					
Low rate vs. Middle rate			–	–	–
(2,3 vs. 4,5)					
Middle rate vs. High rate			–	–	–
(4,5 vs. 6,7)					
Avail vs. No Product			–	–	–
(3,5,7 vs. 2,4,6)					

– No contrast performed, ANOVA Pr > F non significant

Both years of this study resulted in excellent grain yields at or above 14,000 kg ha^{-1}, with the exception of Franklin County in 2009. These high yields can be attributed to the favorable weather and growing conditions during the cropping season. Rainfall in areas of the state where trials were located exceeded the 30 year (1971-2000) average during both years in Northeastern and East Central and in 2009 in North Central Kansas (Table 2.17). Adequate moisture is usually the most limiting factor for corn grown in Kansas, especially in locations without supplemental irrigation. Daily temperature also contributed to favorable conditions with average daily temperatures running approximately one to two degrees below the 30 year average (Table 2.17). During this study, cooler than normal conditions lowered evapotraspiration rates, allowing for more plant available water and ideal soil conditions for nutrient movement via diffusion. These same climatic factors could have played a role in the lack of consistent P responses during plant sampling and at harvest because nutrient recommendations are made with average growing conditions in mind.

Table 2.17 2008 and 2009 growing season weather summary (April 1st - September 1st)

Area of Kansas	Temperature			Precipitation		
	30 Year (1971-2000) Average Daily Mean (c°)	Departure from mean (c°)		30 Year (1971-2000) Average Growing season total (mm)	Departure from total (mm)	
		2008	2009		2008	2009
North East	18.9	-1.4	-1.1	656.6	10.9	157.5
North Central	18.9	-1.3	-1.2	458.5	-41.9	84.1
East Central	19.7	-1.0	-1.0	741.2	98.3	101.6

Similar treatments were combined across years and locations to determine if a consistent response to P fertilization was observed and what effect P enhancement products had on response. Grain yield response is shown in Figure 2.1. Treatments with the combination of enhancing products are not displayed in Figure 2.1.

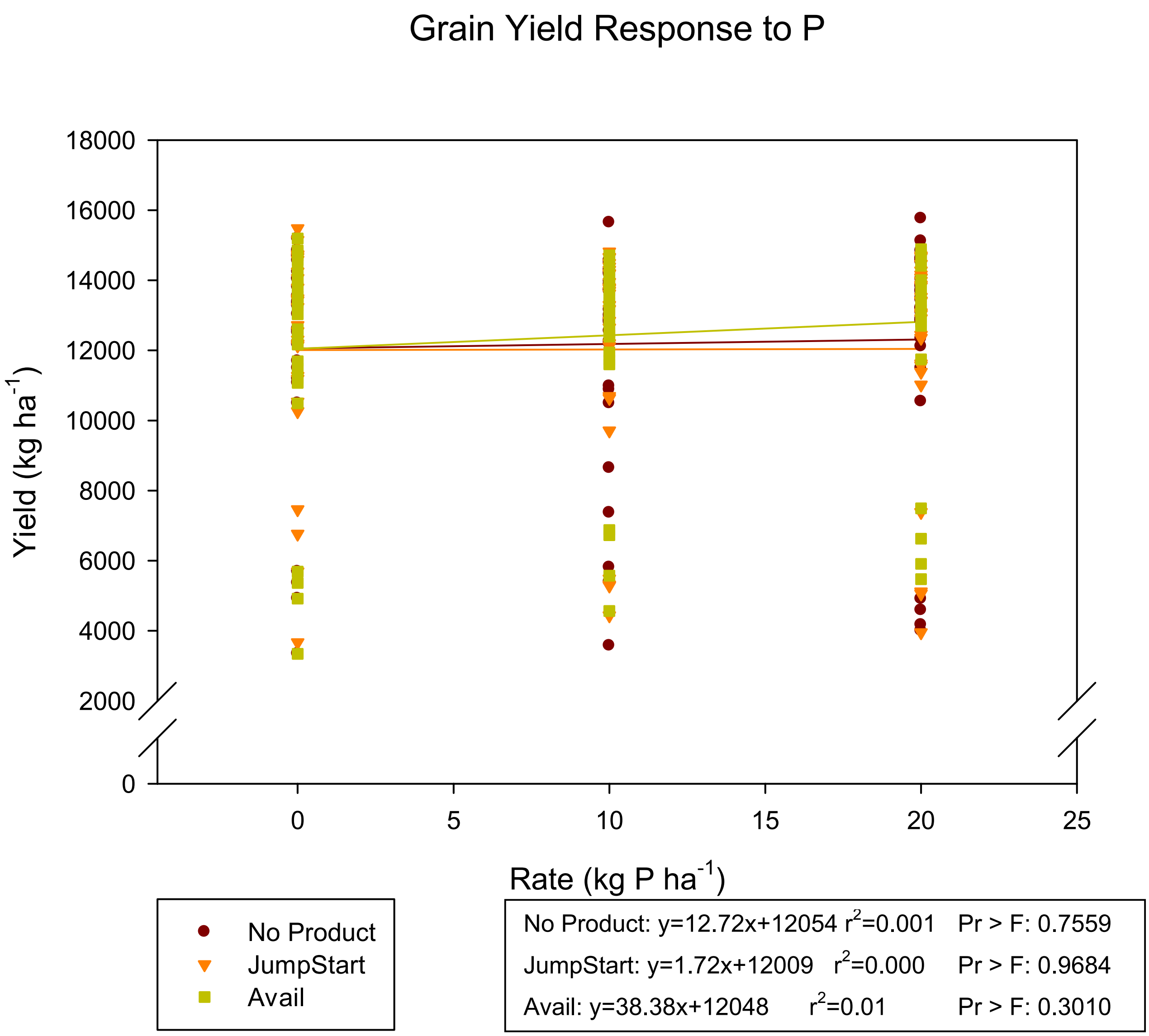

Figure 2.1 Grain yield response to P fertilization by enhancement products

Over eight site years, there was no observed response to the addition of P fertilizer. A regression model was tested for each product's effect on P response (Figure 2.1), none of the models were able to predict response. Each model's slope was non significant, indicating that the line does not differ from zero slope, there fore no response to P fertilizer.

Conclusions

Overall, responses to P were limited even though previous soil samples indicated responsive soil tests levels. During early plant sampling, results were mixed at best, with only two site years showing a response to P fertilization. Early samples often yielded mixed results when comparing products during both trial years. Also, 2008 early sampling did not detect a response from starter placement. Mid-season samples, being consistent with early season, showed few responses overall to P, rate, placement (in 2008) and product. This trend continued with only one location, North Central Experiment Field, showing a consistent response to P at harvest time. Some site years had various responses to products, but never when a P response was seen. The North Central Experiment Field was the most consistent site to show a response to P fertilization; yet never indicated responses to products. This responsiveness can be attributed to the low soil test in combination with cool early season conditions. The combined analysis data indicated no response to added P and no differences between enhancement products.

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CHAPTER 3 - Phosphorus Fertilizer and Phosphorus Availability Enhancing Product Response in Wheat

Abstract

The volatile price of phosphorus (P) fertilizers has created interest among producers in ways to enhance the efficiency of applied P fertilizers. Research has long focused on increasing the efficiency of phosphate fertilizers through the use of various placement methods such as deep banding, starter fertilizer banding and in furrow placement with the seed. Recently, various products have been introduced and heavily marketed with claims of increasing efficiency of applied P fertilizer or increasing availability of native soil P. The objective of this study was to test the use of two such widely advertised products: Avail®, a long chain, organic polymer created to reduce the fixation of fertilizer P by iron, aluminum and calcium, and JumpStart®, a seed inoculant (*Penicillium bialii*) which is said to increases the availability of fertilizer and native soil P to plant roots.

The first study was conducted at five locations across Kansas on winter wheat (*Triticum aestivum* L.) during the 2008-2009 crop season. Selected sites varied in yield potential and soil test P status, with a majority of the locations having a Mehlich III P test of less than 20 mg per kg, the established Kansas P soil test critical level, below which a P response would be expected. Treatments, consisting of P rates from 0 to 20 kg P per ha with and without the addition of Avail, were applied at planting. Two locations also contained treatments including seed treated with JumpStart. Plant samples were collected at three sites before reproductive growth to monitor treatment affects. At harvest, yield and grain property data were collected to measure treatment response.

Plant sample analysis indicated a significant increase in P concentration of 1.5 g per kg as a result of added P at two of three sampled locations; however, P enhancement products did not increase flag leaf P. Only one location showed a significant response in grain yield to applied P fertilizer. Several locations had significant grain property responses to P. No locations showed a significant grain yield increase due to the use of P enhancement products.

A second study was designed to determine the impact of JumpStart seed treatment grain yield of winter wheat. Paired lots of seed wheat, one with and one without JumpStart seed treatment were planted in 20 county wheat variety demonstration trials. A summary of yields showed a significant yield decrease of 225 kg per ha due to the JumpStart seed treatment.

Introduction

Winter wheat production is important to the Kansas economy. Nearly four million hectares of wheat were planted in 2008 (USDA 2009). As a cool season crop, winter wheat presents unique challenges to Kansas producers to provide timely planting, weed and pest control, and appropriate fertilizer management.

Phosphorus (P) plays vital roles in respiration, cell division, and photosynthesis (Ozanne 1980). Additionally, P is required for protein formation and many other plant constituents and processes (farmland unknown). Thus, a shortage of P can have adverse affects on growth, development, and reproduction that could include poor root growth, leaving the plant susceptible to drought and winter injury. Low levels of available P can reduce tillering, grain number per head, and grain fill, lowering yields (Ozanne 1980). This is especially critical for Kansas farmers as roughly half of Kansas soils are known to respond to applications of P fertilizer (Fixen et al. 2006). Wheat is known to respond well to applications of P on soils testing low or very low in available P (Whitney 1997). Current Kansas State University (KSU) soil test interpretations (Leikam et al. 2003) define low or very low P as Bray P-1 or Mehlich III P being less than 10 mg kg^{-1}. The Kansas P response data used to develop these recommendations show that the frequency of fertilizer response in the low to very low range was ≥ 60 percent, with a yield increase due to fertilization when a response was obtained of > 30 percent (Mengel 2006). As soil test values increase, the frequency of a response drops, with soils testing at or above the critical level of 20 mg kg^{-1} responding < 30 percent of the time. The magnitude of the responses obtained on soils testing in this ranges being < 10 percent.

