

PHOSPHORUS FERTILIZATION OF CORN USING SUBSURFACE DRIP IRRIGATION

by

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Abstract

In recent years, subsurface drip irrigation (SDI) acres have increased substantially. The use of SDI on corn (*Zea Mays* L.) in the Great Plains has increased due to increased land costs, reduced irrigation water availability, and higher commodity prices. Applying phosphorus (P) fertilizer through a SDI system becomes a major advantage, but further investigation of the interaction between water and fertilizer is needed. Sub-surface drip irrigation systems can be used to better improve the application efficiencies of fertilizers, applying in wet soil-root zones can lead to better uptake of soil applied materials. The objectives of this study were to determine how corn responds to P fertilizer applied via SDI and to create methodologies to simulate fertilizer and irrigation water compatibility tests for use in SDI systems. A plot sized SDI system was installed near Manhattan, KS to evaluate P treatments. Eight separate P fertilizers were applied via SDI mid-season at a rate of 34 kg P₂O₅ ha⁻¹ and split-plots were created with 2x2 starter band at planting. Nitrogen was a non-limiting factor, with 180 kg N ha⁻¹ applied as urea. Both starter fertilizer and injected fertilizer affected corn grain yield as indicated by the starter by treatment interaction. Split applying starter fertilizer at planting increased yield. A secondary laboratory study was conducted to evaluate the water and fertilizer interactions. A filtration system was used to simulate field conditions and each fertilizer/water mix was filtered through a 400 mesh filter paper to evaluate fertilizer precipitant formation. Sixteen common fertilizers were analyzed with different rates of Avail. Differences were observed between fertilizer treatments, visually and quantitatively. A secondary P soil movement field study was performed to quantify P concentrations around the SDI emitter. Soils were sampled in a 30.5 cm by 30.5 cm square adjacent to the emitter on a control treatment and a fertilized treatment, in both years of the study. Visual and quantitative differences were observed between the two treatments in both years of the study. When P fertilizers were added to the SDI system, higher P concentrations were found very close to the emitter orifice. Control treatments exhibited lower P concentrations around the emitter than fertilized treatments.

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Chapter 1 - Literature Review

Section I: Phosphorus Fertility

Introduction

Phosphorus (P), one of the three primary macronutrients for essential plant growth, is considered one of the most overlooked nutrients in many plant growing environments. Phosphorus fertilizer in the U.S. is a very valuable product and a resource that needs to be conserved and used more efficiently. The P supply and demand balance in the U.S. has been very stable for the last few years. In 2008, 9.2 million T of P fertilizer was produced, 3.9 million T was exported, and 3.3 million T was consumed (FAO, 2008). The use of P fertilizers in the U.S. needs to be closely monitored, as phosphate rock reserves diminish; ways to increase fertilizer efficiencies and better crop responses need to be implemented.

Phosphorus plays an important role in agriculture and is referenced as one of the 17 essential nutrients to plant growth. Many roles and functions of P cannot be performed by any other nutrient. Phosphorus is involved in the genetic ribonucleic acid formation, energy transfer, and many other metabolic processes (Ozanne, 1980). Energy transfer is considered one of the most essential functions of P, adenosine di- and triphosphates act as energy storage substrates for the plant, so as a result P deficiencies are interrelated to the restrictions of plant growth and development (Havlin et al., 2005).

P deficiencies are very difficult to diagnose for most plants compared with other major nutrients. General stunting of the plant and some purpling of the leaves are major P deficiency symptoms in most plants. Corn (*Zea mays L.*) is one of the major cash crops in Kansas; it tends to show some key visual deficiencies. An abnormal discoloration of the leaves show on P deficient plants, the leaves show a bluish color and the stems show a very dark purple color (Griffith, 2006). Phosphorus is very mobile in plants, thus most common deficiencies are translocated from old tissue to young, actively growing plant tissue.

Many explicit growth factors have been related with adequate P supply. Increased root development (Mackay and Barber, 1985), earlier maturity (Peaslee et al., 1971 and Colomb et al., 2000), increased stalk quality and stem strength (Leikam, 2010), better quality of grain

(Leikam, 2010), increased nitrogen fixation capacity (Havlin et al., 2005), and prevention of disease and stress (Havlin et al., 2005) are well documented growth factors that are correlated to increased P supply. However, increased P may have declining effects on iron absorption by roots in some soils (Elliot and Lauchli, 1985). This section will discuss various topics of P fertility, including: P in the soil, P uptake by plants, P sources and applications.

P in the Soil

P content in most soils is very low in the surface layer, less than one percent total P. Since P is the least mobile to plants in most soils, it is a key limiting factor for most plant growth processes (Mikkelsen, 2005). The total P content of any soil may vary quite a bit depending on the organic matter content, parent material, climatic condition, and degree of fertilization. Phosphorus becomes unavailable for plant uptake because of adsorption, precipitation, fixation, and conversion of P to the organic form and thereby over 80% of P becomes immobile or unavailable; ways to keep P available are well justified and very important (Holford 1997).

Soil P can usually be grouped into two categories, organic and inorganic. Within both forms, P in the soil solution is very imperative, defined as the medium from which plants absorb nutrients (Cameron, 1911). To categorize soil P further, labile P and non-labile P are commonly used. Labile P is defined as the available portion that rapidly replenishes solution P at high rates, non-labile P is the dissolution of P at very slow rates (Havlin et al., 2005). Inorganic forms of P are usually found in virgin soils, which are derived from the parent rocks. As soils age, plants, microbial populations, and animals convert it to organic forms of P, therefore when these organisms decompose, both categories of soil P are returned to the soil (Anderson, 1980). Plant roots absorb solution P with young, actively growing root tissue mainly by diffusion, which will be covered later in this chapter.

Organic soil P constitutes about 20-80% of the total P in most soils and is primarily made up of phytic acid (Schachtman et al., 1998). Organic P is found in animal manures, microbial populations, and plant residues that can be easily mineralized into an inorganic, plant available form. Microbial populations can have major effects on organic P concentrations in soils, similar to nitrogen. Microbial populations can mobilize or immobilize P depending on carbon to P ratios (C:P) and organic matter levels (Havlin et al., 2005). Net mineralization occurs when the C:P

ratio is less than 200; in contrast, net immobilization occurs when the C:P ratio is greater than 300 in most residues. Organic matter can have some indirect influences on P availability in most soils. The P content in organic matter is very low (1-2%), however most sources give a C:N:P ratio of 100:10:1 to organic matter (Havlin et al., 2005). Organic P as animal wastes is an excellent source of P for plants. However, the wastes must undergo mineralization before the P is deemed available to the plant.