Once a producer knows that a P application is needed, they are still left with questions about source and application methods. As a relatively immobile nutrient in soil, placement methods for P can affect response of applied fertilizer, especially at low soil test levels (Barber and Kovar 1985). Work conducted by Gordon and Mengel (2008) illustrated how P placed in the seed furrow increased grain yield over the same quantity broadcast applied. Band and seed placement of fertilizer increases efficacy by creating zones of high soil P concentration in close proximity to the plant. Since it is a general conclusion that broadcast application results in lower efficiency (Welch et al. 1966; Chaudhary and Prihar 1974); why would producers broadcast apply P? Generally that decision is based on timeliness, equipment availability and cost, and the possibility of seedling injury from furrow placed P. Producers in no-till systems may decide that broadcast applications are the best choice for reducing soil disturbance in their field. The question then becomes how to increase efficiency of broadcast P fertilizers.

Today's farmer is faced with narrow planting window for obtaining optimum yields. That window is also reduced for many wheat growers by the requirements of rotational crops such as soybean or corn. Thus the issue of timeliness plays a key role in wheat management decisions. Much of the large planting equipment available today does not have fertilizer application as an option. Thus the question becomes how to increase efficiency of broadcast P fertilizers.

Recently introduced and marketed P fertilizer enhancement products such as Avail® (Specialty Fertilizer Products Leawood, KS) and JumpStart® (Novozymes North America Inc. Franklinton, NC.) claim to alter the P interactions in the soil and enhance availability of applied fertilizer or native P. However research with these products on winter wheat, particularly from Land Grant Universities, is not readily available. Specialty Fertilizer Products, the manufacturer of Avail, has results from only eight wheat research studies for Kansas and the Northern Plains on their website (SFP 2009), with none conducted from Land Grant Universities.

Novozymes on the other hand, presents a sizable amount of information concerning JumpStart and wheat (Novozymes 2010). In a list of product demonstrations, Novozymes cites 36 on winter wheat. Averaged over these demonstrations JumpStart resulted in a 283 kg ha^{-1} increase in yield. A detailed list shows no studies conducted in Kansas. A majority of the work is from the Dakotas and Canada. An extensive review of JumpStart use in wheat reveals that *Penicilium bilaii*, the active ingredient, has been the active ingredient in a number of similar products. With a trade name of PB-50, bran inoculated with *P. bilaii* was applied in-furrow to wheat and canola. Later, successful liquid fermentation of *P. bilaii* led to the current dry powder seed inoculant formulation (Gleddie et al. 1991). This inoculant was originally given the trade name of "PROVIDE." Studies conducted by Gleddie et al. (1991) set out to determine the efficacy of PROVIDE in field trials across Western Canada. Their results showed no response to *P. bilaii* product at sites with high soil test P. But in soils with low to medium soil tests (0-10 kg ha^{-1} available P), *P. bilaii* increased yields at none or low rates of applied P fertilizer. This yield increase was not found at a rate of 30 kg ha^{-1} P. Work by Grant et al. (2002) examined effect of *P. bilaii* on grain yield, and grain P concentration in durum wheat. In 11 site years of data, seven sites responded to P fertilization and there was never a response to *P. bilaii*. *P. bilaii* had no affect on the P content of the grain.

Based on the lack of research available with the Avail product on winter wheat, and the limited response to *P. bilaii* in work from Canada, we set out to provide an evaluation of these products in Kansas wheat growers.

The objectives of this study were to:

1. Corroborate current Kansas State University P soil test interpretations and fertilizer recommendations on soils with moderate to low soil test P.
2. Test the response of winter wheat to two advertised products: Avail and JumpStart at different P fertilizer rates on soils/site likely to respond to P fertilization.

Materials and Methods

Field trials were established in fall 2008 at five sites in Kansas, the East Central Experiment Field in Franklin County (ECEF; 38°32’33”N, 95°14’36”W), the Western Agriculture Research Center in Greeley County (WARC; 38°28’03”N, 101°46’03”W), a cooperator field in Riley County (MGL; 39°25’34’’N, 96°46’6’’W), a cooperator field in McPherson County (WNR; 38°19’54”N, 97°46’49”W) and a cooperator field in Stanton County (TKR; 37°26’1’’N, 101°45’47’’W). Sites were identified based on low soil test P (Melich III < 20g kg^{-1}) where a response to P fertilizer would be expected. Soils present at sites are given in Table 3.1. It is important to note that rates applied at the MGL site are below current KSU recommendations.

Two slightly different studies were conducted. At the cooperator fields in Riley and Stanton Counties, a replicated field study consisting of 10 treatments including three rates of P (0, 9.8 and 19.6 kg P ha^{-1}) with and without the addition of Avail to the fertilizer, JumpStart to the seed, or a combination of Avail and JumpStart were used. Fertilizer treatments were broadcast prior to planting and incorporated with the drill. Specific treatments used at these two sites are as follows:

1. Control no P
2. JumpStart, no P
3. 9.8 kg ha^{-1} P, Broadcast
4. 9.8 kg ha^{-1} P, Broadcast + Avail
5. 9.8 kg ha^{-1} P, Broadcast + JumpStart
6. 9.8 kg ha^{-1} P, Broadcast + Avail + JumpStart
7. 19.6 kg ha^{-1} P, Broadcast
8. 19.6 kg ha^{-1} P, Broadcast + Avail
9. 19.6 kg ha^{-1} P, Broadcast + JumpStart
10. 19.6 kg ha^{-1} P, Broadcast + Avail + JumpStart

Table 3.1 Description of soils (0-15cm) present at study sites

Location	Soil Series	Taxonomic Class	pH	O.M.	P	K
				g kg^{-1}	mg kg^{-1}	
Franklin County	Woodson silt loam	Fine, smectitic, thermic Abruptic Argiaquolls	6.7	30	23	165
Greeley County	Ulysses silt loam	Fine-silty, mixed, superactive, mesic Aridic Haplustolls	6.4	14	63	
McPherson County	Crete silt loam	Fine, smectitic, mesic Pachic Argiustolls	4.7		19	
Riley County	Tully silty clay loam	Fine, mixed, superactive, mesic Pachic Argiustolls	5.9		6	
Stanton County	Richfield silt loam	Fine, smectitic, mesic Aridic Argiustolls	7.6		15	

At the cooperator site in McPherson County, the Western Ag Research center and the Central Kansas Experiment Field the same P rates were evaluated, but only the Avail product was tested. Specific treatments used at these locations included:

1. Control no P
2. 9.8 kg ha^{-1} P, Broadcast
3. 9.8 kg ha^{-1} P, Broadcast + Avail
4. 19.6 kg ha^{-1} P, Broadcast
5. 19.6 kg ha^{-1} P, Broadcast + Avail

At all locations, treatments were arranged in a randomized complete block design and replicated four times. Individual plot size was 3 by 15 meters.

A common source of P, monoamonium phosphate (MAP), was used at all locations. Fertilizer was purchased from local retailers, who impregnated MAP with Avail prior to purchase. All plot rates were balanced to a constant N rate at time of application, with the remaining crop N requirement being applied top dressed as urea or UAN according to the management practices at each location. JumpStart seed treatments were applied at a rate of 57g of product per 1,100 kg of seed with 7.0 L of water acting as a carrier (following label instructions). Seed treatment was applied in a 0.099 m^3 concrete mixer, with the appropriate amount of inoculant sprayed over the seed as it turned. Each location was planted to an appropriate seeding rate and variety adapted to the region: MGL Santa Fe at 112 kg ha^{-1}, WNR Fuller at 112 kg ha^{-1}, TKR Danby 67 kg ha^{-1}, WARC Hatcher, and ECE KS 2137.

Tissue Sampling and Analysis

Mid season sampling was done to monitor P uptake before reproductive growth at the Greeley, McPherson, Riley, and Stanton County sites. This sampling consisted of collecting at heading (Feekes 10.1, awns or spikelet visible) 30 flag leaves (leaf at boot) out of the non harvest areas of plot. All samples were dried at 60° C and ground to pass through a 0.5 mm screen. Samples were analyzed for N, P and K by the Kansas State University Soil Testing Lab after digestion with hydrogen peroxide sulfuric acid.

Grain Yield and Analysis

Yield was determined by machine harvesting the center 1.5 m of each plot after trimming approximately 0.5 m from each end at all locations. Grain weights were recorded, and a sub sample was taken and analyzed for moisture content, and test weight with a Dickey-john GAC® 2100 (Dickey-john Auburn, IL). Yields were adjusted to 125 g kg^{-1} moisture content. The sub sample was dried, ground, and analyzed for nutrient content. Grain analytical methods were identical to tissue methods given above.

Statistical Analysis

Data for plant tissue, grain and yield components were analyzed using the PROC MIXED procedure in SAS (SAS, 2007). Locations were analyzed separately and similar treatments pooled across locations.

JumpStart Evaluations by County Extension

In addition to the replicated field trials, non-replicated trials were conducted with the JumpStart seed treatment as part of county wheat variety demonstrations. Five kilograms of JumpStart treated and untreated Fuller seed wheat, from a common lot, was provided to 20 cooperating counties for inclusion in trials. Trials were planted and data collected by county extension agents in charge of test trials. All details of managements such as, seeding rate, fertilizer additions and pest and weed control were left to the discretion of the extension agent in charge. Agents harvested plots and provided information on yield, grain moisture content and test weight.

All data provided was pooled using locations as replications and difference were determined using contrasts in PROC Mixed procedure in SAS.

Results and Discussion

Tissue samples were taken at McPherson County, but with one representative sample taken for each treatment across the site, no statistical testing of this data is possible. This data is presented separately from the other sites, Table 3.2, and since it would not be an equal comparison to the other three sites, it was not included in the summary. Tissue samples from the McPherson County site indicate a possible response to P fertilization. Results for P uptake through mid-season as measured by tissue sample are presented in table 3.3 for the Riley and Stanton County and Western Ag Research Center sites. No tissue samples were taken at East Central Experiment Field. A significant response to P was seen at the Riley County site where rates of 9.8 and 19.6 kg P ha^{-1} than no addition, however were not statistically different between each other. At the Western Ag Center, a significant response to added P and between rates was seen. Sampling at Stanton County site indicated no response to added P and no difference between rates. This was not unexpected because soil test level of 15 mg kg^{-1} is high enough that a response to P would only be expected 50 percent of the time or less. There was no effect on P content of the flag leaf from either Avail or JumpStart enhancement products at Riley or Stanton Counties and no response to the Avail product at Western Ag Research Center.

Table 3.2 Mid-season tissue sampling results for McPherson County cooperator site

	P rate	Enhancement Product	g P kg^{-1}
1	0	none	2.25
2	9.8	none	2.61
3	9.8	Avail	2.65
4	19.6	none	2.58
5	19.6	Avail	2.86

Table 3.3 Mid-season tissue sampling results

Trt. num.	P rate	Enhancement Product	Riley	WARC	Stanton
			--- g P kg^{-1} ---		
1	0	none	1.63	2.13	2.36
2	0	JumpStart	1.73	NA	2.35
3	9.8	none	1.70	2.13	2.45
4	9.8	JumpStart	1.73	NA	2.38
5	9.8	Avail	1.86	2.34	2.41
6	9.8	Avail+JS	1.68	NA	2.26
7	19.6	none	1.87	2.43	2.08
8	19.6	JumpStart	1.73	NA	2.34
9	19.6	Avail	1.66	2.25	2.36
10	19.6	Avail+JS	1.84	NA	2.16
SE			0.05	0.01	0.14
Treatment Pr > F			0.0036	0.0058	NS
Contrast					
Control vs. P			1.55 **	1.5 *	–
(1 vs. 3,7)					
Low vs. High P			NS	1.05 *	–
(3,4,5,6 vs. 7,8,9,10)					
JumpStart vs. Control			NS	NA	–
(1 vs. 2)					
JumpStart vs. No Product			NS	NA	–
(4,8 vs. 3,7)					
Avail vs. No Product			NS	NS	–
(5,9 vs. 3,7)					
Avail vs. JumpStart			NS	NA	–
(4,8 vs. 5,9)					
Combination vs. No Product			NS	NA	–
(6,10 vs. 3,7)					
* indicates significance < 0.05, ** indicates significance ≤ 0.01					
– No contrast performed, ANOVA Pr > F non significant					

Wheat grain yield varied greatly depending on location. Harvest data, including yield and yield components for the Riley and Stanton County sites, where both Avail and JumpStart were used is given in Table 3.4. Table 3.5 presents harvest data from the remaining locations where only the Avail product was used, and grain analysis was not completed.

Table 3.4 Yield and grain property results from Riley and Stanton County cooperator fields

Trt.	P	Enhancement	Riley				Stanton			
num.	rate	Product	Yield	Test Wt.	Moisture	Grain P	Yield	Test Wt.	Moisture	Grain P
			kg ha^{-1}	kg hL^{-1}	---g kg^{-1}---		kg ha^{-1}	kg hL^{-1}	---g kg^{-1}---	
1	0	none	1140	72.9	129	4.03	2620	79.7	97.7	4.47
2	0	JumpStart	1210	71.8	135	4.15	2850	80.1	98.0	4.37
3	9.8	none	1730	76.0	123	4.14	2650	78.6	96.5	4.33
4	9.8	JumpStart	1440	74.5	123	4.13	2840	79.6	97.7	4.43
5	9.8	Avail	1950	74.8	119	4.33	2730	79.7	99.5	4.47
6	9.8	Avail+JS	1610	74.1	121	4.04	2740	80.3	98.7	4.44
7	19.6	none	2030	75.4	117	4.12	2890	78.6	96.7	4.12
8	19.6	JumpStart	2020	74.4	123	4.22	2710	80.3	99.0	4.57
9	19.6	Avail	2170	76.8	120	4.16	3120	80.8	98.5	4.12
10	19.6	Avail+JS	1960	73.7	121	4.15	2600	79.8	97.5	4.36
SE			136	0.84	3.17	0.13	149	0.75	1.55	0.2
Treatment Pr > F			<.0001	0.0047	0.0038	NS	NS	NS	NS	NS
Contrast										
Control vs. P			740 **	2.8 **	(9.0) *	–	–	–	–	–
(1 vs. 3,7)										
Low vs. High P			362.5 **	(0)	1.25	–	–	–	–	–
(3,4,5,6 vs. 7,8,9,10)										
JumpStart vs. Control			70	(1)	6	–	–	–	–	–
(1 vs. 2)										
JumpStart vs. No Product			150	1.25	(3)	–	–	–	–	–
(4,8 vs. 3,7)										
Avail vs. No Product			(180)	(0)	1	–	–	–	–	–
(5,9 vs. 3,7)										
JumpStart vs. Avail			(330) **	(1)	3.5	–	–	–	–	–
(4,8 vs. 5,9)										
Combination vs. No Product			95	1.8 *	(1)	–	–	–	–	–
(6,10 vs. 3,7)										
* indicates significance < 0.05, ** indicates signifcance ≤ 0.01										

Table 3.5 Yield and grain property results from WARC (Greeley County), ECEF (Franklin County), McPherson Cooperator (McPherson County)

Trt.	P	Enhancement	WARC			ECEF			McPherson		
num.	rate	Product	Yield	Test Wt.	Moisture	Yield	Test Wt.	Moisture	Yield	Test Wt.	Moisture
			kg ha^{-1}	kg hL^{-1}	g kg^{-1}	kg ha^{-1}	kg hL^{-1}	g kg^{-1}	kg ha^{-1}	kg hL^{-1}	g kg^{-1}
1	0	none	1770	73	87.3	4380	78.2	109	4180	79	112
2	9.8	none	1590	72.8	84.8	4510	77.6	108	4320	79	112
3	9.8	Avail	1630	73.4	88.3	4610	77.9	108	4490	78.8	111
4	19.6	none	1690	72.9	83.0	4500	77.9	109	4520	78.3	112
5	19.6	Avail	1770	73.8	85.8	4500	77.9	107	4680	78.6	112
SE			313	0.78	1.3	122	0.32	0.75	131	0.31	0.55
Treatment Pr > F			NS	NS	0.05	NS	NS	NS	NS	NS	NS
Contrast											
Control vs. P			–	–	(3.65) *	–	–	–	–	–	–
(1 vs. 2,4)											
Low vs. High P			–	–	2.4	–	–	–	–	–	–
(2,3 vs. 4,5)											
No Product vs. Avail			–	–	3.15 **	–	–	–	–	–	–
(2,4 vs. 3,5)											

* indicates significance < 0.05, ** indicates signifcance ≤ 0.01

Highest grain yields were obtained at East Central Experiment Field and the McPherson county locations with site averages of 4500 and 4380 kg ha^{-1} respectively (Table 3.5). The Western Ag Research Center (Table 3.5), Riley and Stanton County sites (Table 3.4) had lower yields of 1690, 1650 and 2790 kg ha^{-1} respectively. Yields were greater than 2008 county averages at McPherson and Stanton counties, and yield at Riley County was 38 percent lower than the 2008 county average (USDA-NASS 2009).

At McPherson County, grain yields increased 240 kg ha^{-1} with P, however no statistical differences existed between the control and P fertilization and between rates of P. No response to Avail was seen. There were no differences in moisture content at harvest time, and grain P data was not taken. At Stanton County, there was no response to P for grain yield, moisture or grain P content. There was also no observed response to either Avail or JumpStart.

The Riley County site was the most responsive site of this study, as would be expected with the very low soil test level. There was a significant increase in grain yield with the addition of P fertilizer; also there was a significant increase from the 9.8 to 19.6 kg P ha^{-1} rate. The addition of 19.8 kg P increased yield by more that 76 percent over no P added. Although there was a large response to P, there were no significant responses to the addition of Avail or JumpStart over no enhancement product. There was a difference between products, with Avail yielding better than JumpStart. Statistical responses are observed in moisture content at harvest, with the addition of P resulting in significantly lower moisture content over the check. As with yield, there were no differences in grain moisture as a result of using either product. There were no significant effects on grain P content as a result of P rate or enhancement product.

Responses at the Riley County sire were expected due to the very low (6 mg kg^{-1}) soil test P. The pictures below (Figure 3.1 and 3.2) were taken at flag leaf sampling and nicely illustrate P deficiency and response. Note the thin stand and delayed maturity of the 0 rate of P (Figure 3.1); while 19.6 kg P (Figure 3.2) has a thicker and more lush stand.

Figure 3.1 Riley County plot with 0 kg P ha^{-1} added

Figure 3.2 Riley County plot with 19.6 kg P ha^{-1} added

JumpStart Evaluations in County Wheat Variety Trials

The impact of JumpStart on wheat yields in county demonstrations is summarized in Table 3.6. Overall, JumpStart failed to enhance yields in 18 of the 20 comparisons, with a mean reduction in yield of 225 kg ha^{-1}. Using each test location as a replication, and analyzing the data in the same manner as the replicated field trials (Table 3.7), this 242 kg ha^{-1} difference was a significant reduction in yield resulting from the addition of the JumpStart seed treatment.

Why the product would reduce yields is hard to explain. One possible explanation is that the seed treating process damaged the seed in some way. However no visual differences in stand or early season growth were noted by any of the cooperators. A second possible explanation would be enhanced early growth using valuable soil moisture, producing vegetation, which created water stress conditions during grain fill. However again, no differences in early growth were noted, and yields in general were very good. So no reasons for the reduction in yield with the use of JumpStart are offered.

Table 3.6 County Comparisons of JumpStart seed treatment

County	Non-treated	JumpStart treated
	Yield kg ha^{-1}	
Sumner	2822	2620
Sumner	2956	2889
Sumner	3897	3964
Sumner	4233	4233
Mariona	3561	2889
Osborne	4905	4233
Ness	2150	2083
Rush	2889	2889
Smith	5913	5174
Cheyenne	5442	5241
Sedgwick	3964	3763
Sedgwick	4233	4233
McPherson	4300	3897
McPherson	4502	4099
McPherson	3695	4031
McPherson	4502	4703
Saline	5442	5442
Saline	6249	5711
Saline	3225	2688
Meadowlark District	4569	4166
Mean Yield	4172	3947

Table 3.7 Statistical analysis of County Comparisons

	P	Yield
	kg ha^{-1}	kg ha^{-1}
Non treated	0	4172
JumpStart treated	0	3947
SE		167
Contrast		Pr > F
Non vs. Treated		0.0039

Conclusions

The two objectives of this study were to determine if wheat responded to P in a manner that the current KSU fertilizer recommendations would predict, and to determine if the additions of the seed treatment JumpStart, or the fertilizer additive Avail would enhance P response and or yield.