Inorganic P is considered the original source of all P, and comes from the mineral apatite. As stated earlier, P in the soil solution is defined as the medium from which plants absorb nutrients. Two common forms of inorganic P are adsorbed P and mineral P. Adsorbed P on soil constitutes has been commonly referred as labile P in most recent literature; and is very complex. Phosphorus retention is the ability of the soil to retain P, more importantly controlling the release of soil P to water (Ige et al., 2007). This depends on many factors, but most important soil pH. In acidic soils, inorganic P precipitates as iron and aluminum-P minerals and is adsorbed to clay minerals (Wild, 1950). In alkaline soils, inorganic P precipitates as calcium and magnesium-P minerals and is adsorbed to clay minerals (Ige et al., 2007). Many problems exist, such as declining effectiveness of fertilizers and small fractions of P uptake in many high pH, calcareous soils (Lombi et al., 2004). Efficiency of P application on these soils are very low, because the soil applied P reacts with calcium forming minerals, and thereby becomes unavailable (Lindsay, 1979). The P adsorption and fixation concepts are very complex, however, are important for optimum P nutrition and efficient P management programs.

Mineral P, is primarily considered the original source of P, and is mainly found as apatite. Phosphate rock (PR), is a trade name given to a wide variety of rock types, but is commonly defined as a sedimentary rock composed of phosphate materials (Gary et al., 1974). Even though some mineral P is found as sedimentary PR and igneous PR forms, nearly all minerals fall into the apatite group (McClellan and Gremillion, 1980). More information on PR and the sources available will be covered later in the chapter.

P Uptake by Plants

As stated earlier, P plays an extremely vital role in plants. It is mainly known for its role in converting energy into useful plant compounds (Griffith, 2006). Some other notable functions of P in plants are: vital component of the genetic structure of DNA to build proteins, storage,

transfer and release of energy within the plant as ATP (Ozanne, 1980) and the regulation of many metabolic processes (Mikkelsen, 2005).

Phosphorus uptake by plants is mainly regulated by the plants root system. P absorbed by plant roots is either in the form of hydrogen phosphate or di-hydrogen phosphate, which are HPO_4^{2-} or H_2PO_4^- , respectively (Barber, 1980). There have been many studies showing the effect of root length (Mengel and Barber, 1974), plant age (Jungk and Barber, 1975), root appearance (Pellerin et al., 2000) and root hairs (Bhat and Nye, 1974) on P uptake in corn (*Zea mays L.*).

Phosphorus has very strong relations with soil components; therefore it is supplied to plant roots by diffusion and mass flow. Most uptake occurs at the young root tips, which are exposed to the P concentrations found in the soil solution. Nutrients are transported into the plant by the movement of P, from the apoplast across the cell root membranes; this is a very crucial step and requires energy mechanisms to move P through the membranes to the plant roots (Mikkelsen, 2005). A diffusion rate equation was developed by Olsen et al., (1962), it takes into consideration plant removal P and the relationship between soil solution P and other ionic factors in the soil solution. The equation was developed to quantify plant uptake by soil diffusion. Olsen et al., (1962) postulated that since the roots absorb water, soil water will be higher at the early stages of growth, consequently uptake in the early stages will be more rapid than the later stages. There are many factors that affect P diffusion rates; high diffusion rates favor high volumetric water content, low tortuosity, low solution buffering capacity, and high solution temperature (Barber, 1980). Mackay and Barber, (1985) correlated P uptake with mathematical models, and suggested that the increasing soil P increased P uptake by the plant, both by increasing P influx and root growth.

Calcium accumulation and soil pH can have major effects on the availability of P absorbed by the root system. Some recent work on calcareous soils in Australia showed that P from fluid fertilizers diffuse more and were more available to root systems than granular sources (Lombi et al., 2004, and Lombi et al., 2006). Furthermore, with increasing amounts of calcium and higher pHs, the P level in the soil solution will decrease due to more anionic uptake and decreased P solubility. The distribution of fertilizer P in the soil on P uptake is very important and is highly dependent on the rate of diffusion and the ability of the root to absorb P (Barber, 1980). Phosphorus is a very immobile nutrient in the soil and roots must be very close for P

uptake; therefore placement of P fertilizer close to plant roots is a very efficient management practice (Whitney, 1988). The placement and distribution of P fertilizers becomes very applicable and at low rates the localization of P fertilizer can be very useful.

P Sources and Applications

Today, most fertilizer sources all originate from acidified phosphate rock (PR), a finite natural resource found all over the world (IPNI, 2010). Most of the P fertilizers involving PR acidification are largely water soluble, meaning fertilizers are dissolved in water and expressed as a percentage P_2O_5 by weight of the dissolved sample (Whitney, 1988). These include most orthophosphates, superphosphates, and polyphosphates (Engelstad and Terman, 1980). Some phosphates are less soluble in water and are considered citrate soluble, defined as the amount of fertilizer not dissolved in water and is expressed as a percentage P_2O_5 by weight of the citrate solution (Whitney, 1988). Nevertheless, the P available to the plants and the amount labeled on the fertilizer is the sum of water-soluble P and citrate-soluble P. In agriculture, highly water-soluble P fertilizers are applied to soils. After soils are fertilized, P compounds dissolve in soil water and go into the soil solution after many complex reactions (Sample et al., 1980). After this, phosphorus fixation can render less available P depending on soil texture and soil pH.

Most of today's common fertilizers are made by treating PR with sulfuric acid, making them very water soluble phosphoric acid (Penas and Sander, 1982). Phosphoric acid contains around 55% P_2O_5 ; it is used to make, triple superphosphates and dry ammonium phosphates (IPNI, 2010). Ammonium orthophosphates are made by reacting ammonia with phosphoric acid, which are currently the most commonly used dry P sources. A variety of fluid fertilizers can be made, varying in amounts of polyphosphate, especially orthophosphate are present in most fluid fertilizers. Superphosphoric acids are formed, mostly consisting of poly and orthophosphates, by dehydration of phosphoric acid to make an acid that contains 68% P_2O_5 (Leikam, 2010). Ammonium polyphosphate (APP), a very common P liquid fertilizer (34-37% P_2O_5), is produced by the reaction of superphosphoric acid, ammonia, and water. The majority of P in APP is polyphosphate, so hydrolysis occurs to convert polyphosphate into orthophosphate, the anion which plants absorb (Stewart, 2002).