The response to P at the five sites studied in the 2008-2009 crop year was limited. Significant responses to P were only obtained only at Riley County for both tissue P content and grain yield and WARC for tissue P content which had soil test levels of 6 and blank mg P kg^{-1} respectively. No response to P at the East Central Experiment Field and the cooperator sites in McPherson and Stanton Counties were seen. All three of these sites had soil test levels at or above 15 kg P ha^{-1} which decreased the probability of a response to added P. While it is difficult to answer a broad or important question as are the fertilizer recommendations correct with only data from five sites in on year, it does raise question that the current critical level could be too high. Perhaps the original critical level of 15 kg P ha^{-1} was correct. However, 2009 was an exceptional year for wheat production in many locations across Kansas, and fertilizer recommendations are generally made for less productive years, known to be more responsive, not ideal years.

No responses to JumpStart or Avail were observed at any of the locations in 2009. Based on the fact that there was no positive impact on yield, yield component or tissue P were observed, it is difficult to see how these products could provide economic returns for Kansas producers.

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CHAPTER 4 - Summary and General Conclusions

With the volatile price of P fertilizer during the past few years, Kansas producers have raised questions concerning P recommendations and P fertilizer enhancement products. The objective of these studies was to provide local research data to help producers answer these questions.

Current KSU recommendations use a critical level for soil test P of 20 mg kg^{-1} (Liekam, et al. 2004). A majority of selected study locations for the corn and wheat trials were below this critical level, but few responses to P fertilizer were observed. This lack of response can cause concern about the validity of the current recommendation. However, during the 2008 and 2009 cropping years, there was exceptional weather across the state of Kansas. Rainfall was above the 30 year averages for many areas of the state, reducing risk of drought stresses and creating an environment conducive for P uptake. With adequate soil moisture, P diffusion is seldom slowed or stopped, making a larger pool of soil P available for plant uptake. Also, cooler than normal temperatures during the summer months reduced the risk of heat stress and lowered evapo-transpiration rates, helping to conserve soil moisture.

Fertilizer recommendations are made with all growing seasons in mind, both optimum and less than optimal. It would be hasty to make changes to the current interpretations and recommendations based on two years with optimal growing conditions. However, it will be important to continue to monitor P response to see if this trend continues in years with lower than normal precipitation.

When P fertilizer prices were at their peak, producers were looking for ways to enhance the efficacy of applied P fertilizers or ways to make soil P more available to crops. The two products tested in these studies are marketed as tools to achieve these goals.

Overall, JumpStart showed no increased P response when fertilizer P was added. In corn trials, there were few observed increases in P uptake, and no increases in grain yield where this product was used. In replicated wheat trials, there were no observed increases in P uptake or grain yield. Additional strip trials showed an overall negative response to the JumpStart seed treatment.

The Avail trials resulted in few positive results with sites responding to Avail but not to P fertilizer and sites responding to P fertilizer and not to Avail. There was no grain yield response to the use of this product at the P responsive sites for corn and wheat. Overall, this product did not prove to be an effective method of increasing P uptake or yield with broadcasted MAP fertilizer. Theoretical calculations by Osmond et al. (2008) on the effect of Avail on soil CEC help explain this observed lack of response. Based on the product label, if 0.5 kg ha^{-1} of copolymer with a CEC of 250 c mol kg^{-1} is incorporated into the top 15 cm of a sandy soil with a CEC of 4 c mol kg^{-1}, only a minuscule increase in soil CEC is expected, from 4.0000 to 4.0001 c mol kg^{-1}. Expanding on those calculations, the addition of 1.0 kg of copolymer with a charge of 250 c mol kg^{-1} would add the capacity to exchange or complex 2.50 eq of Na for Ca in the immediate vicinity of the surface of applied MAP granules. Assuming an application rate of 100 kg treated fertilizer product ha^{-1}, the polymer could react with or bind approximately 50 g of Ca^{+2}, or 22.5 g of Al^{+3}, preventing reaction with the fertilizer. Considering a 100 kg application rate would have approximately 22.7 kg of P ha^{-1}, it is difficult to understand how a 1% application of copolymer impregnated on the surface of the P granules would significantly impact reactions with Ca or Al in the field.

To conclude, this research does not support the use of JumpStart or Avail for corn and winter wheat production in Kansas. Investing in more P fertilizer rather than diverting money to purchase these additives would likely prove to be a better investment over time.

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Appendix A - Corn Studies

A.1 Treatment schedule for 2008 corn studies

Treatment Number	Despcription of Treatment
1	Control, no P
2	JumpStart, no P
3	9.8 kg ha^{-1} P as Starter
4	9.8 kg ha^{-1} P as Starter + JumpStart
5	9.8 kg ha^{-1} P as Starter + Avail
6	9.8 kg ha^{-1} P as Starter + JumpStart + Avail
7	9.8 kg ha^{-1} P Broadcast
8	9.8 kg ha^{-1} P Broadcast + JumpStart
9	9.8 kg ha^{-1} P Broadcast + Avail
10	9.8 kg ha^{-1} P Broadcast + JumpStart + Avail
11	19.6 kg ha^{-1} P Broadcast
12	19.6 kg ha^{-1} P Broadcast + JumpStart
13	19.6 kg ha^{-1} P Broadcast + Avail
14	19.6 kg ha^{-1} P Broadcast + JumpStart + Avail

A.2 Agronomy North Farm 2008 corn study

Plot	Treatment	Early Season Samples		Earleaf	Late season Samples		Harvest			
		Biomass	P conc.	P conc.	Biomass	P conc.	Yield	Moisture	test wt.	P conc.
		g	%	%	g	%	kg ha	%	lb bu	%
101	1	90	0.398	0.256	3443	0.175	11289	0.236	52	0.353
102	11	66	0.457	0.282	3703	0.164	12954	0.218	52.7	0.346
103	12	80	0.479	0.296	3404	0.162	13023	0.217	52.4	0.343
104	2	88	0.405	0.283	2974	0.133	12238	0.224	52.9	0.352
105	5	62	0.479	0.287	2785	0.119	12424	0.222	52	0.358
106	10	71	0.487	0.287	2448	0.171	13125	0.214	53.3	0.347
107	6	80	0.473	0.311	3168	0.167	11829	0.217	53.5	0.358
108	13	85	0.536	0.298	3253	0.194	13175	0.211	52.9	0.369
109	9	117	0.442	0.302	3097	0.173	11702	0.222	52.7	0.349
110	14	109	0.529	0.291	3165	0.163	12155	0.226	51.9	0.352
111	3	71	0.488	0.299	3948	0.177	12285	0.221	52.9	0.379
112	4	90	0.495	0.283	2875	0.156	12224	0.215	53.5	0.360
113	8	87	0.613	0.284	3480	0.148	12305	0.223	53.3	0.333
114	7	71	0.552	0.288	2561	0.177	8719	0.226	51.7	0.358
201	12	74	0.460	0.321	2822	0.168	11116	0.234	51.1	0.366
202	6	77	0.505	0.311	3014	0.157	12836	0.222	53	0.353
203	4	64	0.481	0.322	2929	0.136	12500	0.23	51.4	0.357
204	10	95	0.437	0.326	3179	0.124	12186	0.224	51.4	0.366
205	11	99	0.458	0.318	2834	0.156	12440	0.221	53.2	0.347
206	14	95	0.500	0.311	3582	0.145	11711	0.218	52.4	0.378
207	1	63	0.471	0.293	3557	0.123	12616	0.226	50.4	0.363
208	13	82	0.471	0.325	3675	0.153	13300	0.219	51.7	0.369
209	2	77	0.479	0.295	3839	0.139	10346	0.227	50.9	0.377
210	8	78	0.456	0.317	3499	0.158	12222	0.225	53.1	0.328
211	5	88	0.516	0.251	3500	0.163	12017	0.225	52.6	0.354
212	3	92	0.385	0.294	3067	0.147	13179	0.22	53.4	0.324

213	9	74	0.481	0.317	2647	0.154	12540	0.218	52.7	0.361
214	7	78	0.509	0.283	2558	0.130	10584	0.217	53.9	0.354
301	10	73	0.535	0.321	2734	0.142	13037	0.213	52.5	0.330
302	9	90	0.527	0.333	2962	0.177	13241	0.207	53.4	0.348
303	14	75	0.533	0.314	3263	0.152	13419	0.212	52.9	0.347
304	4	74	0.434	0.327	2950	0.108	13506	0.225	52.4	0.353
305	8	82	0.499	0.295	2918	0.080	10728	0.229	51.4	0.357
306	6	92	0.541	0.314	3828	0.136	12543	0.221	52.1	0.337
307	12	74	0.488	0.316	3737	0.112	11666	0.221	51.7	0.346
308	13	67	0.488	0.304	3274	0.131	13386	0.223	52.2	0.338
309	2	92	0.404	0.301	3371	0.167	10622	0.233	51.5	0.339
310	7	61	0.443	0.293	3163	0.116	12372	0.241	52.4	0.335
311	3	70	0.458	0.286	2575	0.089	10937	0.214	53.2	0.328
312	5	91	0.497	0.313	3571	0.163	13557	0.225	51.6	0.336
313	1	76	0.481	0.308	3242	0.182	12714	0.22	52.3	0.334
314	11	74	0.531	0.304	2896	0.112	11592	0.219	53.3	0.333

A.3 Kansas River Valley Experiment Field corn studies 2008

Plot	Treatment	Early Season Samples		Earleaf	Late season Samples		Harvest			
		Biomass	P conc.	P conc.	Biomass	P conc.	Yield	Moisture	test wt.	P conc.
		g	%	%	g	%	kg ha	%	lb bu	%
101	1	–	–	0.229	1603	0.088	13657	0.167	58	0.264
102	11	–	–	0.334	1772	0.069	14673	0.155	57.2	0.313
103	12	–	–	0.261	1771	0.095	13195	0.167	58.2	0.278
104	2	–	–	0.268	2001	0.092	14372	0.169	56.9	0.302
105	5	–	–	0.268	1927	0.106	13577	0.166	58.1	0.295
106	10	–	–	0.260	1933	0.067	14690	0.164	57.1	0.273
107	6	–	–	0.235	1447	0.072	13750	0.166	58.3	0.248
108	13	–	–	0.239	1549	0.068	14840	0.161	56.5	0.275
109	9	–	–	0.210	1559	0.053	12799	0.164	57.9	0.261
110	14	–	–	0.265	1693	0.087	12586	0.164	57.3	0.244
111	3	–	–	0.274	846	0.084	9856	0.148	58.1	0.259
112	4	–	–	0.252	726	0.159	8954	0.144	57.3	0.290
113	8	–	–	0.242	810	0.127	9792	0.145	57.7	0.304
114	7	–	–	0.232	1046	0.104	11076	0.151	56.9	0.281
201	12	–	–	0.301	1583	0.098	13143	0.153	57.8	0.279
202	6	–	–	0.275	1984	0.109	13294	0.162	58.6	0.268
203	4	–	–	0.266	1883	0.088	14193	0.166	57.4	0.265
204	10	–	–	0.227	1886	0.128	13857	0.17	57.7	0.275
205	11	–	–	0.256	1835	0.164	14657	0.167	57.8	0.311
206	14	–	–	0.263	2160	0.149	14501	0.166	58	0.294
207	1	–	–	0.243	2145	0.150	13928	0.176	57	0.314
208	13	–	–	0.263	1913	0.124	14541	0.167	57.5	0.312
209	2	–	–	0.204	1851	0.079	14178	0.168	58.6	0.275
210	8	–	–	0.212	1526	0.063	14508	0.16	58.3	0.205
211	5	–	–	0.230	1437	0.069	13979	0.158	58.5	0.267