The chemical and physical properties of commercial P fertilizers have very important effects on individual crop responses; however, various management factors are just as important

(Engelstad and Terman, 1980). Many application methods are suitable for P fertilization: broadcast, starter/band placement, and through irrigation (fertigation). Broadcast, in general, is used very extensively in the Corn Belt, and can be very effective. Timing of broadcast application can be very important to perennials and cereal crops, yet, in annual crops such as corn and soybean, timing of P application doesn't affect yield or uptake (Mallarino et al., 2009). Some studies indicate that with higher P soil tests, broadcast applications are enhanced over starter applications (Barber, 1958); still, a combination of broadcast and starter placement depends on crop species and timing.

Starter placement is defined as a fertilizer application with the seed or in bands near the seed to stimulate early growth (Penas and Sander, 1982). There are three types of starter fertilizer band applications, 2"x2" beside seed, surface dribble, and pop-up in-furrow (Mengel, 2010). Many studies show higher yields and efficiencies with starter band applied P than broadcast applied P in corn (Welch et al., 1966, and Eckert and Johnson, 1985). This can be attributed to fertilizing a fraction of the root zone, stimulating early growth, less fixation, or lower soil test values. Starter fertilizer is a useful tool at low soil test levels; nonetheless, there is no penalty for banding at higher soil test levels (Mengel, 2010). Applying P with irrigation water, also known as fertigation, is another way to apply P, which will be covered later in this chapter.

Summary

Phosphorus is considered one of the primary macronutrients and has been very important to agriculture. It is well documented that P is needed in most every agriculture ecosystem in the U.S. Ways to enhance P availability and correct deficiencies in more efficient manners needs to be well looked at. Phosphorus in the soil is very complex, and many factors are associated with better P uptake into the plant. Mobility is an issue with P in the soil, but it is very mobile in the plant, so placement and application of fertilizers become very important issues in every agriculture operation.

Section II: P Fertigation Using Subsurface Drip Irrigation

Introduction

The application of fertilizer through irrigation systems is becoming a very useful tool in many large-scale agriculture operations. Subsurface drip irrigation (SDI) is the application of water below the soil surface by microirrigation emitters (Lamm and Camp, 2007). Due to the more efficient water use, better application uniformity, and decreased energy costs, many SDI systems are being installed in the Midwest (Lamm and Camp, 2007, and Payero et al., 2005). However, one major advantage of SDI is the ability to apply certain fertilizers through the system.

Fertigation is a common term used when fertilizers are applied with irrigation water, but, SDI fertigation defined, is the injection of soluble fertilizer solutions into the irrigation system via any dosing apparatus (Kafkafi, 2005). Nutrients can be applied directly to the root zone at the right time of growth, thus, optimizing plant uptake and nutrient availability, and minimizing nutrient losses through leaching. Other advantages of SDI fertigation are the flexibility of applying nutrients throughout the growing season, convenient use of balanced liquid fertilizers with micronutrients, precise application of nutrients according to crop demand, maximize fertilizer use efficiency, and the application of nutrients into a portion of the wetted soil area near actively growing roots (Bar-Yosef, 1999, Lamm and Camp, 2007, and Burt et al., 1995). However, many disadvantages hinder the use of fertigation with SDI systems depending on which nutrient is used. The most common nutrients used in SDI systems are nitrogen (N) and potassium (K), and certainly do not cause the problems that phosphorus (P) fertilizers do. For this reason, P fertigation will be covered in this section of the paper. The major problems with P fertigation are dissolution of the fertilizer, which depends on the quality and solubility of the fertilizer, and the precipitation of P as insoluble compounds within the lines and emitters, which depends on water pH and cationic amounts (Ryan and Saleh, 1998). Expensive investments are needed to install and maintain SDI systems regardless of the nutrient type for fertilizer injectors, safety devices, and storage of large quantities of fertilizers. The advantages and disadvantages of fertigation with SDI are well known and documented, further experimentation of fertilizer solubility, fertilizer source, soil mobility, and crop response need to be studied in greater detail. This section will discuss some of these issues in greater detail, such as the fundamentals of fertigation and the P sources and responses with fertigation in SDI.

Fundamentals of Fertigation

Many producers often forget the fundamentals of fertigation before injecting various fertilizers through their respective irrigation systems. Some very important issues to consider are water quality, fertilizer solubility, and fertilizer compatibility.

There are many ways to inject fertilizers into irrigation systems. The method used will be highly dependent on the type of fertilizer, the hazard potential of the fertilizer, and the availability of power (Burt et al., 1995). Fertilizer injection into irrigation water requires three components: a fertilizer supply tank, an injection system, and a safety device (Evans and Waller, 2007). Most fertilizer injectors are installed at the head control unit of the irrigation system and before the filtration system, the injector unit can be installed as one unit or as multiple units. Materials should be injected into the center of the water flow to ensure better dilution rates (Evans and Waller, 2007). Some problems exist when fertilizer's are injected upstream of the filter, some acids can damage the filter; however injecting fertilizers upstream of the filter will trap any contaminants or in-soluble precipitates that may form (Burt et al., 1995). There are two main techniques of fertilizer injection: closed tank and injector pumps. Closed tank systems operate by the pressure created by partially closed valves on the bypass lines (Phocaides, 2000). This system is not commonly used due to unknown dilution ratios and concentrations.

Injector pumps are the more commonly used injection technique. Injection pumps can be subdivided into two types of pumps, venturi and metering. The venturi system creates a differential pressure that forms a vacuum, which pulls the liquid to be injected into the system (Granberry et al., 2005). Injection rates will vary with the pressure differential across the venture, so precise regulating valves and flow meters are needed. Metering pumps are considered positive displacement pumps, and are often diaphragm or piston pumps. They can be powered by either small electric motors or hydraulic systems. Diaphragm pumps are very easy to adjust by the stroke length while the pump is operating, so producers can adjust rates simultaneously with injection (Kranz et al., 1996). For this reason, they are the most common pump in the Midwest. Piston pumps are very similar to diaphragm pumps in power supply and maintenance, but with piston pumps the discharge flow rate will not change if pressure changes and they cannot change flow rates simultaneously with injection (Burt et al., 1995). Piston pumps change discharge rates by controlling the stroke frequency and piston stroke (Kranz et al., 1996).

Before installing a fertilizer injection system, a water quality assessment is recommended. Most irrigation water is filtered downstream to the injection point and before water enters the valves or emitters. Water, therefore must be filtered so solid particles do not plug the small emitter orifices (Flynn, 2001). The plugging potential of water can be evaluated by testing for physical, chemical, and biological components in the irrigation water. Bar-Yosef, (1999), summarized that water quality is controlled by several factors, including: 1.) salinity, total dissolved solids (TDS) or electrical conductivity (EC), 2.) sodicity, or the sodium adsorption ratio (SAR), 3.) anionic composition of the water, 4.) biochemical oxygen demand (BOD), 5.) total suspended solids in water (TSS). Salinity, is measured by TDS or EC, saline water (high EC) provides the crop with the inability to compete with ions in the soil solution for water. So the higher the EC, the less water is available to plants, and the fewer nutrients available to the crop (Bauder et al., 2007). Sodium, measured with SAR, the proportion of sodium to calcium and magnesium cations, has detrimental effects on soil properties at high SAR ratios (Lamond and Whitney, 1992). All of these important characteristics of irrigation water are the standard of knowing when to use fertigation in any given operation. Many threshold values have been determined for quality characteristics, but it is impossible to cover all facets of water quality.

Fertilizer solubility and compatibility is very imperative when considering what types of fertilizers to put with irrigation water. Fertilizer solubility, purity, compatibility, and temperature are some common characteristics to look for before injecting any fertilizer in a SDI system. Fertilizers that are readily dissolved, or have high solubility are the best and easiest fertilizers to inject in most SDI systems. The solubility of a fertilizer compound depends on its physical properties, the water temperature, and the irrigation water quality. The ability of the irrigation water to dissolve fertilizer depends on the water's pH and the presence and concentration of other ions, such as sodium, calcium, magnesium, nitrate, and carbonate (Evans and Waller, 2007). For example, a fertilizer such as anhydrous will increase the pH, which causes mineral precipitates if the water has a high pH and/or calcium and magnesium carbonates are present. Acid fertilizers, such as phosphoric acid and pek-acid cause the pH to decrease when injected; this can be helpful in many operations due to the effect of acidifying with the fertilizer itself. Consequently, increasing water temperature will lower the pH in which carbonate precipitation occurs and also will help with dissolving dry fertilizer (Granberry et al., 2005).

Many special considerations to avoid precipitation of minerals to result in the clogging of SDI emitters should be taken (Bar-Yosef, 1999). Phosphorus readily precipitates and caution needs to be taken when injecting P fertilizer, which will be talked about in the next section. It is very crucial when mixing the fertilizers to be injected; that they are compatible with each other and with the water. Mixing two fertilizers together, such as a calcium salt with a phosphate, may form precipitants of calcium phosphate or calcium sulfate, even at low pH (Kafkafi, 2005). A simple “jar test” can be a common solution to determine if the fertilizer(s) and water are compatible with each other (Burt et al., 1995). The test involves putting an amount of fertilizer, usually at the rate that simulates field conditions, into a jar with a known amount of water. If cloudiness occurs, there is a chance that injection of the respective fertilizer will cause emitter plugging. So as a general rule, the fertilizers injected should be highly soluble in water and very compatible with the irrigation water. Burt et al., (1995), provides very informative tables of solubility and compatibility of various commonly used fertilizers.

P Sources and Responses with Fertigation in SDI

Very little research on the injection of P fertilizer into SDI systems has been done due to the detrimental reaction of P fertilizers with irrigation water. Bar-Yosef, (1999), summarizes the earlier work on crop response to P fertilizers in SDI, much of this work is in vegetable crop production, very little concentrates on field crop production.

When choosing a P fertilizer to inject into a SDI system, many factors need to be considered such as: water quality, filtration, fertilizer solubility, compatibility, and state. As mentioned above, water quality is very important especially the salinity and pH; precipitation of fertilizers can be avoided if the pH is kept low enough for the salts to remain soluble (Mikkelsen, 1989). A lower pH can be obtained by using an acidic P source such, as phosphoric acid (H_3PO_4), urea phosphate (UP), or PekAcid (PA). However, the uses of traditional P fertilizer sources, such as superphosphate or triplesuper phosphate are not suitable for drip systems, the new developments in fertilizer have led to more soluble P blends that are suitable for water application (Haynes, 1985). Some liquid P sources are very soluble and can be applied with irrigation water; nevertheless their reactions with high calcium and sodium in the water tend to leave in-soluble precipitates, which can cause emitter plugging (Ryan and Saleh, 1998).

Other granular sources of P, such as monoammonium phosphate ($\text{NH}_4\text{P}_2\text{O}_4$) and monopotassium phosphate (KH_2PO_4), are commonly used, and are slightly acidic. In all cases of P fertigation, the product tends to be slightly acidic and highly water soluble. Some additional P liquid fertilizer blends are used on the market worldwide, needless to say the water quality, solubility, and compatibility needs to be well studied before further use.

Many responses to P fertigation have been found in many horticulture crops such as tomato and lettuce, but very little evidence in field crops, such as cotton, sweet corn, and potato. So much of the review will be on certain P sources that responded to P fertigation in SDI systems. The majority of the research has been on phosphoric acid and the rates applied to achieve maximum efficiency and yield. The P responses to sweet corn (Bar-Yosef et al., 1989), tomato (Ayars et al., 1999), and potato (Papadopoulos, 1992) were very similar when phosphoric acid was injected via SDI. In most cases, the response reached a peak in applied P depending on the need of the respective crop and the timing, P uptake was enhanced by the injection of P based on petiole analysis. The precise application of P via SDI is based on the timing of when the crop needs it. Bar-Yosef, (1999) summarizes the nutrient needs of most horticulture crops based on daily application amounts.