212	3	–	–	0.232	1335	0.117	12110	0.15	58.5	0.261
213	9	–	–	0.229	1383	0.083	14157	0.152	57.8	0.263
214	7	–	–	0.213	1651	0.119	14336	0.161	57.5	0.237
301	10	–	–	0.271	1003	0.185	10579	0.15	57.3	0.321
302	9	–	–	0.262	1552	0.068	13021	0.152	58.3	0.276
303	14	–	–	0.264	1931	0.097	14500	0.156	56.9	0.275
304	4	–	–	0.283	2124	0.108	14336	0.17	58	0.283
305	8	–	–	0.247	1954	0.120	14779	0.172	57.3	0.305
306	6	–	–	0.297	2013	0.149	14582	0.168	58.1	0.283
307	12	–	–	0.278	1567	0.173	14791	0.167	56.9	0.304
308	13	–	–	0.284	1826	0.136	14814	0.169	58.4	0.303
309	2	–	–	0.265	1694	0.109	15275	0.17	58.3	0.292
310	7	–	–	0.266	1864	0.079	13791	0.167	58.4	0.281
311	3	–	–	0.257	1744	0.067	13802	0.171	56.9	0.260
312	5	–	–	0.233	1453	0.101	13665	0.157	58	0.293
313	1	–	–	0.276	1550	0.071	13503	0.161	57.6	0.245
314	11	–	–	0.247	1725	0.080	13606	0.157	57.5	0.250

A.4 North Central Experiment Field corn studies 2008

Plot	Treatment	Early Season Samples		Earleaf	Late season Samples		Harvest			
		Biomass	P conc.	P conc.	Biomass	P conc.	Yield	Moisture	test wt.	P conc.
		g	%	%	g	%	kg ha	%	lb bu	%
101	1	135.2	0.265	0.224	3746	0.084	13454	0.225	54.2	–
102	11	126.2	0.288	0.254	4157	0.059	14757	0.224	53.6	–
103	12	133.4	0.291	0.238	3987	0.109	12552	0.236	53.4	–
104	2	123.7	0.247	0.235	4110	0.094	12650	0.225	54.2	–
105	5	137	0.292	0.243	4018	0.066	13556	0.228	54.6	–
106	10	115.8	0.279	0.254	4418	0.059	12584	0.228	53.8	–
107	6	125.3	0.316	0.240	4160	0.048	14140	0.224	53.8	–
108	13	123.8	0.275	0.246	3928	0.071	13265	0.233	53.8	–
109	9	129.2	0.274	0.232	3565	0.061	14833	0.236	53.1	–
110	14	135.5	0.295	0.253	4014	0.080	14221	0.228	54.7	–
111	3	132.8	0.282	0.251	3979	0.069	13061	0.227	53.8	–
112	4	119.3	0.294	0.238	3981	0.070	13763	0.225	52.5	–
113	8	125	0.286	0.246	3867	0.073	14069	0.239	52	–
114	7	127.5	0.284	0.258	3770	0.078	13976	0.233	53.3	–
201	12	120.3	0.262	0.255	3904	0.086	13534	0.235	53.4	–
202	6	125.7	0.268	0.247	4071	0.077	13809	0.231	53.4	–
203	4	116.2	0.261	0.206	3607	0.049	12925	0.229	54.4	–
204	10	132.1	0.316	0.259	3584	0.062	13466	0.236	52.6	–
205	11	118.5	0.284	0.267	3799	0.106	13994	0.232	53.2	–
206	14	128.2	0.281	0.257	3859	0.083	14177	0.244	54.1	–
207	1	108.6	0.284	0.252	4083	0.068	13145	0.237	54.4	–
208	13	135.1	0.269	0.257	3620	0.083	13281	0.235	51.5	–
209	2	119.3	0.271	0.258	3501	0.045	13903	0.237	54.3	–
210	8	122.4	0.246	0.254	3497	0.053	12756	0.233	53.5	–
211	5	116.4	0.266	0.269	3583	0.090	13780	0.224	53.6	–

212	3	124.3	0.257	0.252	4060	0.048	12808	0.236	53.1	–
213	9	114.7	0.299	0.284	3778	0.080	14045	0.232	52.8	–
214	7	129.1	0.371	0.285	3450	0.053	14428	0.236	52.8	–
301	10	127.7	0.276	0.271	3771	0.080	13335	0.223	54.4	–
302	9	108.1	0.290	0.279	3449	0.056	13627	0.221	54.5	–
303	14	124	0.271	0.262	3560	0.101	14660	0.228	53.7	–
304	4	129.9	0.267	0.250	3357	0.081	13027	0.232	53.1	–
305	8	117.7	0.262	0.233	3371	0.068	10788	0.221	53.9	–
306	6	110	0.260	0.247	3363	0.059	12401	0.233	52.9	–
307	12	127.9	0.299	0.228	3323	0.067	13944	0.232	53.9	–
308	13	126	0.295	0.228	3274	0.082	13914	0.228	52.8	–
309	2	126.7	0.251	0.236	3693	0.061	12825	0.235	53.4	–
310	7	127.1	0.281	0.225	3307	0.058	13575	0.224	53.8	–
311	3	119.8	0.295	0.231	4109	0.066	12960	0.233	53.6	–
312	5	124.4	0.281	0.232	4185	0.071	13503	0.231	53.5	–
313	1	118.1	0.255	0.218	3232	0.051	11591	0.246	53.7	–
314	11	122.3	0.271	0.236	3309	0.065	13554	0.231	53.8	–
401	1	105.4	0.273	0.195	3081	0.036	11171	0.254	54.5	–
402	2	103.6	0.271	0.184	3421	0.052	11280	0.24	52.8	–
403	11	112.3	0.282	0.202	3359	0.059	13300	0.228	54.2	–
404	6	117.6	0.276	0.204	3421	0.068	13266	0.227	54.2	–
405	7	119.7	0.293	0.196	3358	0.046	13011	0.233	53.6	–
406	12	118.2	0.298	0.209	3315	0.068	13638	0.232	53.4	–
407	8	119.1	0.260	0.210	4012	0.081	13816	0.239	53.1	–
408	10	115.7	0.285	0.225	3572	0.075	13112	0.236	52.1	–
409	4	107.5	0.280	0.244	3266	0.061	12858	0.233	52.5	–
410	5	120	0.300	0.234	3316	0.045	12908	0.23	53.5	–
411	9	108.8	0.284	0.241	3635	0.052	13281	0.235	53.3	–
412	13	112	0.251	0.224	3544	0.050	12926	0.238	52.7	–
413	14	121.7	0.293	0.245	3592	0.055	14198	0.232	53.6	–
414	3	98.4	0.312	0.248	3679	0.068	14264	0.242	53.3	–

A.5 Treatment schedule for 2009 corn studies

Treatment Number	Despcription of Treatment
1	Control, no P
2	JumpStart, no P
3	4.9 kg ha^{-1} P Broadcast
4	4.9 kg ha^{-1} P Broadcast + JumpStart
5	4.9 kg ha^{-1} P Broadcast + Avail
6	4.9 kg ha^{-1} P Broadcast + JumpStart + Avail
7	9.8 kg ha^{-1} P Broadcast
8	9.8 kg ha^{-1} P Broadcast + JumpStart
9	9.8 kg ha^{-1} P Broadcast + Avail
10	9.8 kg ha^{-1} P Broadcast + JumpStart + Avail
11	19.6 kg ha^{-1} P Broadcast
12	19.6 kg ha^{-1} P Broadcast + JumpStart
13	19.6 kg ha^{-1} P Broadcast + Avail
14	19.6 kg ha^{-1} P Broadcast + JumpStart + Avail

A.6 Agronomy North Farm corn study 2009

Plot	Treatment	Early Season Samples		Earleaf	Harvest			
		Biomass	P conc.	P conc.	Yield	Moisture	test wt.	P conc.
		g	%	%	kg ha	%	lb bu	%
101	1	50.3	0.434	0.313	12691	0.185	58.0	0.325
102	11	48.8	0.513	0.282	13198	0.187	57.9	0.297
103	12	45.6	0.428	0.303	12458	0.179	58.2	0.337
104	2	46.4	0.461	0.262	12298	0.186	57.6	0.347
105	5	44.3	0.421	0.247	14384	0.190	57.0	0.327
106	10	47.2	0.409	0.262	12853	0.185	57.5	0.324
107	6	49.5	0.456	0.244	14796	0.188	57.9	0.306
108	13	44.4	0.492	0.259	13525	0.190	57.8	0.359
109	9	49.9	0.471	0.270	13953	0.187	57.5	0.366
110	14	44.7	0.439	0.236	12729	0.186	58.1	0.340
111	3	44.6	0.443	0.231	13505	0.188	58.1	0.327
112	4	42.8	0.410	0.255	13290	0.178	58.2	0.305
113	8	45.6	0.480	0.314	13882	0.188	56.8	0.319
114	7	50.5	0.400	0.219	12304	0.182	56.4	0.310
201	12	42.1	0.450	0.309	11479	0.179	57.7	0.349
202	6	39.7	0.425	0.319	12195	0.182	58.0	0.345
203	4	37.6	0.424	0.299	12092	0.178	57.2	0.321
204	10	42.3	0.447	0.237	11111	0.174	57.5	0.305
205	11	42.4	0.459	0.352	12963	0.178	57.6	0.315
206	14	47.2	0.424	0.290	12334	0.180	57.9	0.344
207	1	44.3	0.440	0.279	14687	0.194	58.0	0.363
208	13	44.1	0.441	0.312	14850	0.188	57.5	0.322
209	2	43.3	0.427	0.239	15614	0.193	58.1	0.376
210	8	44.2	0.465	0.272	14420	0.194	57.4	0.322
211	5	44.0	0.413	0.293	13937	0.191	57.5	0.341
212	3	43.0	0.417	0.240	14188	0.192	56.8	0.324