Other studies show that fertilizers such as triple super phosphate (Zhang et al., 2010) and potassium phosphate (Kafkafi and Bar-Yosef, 1980) can be injected into SDI systems. The injection of triple super phosphate didn't affect tomato yields due to the high background levels of soil P. In the second study, potassium phosphate was injected daily through the drip system and superphosphate was applied in the seed furrow at planting. It was postulated that by dually injecting P and banding P, more P was available throughout the growing season of tomato (Kafkafi and Bar-Yosef, 1980). Earlier work by Rauschkolb et al., (1976), suggested that organic phosphates, such as glycerophosphoric acid, were capable of being applied through drip systems. It was thought that phosphoric acid could be applied when extreme care was used, but the organic phosphate will move further in soils, and it was also easily applied without clogging of emitters.

Studies in Texas have reported phosphoric acid to work well with SDI systems in cotton producing areas (Enciso-Medina et al. 2007). In 2003-2005, phosphoric acid was injected at two rates with a control, $32.9 \text{ kg P ha}^{-1}$ and $65.7 \text{ kg P ha}^{-1}$, the control received zero P each year. With all years combined, lint yields were the same for the high and low rates of phosphoric acid

and both rates were significantly different from the control. These results show when injecting P for cotton production, base the rates on soil fertility status. Another study was conducted in Texas to compare injecting phosphoric acid and knifing phosphoric acid in cotton production (Enciso-Medina et al., 2009). Knifing vs. injecting P with SDI systems found no significant effect on lint yield or cotton quality. These results indicate that a producer can inject phosphoric acid instead of knife his P to save on inputs and costs, and not lose yield.

Summary

Phosphorus fertigation can be a useful tool in many operations, but many careful management and quality issues have to be considered at before application. Water quality, fertilizer solubility, fertilizer compatibility, and fertilizer source are a few key points to look prior to applying fertilizer. Many acidic water soluble P sources are deemed acceptable for injecting P into a SDI system; however some acidic liquid formulations need to be looked at for solubility and compatibility with the irrigation water.

Chapter 2 - P Application to Corn Using Subsurface Drip Irrigation

Introduction

In recent years, SDI acres have increased dramatically. This expansion has been stimulated by increased land costs, reduced irrigation water availability, and higher commodity prices. Cost of installation for a SDI system is significant and using the system to make fertilizer applications is one way to reduce application costs and gain an additional benefit from the system. The application of fertilizer through irrigation systems is becoming a very useful tool in many large-scale agriculture operations. Many SDI systems are currently being installed in the Western Midwest to benefit from numerous advantages that SDI systems bring to the table.

Fertigation is a common term used when fertilizers are applied with irrigation water, but, SDI fertigation, is the injection of soluble fertilizer solutions into the irrigation system via any dosing apparatus (Kafkafi, 2005). Nutrients can be applied directly to the root zone at the right time of growth, thus, optimizing plant uptake and nutrient availability, and minimizing nutrient losses through leaching. Other advantages of SDI fertigation are the flexibility of applying nutrients throughout the growing season, convenient use of balanced liquid fertilizers with micronutrients, precise application of nutrients according to crop demand, maximize fertilizer use efficiency, and the application of nutrients into a portion of the wetted soil area near actively growing roots (Bar-Yosef, 1999., Lamm and Camp, 2007., and Burt et al., 1995). Since SDI irrigations are typically made on a daily basis, the application of fertilizers is likely to be more efficient and potentially more cost effective. However, many disadvantages hinder the use of fertigation with SDI systems depending on which nutrient is used. The most common nutrients used in SDI systems are nitrogen (N) and potassium (K), and indeed do not cause the problems that phosphorus (P) fertilizers can. However, as new SDI systems are installed, a new set of management questions and issues are likely to rise. The objectives of this study are:

- 1.) Evaluate various fertilizers injected into the SDI systems both qualitatively and quantitatively in corn.
- 2.) Determine if starter P applications at planting influence in-season fertigation applications on corn.

3.) Develop nutrient management strategies to help producers maximize the potential of their SDI system.

Materials and Methods

Research was conducted in 2009 and 2010 near Manhattan, KS at the Kansas State University (KSU) Ashland Bottoms Farm (39°8'16"N, 96°38'12"W). Soil types for this area include a Belvue silt loam [course-silty, mixed, superactive, nonacid, mesic Typic Udifluvents] and a Eudora silt loam [course-silty, mixed, superactive, mesic Fluventic Hapludolls]. A 1.2 ha SDI system was installed at the KSU Ashland Bottoms Research Farm in 2008. There are eight treatment zones replicated three times, therefore each block is 0.4 ha, or 60.8 m by 63.8 m (Figure 2.1). A border plot on each block edge was installed to encompass bordering effects. Each plot is 6.1 m wide and 63.8 m long (8 rows wide on 76 cm row spacing). The SDI laterals were installed 38 to 46cm deep with every lateral centered between 76 cm row spacing in the plot. Pressure compensating emitters are evenly spaced on the laterals at 0.5m with a 0.6 L hr⁻¹ discharge rate. Sequentially, flow meter, pressure transducer, and filtration systems were installed, all managed by a NMC-64L Netafim irrigation controller (Netafim USA, Fresno, CA¹). The filtration system consisted of 7.6 cm twin manual disc filters, equipped with two 100 micron filters. The eight separate treatments on each block were electronically controlled by Aquanet Plus electric valves¹, which are designed for flows from 0.03 to 7.0 m³ hr⁻¹ at a pressure of 0.2 bar. Flush out ball valves were installed to ensure correct flow to each respective treatment. The main 7.6 cm supply lines were plumbed so two irrigation wells, one well (605 L min⁻¹) for irrigating the entire 1.2 ha, and a small well (95 L min⁻¹) for the in-season fertigation applications could be used. A Multifertic MFD¹ (2002-MF-7523M) fertilizer injection pump was installed so fertilizers could be injected prior to filtering irrigation water.

All three blocks were soil sampled prior to the 2009 growing season for organic matter (OM), pH, nitrogen (NH₄-N and NO₃-N), phosphorus (P), and potassium (K) (Table 2.1). The P levels for the three blocks were moderate to high with P levels ranging from 32 to 47 mg kg⁻¹,

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nonetheless starter P was still recommended in the build and maintain program (Leikam et al., 2003). Prior to the 2010 growing season, the three blocks were soil sampled again with the same procedures as above except multiple depths were taken from each core, a 0 to 5 cm and a 15 to 30 cm (Table 2.1). The K and N levels were much lower in 2010 as expected from a high yielding corn crop in 2009. In 2010, the P levels were similar to 2009 ranging from 42 to 53 mg kg⁻¹ in the shallow layer and from 26 to 28 mg kg⁻¹ in the deeper layer. In both years, soil pH results were very alkaline due to the previous management of the field and the high pH irrigation water. In 2010, secondary macro-nutrients and micronutrients were tested at the 0 to 5 cm and 15 to 30 cm depth including, calcium, magnesium, sulfur, zinc, iron, chloride, and cation exchange capacity (Table 2.2).

Corn (*Zea Mays L.*) was no-till planted in all plots both years. In-season cumulative growing degree units (GDUs) were calculated using the maximum and minimum temperatures from 1 April through 31 October in both years with the base temperature for corn at 10° C (KSU Weather Data Library). Cumulative in-season precipitation amounts were summed for rainfall events from 1 April to 31 October (KSU Weather Data Library). Irrigation events throughout the growing season were determined by the KanSched 2.0 (Rogers et al., 2006). This program estimates the root zone water balance and schedules irrigation events based on evapotranspiration (ET) and rainfall data. Water budgets started 18 May, 2009 and 28 May, 2010, respectively. Crop emergence was an input in calculating growth stages and crop ET in 2009 and 2010, emergence dates were 17 May and 14 May, respectively. The soil available water holding capacity value is a measure of the maximum amount of water the soil can hold that can be used by the crop within a growing season (Rogers et al., 2006). Available water holding capacity was calculated using soil texture, water holding capacity, and permanent wilting point. In each year, a silt loam soil was used, 0.2 mm water mm soil⁻¹ and 0.19 mm water mm soil⁻¹ were used as water holding capacity and permanent wilting point values, respectively. Evapotranspiration values were calculated using an alfalfa based (Penman) system from the KSU Weather Data Library with 0.2 as the initial crop coefficient and 0.5 as the maximum crop coefficient. Other factors associated with irrigation scheduling were set as the defaults in KanSched 2.0. Daily water budgets were made and a 50% maximum allowable depletion (MAD) was used, so in both years irrigation events kept the water table from falling below the

50% MAD level. The forecast option and the daily budgets determined when irrigation events were scheduled.

Plots were arranged in a randomized complete block, split-plot design with three replications, the fertigation treatments being the main treatments and the starter at planting being the split-plots. All plots were randomly selected for 2009, however in 2010; all plots were assigned to the same plots as the previous year. In both years, Pioneer ‘33T57’ (Bt), a 113 day corn hybrid (Pioneer Hi-Bred International, Johnston, IA¹) was planted at 74 100 seeds ha⁻¹ in early May with a four-row no-till planter (White Model 5100, AGCO Corp., Duluth, GA) (Table 2.3). Each eight row treatment was sub-divided into four rows of corn for split-plots (3.05 m wide), one with starter band applied and one without starter band applied at planting. Each year, corn was planted so each row of corn would fall between a SDI lateral (Figure 2.2). Starter fertilizer, 17-17-0, a blend of urea ammonium nitrate and ammonium polyphosphate, was band applied with the planter at rates of 78.6 L ha⁻¹ to all starter split plots (Table 2.3). Starter fertilizer was applied 5 cm below the soil surface and 5 cm to the side of the seed, commonly referred to as “2x2” starter band application (Mengel, 2010). Nitrogen was applied as surface-applied urea (46-0-0) to all plots as a broadcast application at rates of 179 kg N ha⁻¹, 10-20 days after planting (Table 2.4).

Even though further applications of P were not recommended other than starter P; seven P fertilizers were injected via SDI as fertigation applications to see if placement of P fertilizer had positive effects on yields. One treatment served as a control plot both years. Both years, 34 kg P₂O₅ ha⁻¹ was applied equally to the seven separate treatments (Table 2.5 and Table 2.6). The seven separate treatments were injected at the V6 growth stage (Ritchie et al., 1997). Total P applied was calculated as the sum of P fertigation and starter band at planting. Total N applied was calculated as the sum of N in the P fertigation products, starter band at planting, and N applied as urea.

In 2009, four different fertilizers were injected, with three of them having P-enhancing additives, totaling seven treatments. Nutra-Flo Goldstart 6-24-6 (Nutra-Flo Company, Sioux City, IA¹), a liquid, brown, neutral pH, highly soluble fertilizer was applied in the second and third treatments, without and with Avail (0.5 % v/v) (Specialty Fertilizer Products, LLC, Belton,

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MO¹) respectively. The Avail technology surrounds P in a water-soluble barrier. This barrier expands to block the elements that tie up P in the soil such as calcium, iron, and magnesium at high pH. Assure Crop 5-20-5 (Assure Crop Liquid Fertilizer, Seneca, KS¹), a liquid, clear, neutral pH, highly soluble fertilizer was applied in the fourth and fifth treatments, without and with Plen-T-Phos (PTP) (0.5 % v/v) (Nano Chem Solutions, Inc, Bedford Park, IL¹), respectively. Plen-T-Phos is a patented synthetic protein derived from the amino acid, aspartic acid; it is a crystal growth inhibitor, which means it delays the formation of insoluble precipitates due to the interaction of important cations. Haifa Multi-MAP 12-61-0 (Haifa Chemicals, Ltd., Haifa Bay, Israel¹), a fully water soluble powder, very pure, moderately acidic fertilizer, was applied in the sixth treatment. This soluble powder fertilizer was dissolved in 18.9L of water prior to injecting to form a liquid solution. Nutra-Flo Diamond 9-18-9 (Nutra-Flo Company, Sioux City, IA¹), a liquid, clear, highly soluble, neutral pH fertilizer was applied in the seventh and eighth treatments, with and without Avail (0.5 % v/v), respectively. Each fertigation treatment was applied as a function of irrigation programming, each 0.04 ha treatment per block was programmed so all treatments were injected over the same amount of time, so 0.12 ha were turned on by three electric valves to apply each fertilizer. In 2009, the fertigation application date was 12-13 June (Table 2.4). Actual rates applied varied between fertilizer treatments, since the percentage of P₂O₅ and N was not constant in all fertilizers used (Table 2.5). The amount of time a fertilizer is injected should be followed by a similar water flushing time. The fertilizer run times and water flush times are found on Table 2.7 for all fertilizers injected in 2009.