213	9	41.8	0.462	0.198	14545	0.187	58.4	0.347
214	7	47.6	0.430	0.250	14617	0.189	57.0	0.297
301	10	42.9	0.434	0.256	11924	0.182	57.1	0.341
302	9	38.6	0.482	0.313	12629	0.182	57.8	0.349
303	14	45.3	0.466	0.282	12469	0.171	58.6	0.322
304	4	41.2	0.422	0.307	12986	0.180	58.2	0.328
305	8	40.8	0.452	0.194	14616	0.180	56.8	0.333
306	6	47.2	0.468	0.320	13296	0.181	58.0	0.345
307	12	47.6	0.471	0.356	14833	0.186	58.0	0.351
308	13	46.1	0.478	0.318	14616	0.192	57.3	0.358
309	2	43.4	0.480	0.291	14705	0.193	57.4	0.334
310	3	45.0	0.459	0.253	14757	0.196	56.8	0.363
311	7	47.1	0.387	0.269	14295	0.192	57.4	0.352
312	5	41.2	0.480	0.277	14615	0.195	57.4	0.326
313	1	45.4	0.437	0.282	14830	0.192	57.7	0.330
314	11	49.3	0.446	0.253	13015	0.185	56.9	0.313
401	1	44.8	0.528	0.273	12334	0.180	57.5	0.366
402	2	49.6	0.466	0.336	13600	0.179	57.9	0.360
403	11	48.9	0.490	0.302	10634	0.177	58.8	0.317
404	6	53.4	0.469	0.300	12330	0.173	59.5	0.415
405	7	46.3	0.497	0.343	12660	0.180	58.1	0.346
406	12	52.1	0.446	0.375	11725	0.177	58.3	0.342
407	8	45.0	0.519	0.297	13737	0.187	58.0	0.360
408	10	45.5	0.481	0.306	13972	0.189	57.9	0.356
409	4	44.8	0.523	0.267	11773	0.185	56.2	0.331
410	5	46.9	0.567	0.303	12559	0.190	57.7	0.336
411	9	48.4	0.491	0.288	12544	0.184	57.3	0.346
412	13	41.9	0.546	0.318	11845	0.180	58.1	0.356
413	14	44.0	0.479	0.299	13158	0.176	57.2	0.326
414	3	50.1	0.454	0.265	12846	0.175	58.7	0.324

A.7 Kansas River Valley Field corn study 2009

Plot	Treatment	Early Season Samples		Earleaf	Harvest			
		Biomass	P conc.	P conc.	Yield	Moisture	test wt.	P conc.
		g	%	%	kg ha	%	lb bu	%
101	1	34.7	0.396	0.248	14163	0.158	57.2	0.274
102	11	38.4	0.441	0.276	15246	0.160	57.3	0.302
103	12	39.8	0.399	0.285	14395	0.161	56.4	0.280
104	2	39.9	0.395	0.280	14848	0.160	57.1	0.240
105	5	42.4	0.416	0.258	13053	0.161	55.9	0.233
106	10	40.4	0.397	0.268	15658	0.160	56.5	0.270
107	6	39.2	0.494	0.259	15045	0.157	56.2	0.236
108	13	36.3	0.450	0.245	14744	0.153	53	0.215
109	9	37.5	0.455	0.271	14409	0.143	55.9	0.236
110	14	37.5	0.434	0.226	14499	0.153	56.3	0.234
111	3	39.3	0.413	0.273	14005	0.143	56.3	0.242
112	4	35.7	0.396	0.264	14465	0.153	56.9	0.260
113	8	39.5	0.461	0.290	14942	0.142	56.5	0.242
114	7	39.0	0.410	0.337	15782	0.149	57.4	0.226
201	12	38.6	0.428	0.326	13993	0.147	55.8	0.268
202	6	37.2	0.384	0.298	14464	0.156	57.1	0.307
203	4	34.1	0.328	0.257	14462	0.164	55.8	0.228
204	10	34.2	0.450	0.282	15113	0.159	56.2	0.272
205	11	34.5	0.524	0.265	13323	0.162	55.4	0.290
206	14	33.8	0.503	0.265	13638	0.161	56.7	0.245
207	1	32.6	0.510	0.265	14928	0.162	56.5	0.238
208	13	33.5	0.437	0.272	14797	0.162	56.3	0.231
209	2	32.0	0.443	0.282	13537	0.162	55.9	0.245
210	8	30.3	0.405	0.247	14324	0.156	56.4	0.256
211	5	33.4	0.422	0.252	14018	0.155	57	0.246
212	3	33.7	0.384	0.258	13853	0.154	56.9	0.208

213	9	34.5	0.453	0.288	14837	0.141	56.2	0.223
214	7	37.1	0.567	0.246	13826	0.144	56.6	0.242
301	10	32.9	0.457	0.322	15044	0.151	56.1	0.259
302	9	34.7	0.404	0.308	14285	0.150	55.6	0.244
303	14	34.0	0.432	0.263	13956	0.151	56.1	0.281
304	4	34.6	0.483	0.297	13841	0.156	55.9	0.223
305	8	33.3	0.542	0.293	12954	0.150	55.8	0.245
306	6	34.8	0.492	0.252	13606	0.162	55	0.241
307	12	32.6	0.531	0.257	13517	0.153	56.7	0.244
308	13	34.2	0.503	0.235	14044	0.164	54.8	0.283
309	2	31.9	0.449	0.259	14860	0.160	57.1	0.222
310	3	32.7	0.497	0.206	14065	0.155	56.2	0.253
311	7	32.3	0.472	0.321	14384	0.162	56.5	0.242
312	5	32.0	0.423	0.263	13944	0.159	56.8	0.226
313	1	32.7	0.472	0.297	13385	0.158	56.9	0.201
314	11	31.1	0.523	0.273	14732	0.158	57.7	0.255
401	1	31.4	0.455	0.273	15320	0.153	55.8	0.263
402	2	32.8	0.431	0.304	14786	0.160	56	0.228
403	11	32.5	0.457	0.243	14658	0.163	55.7	0.245
404	6	33.5	0.482	0.295	15595	0.147	56.3	0.249
405	7	35.4	0.552	0.271	14686	0.147	55.5	0.218
406	12	35.0	0.517	0.303	14100	0.143	55.9	0.259
407	8	35.8	0.558	0.284	14787	0.144	56.4	0.265
408	10	35.0	0.549	0.252	15640	0.146	56.4	0.234
409	4	33.6	0.483	0.273	13743	0.140	56.1	0.250
410	5	33.8	0.536	0.275	15124	0.155	55.9	0.264
411	9	36.1	0.565	0.288	14685	0.148	56.6	0.266
412	13	35.3	0.488	0.267	14884	0.156	57	0.254
413	14	32.4	0.594	0.267	16141	0.156	57	0.264
414	3	32.1	0.515	0.273	15001	0.159	57	0.265

A.8 North Central Experiment Field corn study 2009

Plot	Treatment	Early Season Samples		Earleaf	Harvest			
		Biomass	P conc.	P conc.	Yield	Moisture	test wt.	P conc.
		g	%	%	kg ha	%	lb bu	%
101	1	43.8	0.342	0.203	12273	0.055	58.8	0.154
102	11	39.2	0.420	0.248	14966	0.049	59	0.193
103	14	38.6	0.330	0.219	14712	0.071	60.5	0.195
104	9	42.6	0.298	0.224	13823	0.085	60.4	0.178
105	5	41.9	0.265	0.161	12811	0.088	60	0.126
106	7	42.3	0.238	0.220	13849	0.05	59.5	0.180
107	10	42.1	0.333	0.207	13066	0.052	57.4	0.182
108	3	41.4	0.309	0.124	13694	0.052	59.1	0.171
109	4	44.6	0.312	0.206	13913	0.075	59	0.179
110	8	48.1	0.288	0.222	13913	0.075	59.4	0.169
111	6	45.4	0.283	0.202	12010	0.056	59.1	0.133
112	2	40.4	0.315	0.191	11363	0.078	59.8	0.161
113	13	40.6	0.336	0.223	15013	0.048	59	0.185
114	12	42.4	0.301	0.217	14188	0.081	59.5	0.197
201	3	40.0	0.296	0.237	14096	0.087	58.9	0.189
202	9	41.3	0.307	0.217	14203	0.064	59.4	0.186
203	12	37.9	0.303	0.258	14588	0.094	59.3	0.195
204	2	37.0	0.303	0.175	12411	0.054	59.3	0.154
205	11	39.7	0.305	0.191	13831	0.064	60.7	0.207
206	5	43.2	0.309	0.179	13806	0.074	59.2	0.178
207	14	36.4	0.295	0.230	15041	0.062	59	0.199
208	13	37.2	0.331	0.220	14918	0.046	57.8	0.197
209	1	36.8	0.262	0.258	13663	0.067	59.8	0.171
210	8	40.3	0.318	0.202	14307	0.053	58	0.207
211	6	43.1	0.318	0.227	12078	0.084	59	0.169
212	7	38.5	0.288	0.269	14092	0.059	57.9	0.174

213	4	39.2	0.314	0.292	14352	0.05	58.6	0.187
214	10	37.3	0.372	0.297	13808	0.082	60.3	0.196
301	1	40.4	0.327	0.212	11794	0.073	59.2	0.193
302	5	36.3	0.329	0.229	12308	0.085	58.5	0.158
303	2	32.6	0.327	0.274	13352	0.054	59.5	0.197
304	8	36.3	0.320	0.228	13292	0.067	59.4	0.190
305	7	36.7	0.324	0.266	13268	0.051	58.8	0.187
306	11	40.0	0.327	0.249	13942	0.069	59.6	0.189
307	14	35.9	0.377	0.269	14449	0.076	59.3	0.198
308	12	39.4	0.386	0.261	14279	0.059	59.9	0.188
309	4	39.1	0.361	0.229	12143	0.065	58.3	0.182
310	13	41.0	0.325	0.220	13668	0.075	58.6	0.170
311	3	37.4	0.322	0.243	12855	0.049	58.3	0.174
312	6	36.1	0.332	0.182	11066	0.067	59	0.175
313	10	36.7	0.335	0.208	11867	0.109	58.7	0.162
314	9	35.8	0.330	0.200	12495	0.089	59.5	0.182
401	1	38.7	0.313	0.198	10583	0.066	59.5	0.146
402	13	43.4	0.280	0.208	12811	0.088	57.9	0.197
403	6	38.0	0.381	0.224	11784	0.088	58.4	0.155
404	9	36.9	0.393	0.220	12048	0.077	58.6	0.164
405	5	40.6	0.341	0.242	11783	0.069	58.8	0.171
406	4	45.5	0.394	0.241	12258	0.102	59	0.155
407	14	41.5	0.285	0.271	13536	0.088	59.4	0.224
408	7	39.4	0.407	0.210	12913	0.054	59.4	0.174
409	10	38.2	0.402	0.194	12842	0.111	58.3	0.201
410	11	42.2	0.346	0.241	13324	0.086	59.9	0.206
411	8	47.3	0.301	0.218	13408	0.076	58.2	0.177
412	2	42.6	0.342	0.251	12293	0.063	58.2	0.190
413	3	40.3	0.359	0.224	12247	0.057	59.2	0.203
414	12	36.8	0.410	0.265	14199	0.056	60.2	0.207