In 2010, treatments were similar to 2009, in that five different fertilizers were injected, with two of them having P-enhancing additives, totaling seven treatments. The only treatment changed was treatment seven, Rotem PekAcid 0-60-20 (ICL Fertilizers, Beer Sheva, Israel¹), a crystal like, N free, white, very acidic fertilizer, was applied instead of the Nutra-Flo Diamond 9-18-9 with Avail. All other treatments were identical to 2009 (Table 2.6) All injection methods in 2010 were the same as 2009. In 2010, the fertigation application date was 14-15 June (Table 2.4). Actual rates applied varied between fertilizer treatments, since the percentage of P₂O₅ was not constant in all fertilizers used (Table 2.6). The fertilizer run times and water flush times are found on Table 2.7 for all fertilizer's injected in 2010.

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Weed control was accomplished by the use of contact herbicides as burndown applications and residual herbicides as pre-emergence applications (Table 2.8). An all terrain vehicle mounted with a boom sprayer was used to apply the herbicides. All plots in 2009 were treated with a burn down application of 1.1 kg ha^{-1} glyphosate [N-(phosphonomethyl)glycine] on 28 April. A pre-emergence application of 0.70 kg ha^{-1} atrazine plus 1.9 kg ha^{-1} s-metolachlor plus 0.2 kg ha^{-1} mesotrione was applied on 5 May 2009 (Table 2.8). All plots in 2010 were treated with a burndown application of 0.3 kg ha^{-1} 2-ethylhexyl ester[2,4-dichlorophenoxyacetic acid] plus 1.2 kg ha^{-1} glyphosate [N-(phosphonomethyl)glycine] on 2 May. A pre-emergence application of 1.5 kg ha^{-1} atrazine plus 1.5 kg ha^{-1} s-metolachlor plus 0.2 kg ha^{-1} mesotrione was applied on 5 May 2010 (Table 2.8). No further resistance problems or other weed problems existed throughout the growing season in either year.

Corn was harvested after physiological maturity, on 27 October, 2009 and 9 October 2010, respectively. In 2009, all plots were hand harvested with a harvest area of 6.9 m^2 (1.5 m by 4.6 m) from the middle two rows of the four row plots. After harvesting, plot grain weights were measured after shelling by using an Almaco ECS Sheller (Almaco, Nevada, IA). Moisture content and test weight at shelling were measured with a Dickey-john GAC 2000 grain analysis computer (Dickey-john Corp., Springfield, IL). Grain yields were calculated from the shelled grain weights and were adjusted to correct plot weights to 155 g kg^{-1} moisture content. Individual kernel weights were determined by the weighing 100 seeds after oven-drying for 36 hours at 100°C .

In 2010, all plots were harvested by using a two row Gleaner E3 plot combine (AGCO Corp., Duluth, GA). The harvest area was 23.1 m^2 (1.5m by 15.2m) from the middle two rows of the four row plots. During harvest, plot grain weights were measured using a load cell and indicator, constant time was allowed for combine clean out between plots. Samples were taken representatively for each plot to obtain moisture content and test weight. Moisture content and test weight at shelling were measured with a Dickey-john GAC 2000 grain analysis computer (Dickey-john Corp., Springfield, IL). Grain yields were calculated from the shelled grain weights and were adjusted to correct plot weights to 155 g kg^{-1} moisture content. Individual kernel weights were determined by weighing 100 seeds after oven-drying for 36 hours at 100°C .

Nitrogen (N), phosphorus (P), and potassium (K) concentrations of plant and grain were determined both years. Ten sequential whole plant samples without the grain were taken the

same day, prior to harvest, from one of the two middle rows of each plot. Samples were ground to pass through a 2mm sieve by shredding the material first using a chipper shredder, then by using a Model 4 Thomas-Wiley laboratory mill equipped with a 2 mm sieve (Thomas Scientific, Swedesboro, NJ). Grain samples were ground to pass through a 1mm particle sieve with a UDY cyclone sample mill (UDY Corp., Boulder, CO). Both plant and grain samples were analyzed for total N, P, and K by using the sulfuric acid/hydrogen peroxide wet digestion method by the Kansas State University Soil Testing Laboratory (Miller and Miller, 1948). Nutrient removal in N, P, and K by grain was calculated as the product of dry basis grain yield and nutrient concentration.

Due to the difference in treatments across years, the individual years were analyzed separately. A combined year analysis was ran and all yield determinates and nutrient concentrations posed significant differences between years, due to hot and dry weather conditions in 2010. All data in tables are separated by year and conclusions should be made within years, but conclusions should consider that 2009 was a wet and cool year and 2010 was a dry and hot year relative to Kansas conditions. Data were analyzed with Fisher's protected LSD test, pdmix 800, and orthogonal contrasts using PROC MIXED in SAS version 9.1 (SAS Institute, Cary, NC). The significance of main effect differences and their interactions were determined with treatment, starter, and treatment by starter as fixed effects; with block and block by treatment as random effects. Mean separations were used only if the F-tests for fixed effects were significant ($p=0.05$). Co-variance was tested with confidence limits by year and denominator degree of freedom was testing using the Satterthwaite method. Linear and quadratic regression's were analyzed using PROC REG in SAS version 9.1 (SAS Institute, Cary, NC) and graphical plots were made using Sigma Plot 11 (Systat Software, San Jose, CA).