A.9 East Central Experiment Field corn study 2009

Plot	Treatment	Early Season Samples		Earleaf	Harvest			
		Biomass	P conc.	P conc.	Yield	Moisture	test wt.	P conc.
		g	%	%	kg ha	%	lb bu	%
101	1	40.9	0.515	0.276	4963	0.139	55.2	0.216
102	11	38.0	0.514	0.266	4952	0.141	54.3	0.265
103	12	42.9	0.508	0.259	3989	0.14	54.9	0.274
104	2	46.6	0.472	0.277	7531	0.139	54.1	0.208
105	5	49.7	0.522	0.279	6685	0.145	56.1	0.282
106	10	53.7	0.511	0.299	6219	0.139	55.4	0.287
107	6	50.8	0.581	0.286	5445	0.135	55.4	0.276
108	13	34.7	0.499	0.258	7561	0.142	53.4	0.284
109	9	41.1	0.548	0.244	6789	0.139	54.9	0.227
110	14	40.0	0.479	0.235	5420	0.139	55.6	0.253
111	3	44.9	0.468	0.265	4855	0.138	53.3	0.285
112	4	46.9	0.460	0.280	4872	0.135	54.4	0.232
113	8	46.8	0.496	0.307	5330	0.135	53.6	0.268
114	7	50.5	0.454	0.289	7434	0.137	54.2	0.270
201	12	39.3	0.422	0.257	7448	0.142	55.6	0.251
202	6	39.0	0.381	0.288	5009	0.141	56	0.244
203	4	42.2	0.461	0.262	5003	0.142	55.4	0.276
204	10	37.6	0.516	0.268	3045	0.133	54.7	0.249
205	11	46.2	0.413	0.283	4207	0.142	54.4	0.296
206	14	40.6	0.452	0.267	4872	0.135	54	0.266
207	1	45.4	0.425	0.283	3374	0.137	54.4	0.223
208	13	43.4	0.374	0.208	5961	0.135	53.6	0.270
209	2	38.1	0.412	0.185	6822	0.142	54.3	0.239
210	8	38.0	0.432	0.254	5363	0.139	55.4	0.283
211	5	37.3	0.372	0.216	3941	0.138	55	0.274
212	3	42.5	0.396	0.262	5273	0.135	54.1	0.276

213	9	41.1	0.424	0.270	4607	0.131	54.2	0.264
214	7	40.6	0.409	0.252	5863	0.141	55.2	0.275
301	10	42.1	0.371	0.258	5420	0.139	53.8	0.256
302	9	40.6	0.366	0.275	5622	0.143	53.9	0.265
303	14	39.6	0.434	0.248	5451	0.143	55.6	0.291
304	4	42.7	0.420	0.321	5249	0.139	55	0.293
305	8	42.6	0.408	0.297	4476	0.134	54.5	0.297
306	6	40.8	0.405	0.277	5032	0.137	53	0.270
307	12	45.1	0.380	0.279	5164	0.134	53.3	0.313
308	13	49.4	0.388	0.256	5521	0.141	54.5	0.296
309	2	42.6	0.339	0.264	3704	0.14	54.1	0.259
310	3	47.1	0.444	0.268	3176	0.144	55.5	0.278
311	7	41.7	0.392	0.267	5439	0.136	56.9	0.278
312	5	46.1	0.436	0.300	3651	0.139	56.1	0.261
313	1	41.7	0.448	0.277	5414	0.14	55.1	0.236
314	11	47.1	0.484	0.272	4627	0.138	55	0.300
401	1	55.7	0.336	0.200	5742	0.142	53	0.229
402	2	43.4	0.324	0.226	5742	0.142	53.3	0.219
403	11	50.5	0.351	0.229	4037	0.142	55.1	0.273
404	6	50.8	0.416	0.201	6097	0.14	55.6	0.260
405	7	46.8	0.397	0.299	3607	0.136	56	0.278
406	12	44.5	0.401	0.310	5105	0.144	54.8	0.255
407	8	43.1	0.472	0.287	5534	0.139	55	0.281
408	10	64.0	0.399	0.241	5565	0.143	55.2	0.247
409	4	52.1	0.384	0.217	5779	0.145	54.8	0.273
410	5	50.9	0.351	0.230	5230	0.142	54.4	0.259
411	9	45.9	0.419	0.264	6936	0.142	54	0.275
412	13	50.9	0.447	0.270	6685	0.145	55.8	0.264
413	14	48.6	0.444	0.292	7846	0.142	54.2	0.266
414	3	44.8	0.423	0.285	3704	0.14	55.6	0.274

A.10 Hook Farm corn study 2009

Plot	Treatment	Early Season Samples		Earleaf	Harvest			
		Biomass	P conc.	P conc.	Yield	Moisture	test wt.	P conc.
		g	%	%	kg ha	%	lb bu	%
101	1	46.6	0.333	0.359	14367	–	57.3	0.315
102	3	56.9	0.369	0.371	16211	–	57.9	0.273
103	5	60.1	0.403	0.393	14103	–	58.8	0.298
104	7	48.9	0.387	0.446	13997	–	57.2	0.304
105	9	51.3	0.431	0.442	13978	–	57.6	0.294
106	11	49.1	0.353	0.415	12216	–	56	0.332
107	13	32.6	0.357	0.412	14818	–	57.6	0.305
201	1	45.2	0.358	0.402	14825	–	56.7	0.298
202	3	48.2	0.385	0.400	15232	–	57.9	0.266
203	5	42.6	0.381	0.460	14887	–	58	0.296
204	7	43.4	0.329	0.397	10974	–	59.7	0.320
205	9	53.1	0.384	0.435	13326	–	58	0.325
206	11	44.6	0.344	0.398	14154	–	59.1	0.321
207	13	47.4	0.388	0.406	13890	–	58.9	0.304
301	1	56.4	0.395	0.358	14981	–	58.2	0.295
302	3	34.3	0.329	0.382	12197	–	58.3	0.293
303	5	39.4	0.316	0.435	13069	–	57.7	0.242
304	7	53.6	0.363	0.431	14693	–	57.6	0.291
305	9	47.6	0.343	0.393	13483	–	58.7	0.292
306	11	50.1	0.341	0.434	15897	–	56.8	0.285
307	13	46.9	0.343	0.345	14129	–	57.1	0.269
401	1	49.1	0.398	0.377	14154	–	57	0.301
402	3	51.5	0.402	0.346	13552	–	57.5	0.307
403	5	51.8	0.432	0.361	13326	–	59.3	0.293
404	7	37.3	0.365	0.395	13113	–	58.7	0.291

405	9	33.6	0.369	0.422	11827	–	57.6	0.323
406	11	53.7	0.388	0.398	13790	–	58.8	0.272
407	13	53.2	0.376	0.412	13044	–	59.3	0.303

Appendix B - Winter Wheat Studies

B.1 Treatment schedule for winter wheat study in Riley and Stanton Counties

Treatment Number	Despcription of Treatment
1	Control no P
2	JumpStart, no P
3	9.8 kg ha-1 P, Broadcast
4	9.8 kg ha-1 P, Broadcast + Avail
5	9.8 kg ha-1 P, Broadcast + JumpStart
6	9.8 kg ha-1 P, Broadcast + Avail + JumpStart
7	19.6 kg ha-1 P, Broadcast
8	19.6 kg ha-1 P, Broadcast + Avail
9	19.6 kg ha-1 P, Broadcast + JumpStart
10	19.6 kg ha-1 P, Broadcast + Avail + JumpStart

B.2 Riley County winter wheat 2008-2009

Plot	Treatment Number	Flag leaf P	Grain Moisture	Test Wieght	Grain Yield	Grain P
		% P	g kg	kg hL	kg ha	% p
101	5	0.199	125	74.5	2068.3	0.432
102	8	0.186	126	74.1	2514.2	0.426
103	2	0.195	155	69.3	1149.4	0.444
104	7	0.192	127	75.3	2044.1	0.403
105	10	0.182	123	75.7	2092.6	0.408
106	9	0.176	120	77.7	2295.9	0.382
107	1	0.161	131	73.0	1027.0	0.411
108	3	0.173	124	75.8	1621.3	0.387
109	6	0.182	122	74.2	1625.0	0.394
110	4	0.169	120	77.0	1825.0	0.410
201	1	0.163	132	71.6	1025.9	0.384
202	4	0.168	122	75.9	1683.8	0.409
203	10	0.179	117	74.0	2028.1	0.452
204	5	0.176	117	77.4	2146.3	0.413
205	3	0.177	120	75.4	2021.2	0.438
206	8	0.165	119	75.8	2161.0	0.410
207	6	0.157	114	75.0	2054.8	0.389
208	2	0.156	123	72.4	1349.4	0.449
209	7	0.198	112	76.6	2495.0	0.418
210	9	0.170	116	75.8	2365.5	0.434
301	6	0.160	129	74.2	1592.7	0.459
302	1	0.159	131	75.0	1337.1	0.431
303	8	0.167	124	76.2	1738.6	0.418
304	3	0.164	128	77.0	1477.8	0.414
305	9	0.158	121	77.3	2038.5	0.407
306	2	0.175	130	74.5	1261.0	0.377
307	7	0.175	113	75.9	2116.4	0.449
308	5	0.188	112	73.6	1861.4	0.451
309	4	0.183	124	71.8	1191.6	0.394
310	10	0.191	121	75.0	1920.9	0.379
401	8	0.172	126	71.6	1695.6	0.431
402	6	0.173	120	73.3	1197.0	0.375
403	7	0.184	116	74.1	1498.2	0.379
404	9	0.162	124	76.6	2012.0	0.440
405	4	0.172	126	73.4	1091.4	0.437
406	10	0.183	123	70.4	1799.2	0.420
407	1	0.169	123	72.4	1173.4	0.386

408	5	0.179	122	74.0	1762.1	0.434
409	3	0.165	121	76.1	1803.3	0.415
410	2	0.164	132	71.0	1103.3	0.390

B.3 Stanton County winter wheat 2008-2009

Plot	Treatment Number	Flag leaf P % P	Grain Moisture g kg	Test Wieght kg hL	Grain Yield kg ha	Grain P % p
101	3	0.260	97	79.1	2958.0	0.460
102	8	0.251	102	80.4	3099.8	0.502
103	2	0.290	100	80.6	3116.8	0.467
104	7	0.222	103	81.0	2330.3	0.425
105	5	0.250	103	81.4	3046.4	0.455
106	6	0.211	101	81.0	3067.2	0.503
107	1	0.299	102	82.6	2799.5	0.479
108	10	0.180	96	79.6	2705.3	0.439
109	9	0.237	98	81.8	3091.5	0.429
110	4	0.219	97	79.4	2873.5	0.424
201	1	0.201	99	79.9	2455.2	0.488
202	4	0.249	99	80.6	2879.1	0.477
203	10	0.231	98	80.0	2618.9	0.482
204	5	0.270	97	78.2	2654.0	0.484
205	3	0.196	97	78.9	2815.1	0.454
206	8	0.230	101	81.1	2912.9	0.464
207	9	0.222	99	81.8	3168.5	0.409
208	2	0.216	95	78.6	2619.5	0.497
209	7	0.205	95	78.7	2918.2	0.409
210	6	0.214	96	80.4	2616.6	0.500
301	5	0.208	98	79.5	2399.6	0.429
302	4	0.254	99	79.4	2841.0	0.462
303	8	0.247	99	80.2	2505.4	0.437
304	3	0.257	101	80.2	2280.4	0.413
305	9	0.237	98	80.3	3421.4	0.380
306	2	0.229	102	83.2	3354.2	0.387
307	7	0.199	91	75.5	3407.4	0.399
308	6	0.212	100	81.4	2472.6	0.360
309	1	0.227	94	78.1	2416.3	0.429
310	10	0.217	97	79.8	2573.4	0.409
401	5	0.237	100	79.9	2845.8	0.422
402	6	0.266	98	78.5	2816.0	0.414
403	4	0.229	96	79.2	2798.0	0.409
404	9	0.248	99	79.5	2826.9	0.432
405	7	0.208	98	79.4	2934.6	0.417
406	10	0.236	99	79.8	2533.6	0.416
407	1	0.218	96	78.3	2828.3	0.391

408	8	0.208	94	79.8	2327.4	0.424
409	3	0.267	91	76.3	2568.2	0.405
410	2	0.204	95	78.3	2314.8	0.396

B.4 Treatment schedule for winter wheat study in McPherson County and East Central Experiment Field 2008-2009

Treatment Number	Despcription of Treatment
1	Control no P
2	9.8 kg ha-1 P, Broadcast
3	9.8 kg ha-1 P, Broadcast + Avail
4	19.6 kg ha-1 P, Broadcast
5	19.6 kg ha-1 P, Broadcast + Avail

B.5 McPherson County winter wheat 2008-2009

Plot	Treatment Number	Flag leaf P	Grain Moisture	Test Wieght	Grain Yield	Grain P
		% P	g kg	kg hL	kg ha	% p
101	5	–	113	78.5	4468	–
102	4	–	113	77.4	4589	–
103	1	–	113	79.0	4003	–
104	2	–	113	79.1	4412	–
105	3	–	111	77.8	4256	–
201	4	–	112	79.1	4632	–
202	2	–	113	78.5	3962	–
203	5	–	112	78.6	5105	–
204	1	–	110	78.6	4456	–
205	3	–	110	78.6	4469	–
301	3	–	112	79.8	4531	–
302	5	–	112	79.0	4439	–
303	1	–	111	79.0	3835	–
304	2	–	111	79.9	4671	–
305	4	–	111	78.7	4613	–
401	1	–	112	79.5	4415	–
402	2	–	112	78.6	4254	–
403	4	–	111	78.1	4249	–
404	3	–	112	79.0	4695	–
405	5	–	110	78.2	4691	–

B.6 East Central Experiment Field winter wheat 2008-2009

Plot	Treatment Number	Flag leaf P	Grain Moisture	Test Wieght	Grain Yield	Grain P
		% P	g kg	kg hL	kg ha	% p
101	3	–	106	77.4	4561	–
102	5	–	106	77.4	4378	–
103	1	–	110	78.1	4189	–
104	2	–	108	76.7	4142	–
105	4	–	108	76.7	4340	–
201	2	–	106	78.1	4957	–
202	3	–	107	78.1	4909	–
203	4	–	110	78.1	4527	–
204	5	–	106	78.1	4589	–
205	1	–	106	78.7	4716	–
301	1	–	108	77.4	4579	–
302	5	–	107	78.1	4627	–
303	4	–	110	78.1	4414	–
304	3	–	108	77.4	4480	–
305	2	–	107	78.7	4556	–
401	3	–	110	77.4	4484	–
402	1	–	111	78.7	4030	–
403	2	–	109	78.1	4391	–
404	5	–	107	78.1	4387	–
405	4	–	108	78.7	4664	–

B.7 Treatment schedule for winter wheat study at Western Ag Research Center, Tribune 2008-2009

Treatment Number	Despcription of Treatment
1	Control, no P
2	9.8 kg ha^{-1} P in row
3	19.6 kg ha^{-1} P in row
4	9.8 kg ha^{-1} P in row + Avail
5	19.6 kg ha^{-1} P in row + Avail
6	9.8 kg ha^{-1} P Broadcast
7	19.6 kg ha^{-1} P Broadcast
8	9.8 kg ha^{-1} P Broadcast + Avail
9	19.6 kg ha^{-1} P Broadcast + Avail

B.8 Western Ag Research Center winter wheat 2008-2009

Plot	Treatment Number	Flag leaf P	Grain Moisture	Test Wieght	Grain Yield	Grain P
		% P	g kg	kg hL	kg ha	% p
101	3	0.227	87	72.0	889	–
102	5	0.213	84	69.6	704	–
103	4	0.228	84	71.4	856	–
104	7	0.258	80	71.3	923	–
105	2	0.225	81	71.7	859	–
106	6	0.214	83	69.7	685	–
107	8	0.241	88	72.1	976	–
108	1	0.205	86	71.0	1185	–
109	9	0.230	81	71.3	1440	–
201	6	0.204	86	73.2	1251	–
202	8	0.233	89	73.4	1030	–
203	9	0.218	86	74.5	1328	–
204	1	0.212	90	73.2	1451	–
205	5	0.253	87	74.4	1420	–
206	4	0.233	87	72.4	1337	–
207	2	0.232	85	71.7	1282	–
208	7	0.220	81	72.5	1305	–
209	3	0.228	86	72.5	1430	–
301	8	0.213	86	74.7	2292	–
302	7	0.232	87	74.6	2377	–
303	4	0.227	91	75.3	2471	–
304	1	0.207	84	73.8	2151	–
305	6	0.209	86	74.9	2171	–
306	3	0.213	84	72.9	1844	–
307	9	0.224	86	74.1	2058	–
308	5	0.242	87	73.2	1879	–
309	2	0.219	87	74.0	1857	–
401	5	0.236	88	74.1	2114	–
402	3	0.240	88	73.2	1957	–
403	9	0.229	90	75.3	2257	–
404	8	0.248	90	73.3	2205	–
405	4	0.244	88	74.1	2067	–
406	7	0.264	84	73.3	2164	–
407	2	0.250	87	72.6	2124	–
408	6	0.225	84	73.6	2236	–
409	1	0.227	89	73.8	2282	–

B.9 County trials of JumpStart seed treatment

Location County	Plot	Treatment Number	Yield kg ha^{-1}
Conway	101	1	2822
Conway	102	2	2620
Conway	101	1	2956
Conway	102	2	2889
Caldwell	101	1	3897
Caldwell	102	2	3964
Caldwell	101	1	4233
Caldwell	102	2	4233
Hillsboro	101	1	3561
Hillsboro	102	2	2889
Osborne	101	1	4905
Osborne	102	2	4233
Ness	101	1	2150
Ness	102	2	2083
Rush	101	1	2889
Rush	102	2	2889
Smith	101	1	5913
Smith	102	2	5174
Cheyenne	101	1	5442
Cheyenne	102	2	5241
Sedgwick	101	1	3964
Sedgwick	102	2	3763
Sedgwick	101	1	4233
Sedgwick	102	2	4233
Mac	101	1	4300
Mac	102	2	3897
Mac	101	1	4502
Mac	102	2	4099
Mac	101	1	3695
Mac	102	2	4031
Mac	101	1	4502
Mac	102	2	4703
Ryan	101	1	5442
Ryan	102	2	5442
Isaccson	101	1	6249
Isaccson	102	2	5711
Banker	101	1	3225
Banker	102	2	2688

Meadow	101	1	4569
Meadow	102	2	4166

Appendix C - SAS Example

The following SAS code is an example of contrast run on corn and wheat trials.

```
Proc sort data=nceyield; by treat;
run;

proc mixed data=nceyield order=data;
class location block treat;
model moist = treat ;
random block;
lsmeans  treat/pdiff=control ('0n');

contrast 'control vs p' treat 0 3 0 0 0 -1 0 0 0 -1 0 0 0 -1/e;
contrast 'low vs high p' treat 0 0 1 1 1 1 0 0 0 0 -1 -1 -1 -1/e;
contrast 'JumpStart vs Control' treat -1 1/e;
contrast 'Broadcast vs Starter' treat 0 0 1 1 1 1 -1 -1 -1 -1/e;
contrast 'JumpStart vs No Product' treat 0 0 0 0 1 -1 0 0 1 -1 0 0 1 -1/e;
contrast 'Avail vs No Product' treat 0 0 1 0 0 -1 1 0 0 -1 1 0 0 -1/e;
contrast 'Avail vs JumpStart' treat 0 0 1 0 -1 0 1 0 -1 0 1 0 -1 0/e;
contrast 'Combo vs No Product' treat 0 0 0 1 0 -1 0 1 0 -1 0 1 0 -1/e;
run;

ods tagsets.Csv close;
      quit;
```