Results and Discussion

In-season cumulative precipitation and GDUs for the two years, and the 30 year average are illustrated in Table 2.9 (KSU Weather Data Library). In-season precipitation was above average in 2009, and below average in 2010. Growing degree units were also below average in 2009, and above average in 2010. In 2009, cooler temperatures and narrower temperature ranges led to decreased GDUs compared with the normal (Table 2.9). In 2010, hot and dry periods throughout the tassel and grain fill stages occurred, resulting in above average GDUs and below

average rainfall. Cumulative precipitation and irrigation amounts are listed in Table 2.10. As stated earlier, rainfall was above average in 2009 and below average for 2010; consequently lower irrigation amounts were required in 2009 compared with 2010. In-season daily cumulative precipitation and irrigation amounts are illustrated in Figure 2.3. In 2009, dry periods in May caused earlier initiation of irrigation in mid-May. Dry stages in late-June and early-August in 2010 caused greater irrigation needs throughout the latter part of the growing season. Irrigation water quality results are summarized in Table 2.11. The levels of elements in the water were relatively low and rated as excellent to good as irrigation water, with the exception of iron at a concentration of 2.60 mg L⁻¹ which is considered a high level of concern on SDI systems (Rogers et al., 2003). A pH measurement was taken and was considered to be a moderate level of concern at 7.66.

Each year, KanSched 2.0 (Rogers et al., 2006) produced an output which reported the daily budgets throughout the growing season (Appendix A). In 2009 rainfall events were steady and irrigation timing helped soil water availability, so that the soil water availability never fell below 50% MAD (Appendix A.1). With the hot and dry periods in early August 2010, soil water availability dropped well below 50% even with maximum irrigation events each day. In mid-August, available soil water content dropped to 51.1mm and the root zone water deficit increased to 108 mm (Appendix A.2). Due to the changing of treatment seven in 2010, all results will be analyzed separately, by years due to unequal variance.

Grain Yield

A significant treatment by starter interaction was observed ($p=0.05$) for grain yields in 2009. Grain yields averaged 13.1 Mg ha⁻¹ across all treatments, and ranged from 12.2 to 14.8 Mg ha⁻¹ (Table 2.12). Starter banded fertilizer at planting helped early season growth (Figure 2.4 and Figure 2.5). Giving that corn plant an extra boost around the seed at planting can help the nutrition of the plant across the growing season (Mengel, 2010). Treatments having the highest grain yields were those with both a starter band at planting and a fertigation treatment during the growing season. The only treatments responding significantly to the starter band at planting were the three highest yielding treatments, Nutra-Flo 6-24-6 with Avail, Assure Crop 5-20-5 with Plen-T-Phos, and Haifa 12-61-0; all other treatments did not respond significantly to the starter band at planting.

The fertigation treatments of Nutra-Flo 6-24-6 with Avail, Assure Crop 5-20-5 with Plen-T-Phos, and Haifa 12-61-0 only responded to fertigation applications if the starter banded fertilizer at planting was applied. The treatments of control, Nutra-Flo 6-24-6 without Avail, Nutra-Flo 9-18-9 with Avail, and Nutra-Flo 9-18-9 without Avail caused the interaction due to the non significance between the starter and non-starter applications. This could be attributed to Liebig's Law of Minimum, if not enough P in the soil is available, another limiting nutrient factor such as N or K could become limiting and hinder P availability (Liebig, 1840). Treatments responded to the fertigation application only if starter fertilizer was applied, all treatments were the same when the starter band at planting was not applied. Treatment 3, a fluid application of Nutra-Flo 6-24-6 with Avail had a mean of 14.2 Mg ha^{-1} and was significantly different from the control treatment. Treatment 6, a granular treatment of Haifa 12-61-0 responded very well to fertigation and was one of the highest yielding treatments. P-enhancing products can help advance the availability of P to the plant in many situations. In high pH soils, magnesium and calcium readily precipitate the P and hinder the P from entering the plant. These products help tie up the antagonistic cations and help the P be readily available to the plant. P-enhancing products, such as Avail helped the overall vigor of the plant (Figure 2.6) and the stalk strength (Figure 2.7), but only increased yield in one treatment. Plen-T-Phos added to Assure Crop 5-20-5 increased grain yield from 13.2 to 14.8 Mg ha^{-1} in 2009.

Three orthogonal contrasts were conducted to compare the control treatments with all other fertigation treatments (Table 2.12). A significant difference ($p=0.05$) was observed between the control plot with starter applied and all other treatments with starter applied. This implies that split applying nutrients at two different times, both at planting and in the middle of the growing season can help irrigated corn yields. Conversely, no difference between the no starter applied control plot versus all other no starter applied treatments was found. By using the means of both the starter and non-starter applied treatments versus the means of all other treatments, one can imply if the fertigation treatments affected irrigated corn yields regardless of starter application method. A difference between the control treatment and all other treatments was found in 2009.

A significant starter main effect ($p=0.05$) was observed in the 2010 season (Table 2.12). However, no significant treatment by starter interaction or treatment effect was found. Irrigated corn yields averaged 10.1 Mg ha^{-1} , ranging from 9.0 to 10.9 Mg ha^{-1} . All starter band applied

treatments yielded higher than no starter band applied treatments, with mean grain yields of 10.5 Mg ha⁻¹ and 9.6 Mg ha⁻¹, respectively (Table 2.13). Despite the high P-levels in the soil, starter band applied P can still help early season growth and corn seedling health. Due to the higher P-levels in the soil and the potential loss of N through volatilization from the surface applied urea in the early season could attribute to the fact no interaction or treatment main effect was observed in 2010. The loss of N through volatilization was due to the warm drying soil, high pH soil, and the need for water in the urea hydrolysis reaction after the application of urea (Leikam, 2010).

A significant ($p=0.05$) starter main effect was observed for individual seed weight in 2009 (Table 2.14). No specific differences were found in 2010. Individual seed weight was greater for all starter band applied treatments with respect to no starter band applied treatments, mean seed weights were 280 mg seed⁻¹ and 262 mg seed⁻¹ for the respective treatments.

Grain Nutrient Concentrations

Grain nutrient concentrations were analyzed separately due to the treatment change and unequal variances in years. A significant ($p=0.05$) treatment main effect was observed for grain P concentration (Table 2.16) and a significant ($p=0.05$) starter main effect was observed for grain N concentration in 2009 (Table 2.15). Grain K concentration did not follow any patterns and relatively constant at approximately 3.6 g kg⁻¹ for all treatments. Grain P concentration for the control treatment was 3.09 g kg⁻¹. The control treatment was different from only one treatment, the granular, Haifa 12-61-0, which had a mean P concentration of 3.34 g kg⁻¹ (Table 2.16). All other treatments were very similar with respect to grain P concentration. Grain N concentration was considerably lower for the no starter band at planting, 10.20 g kg⁻¹ than the starter band at planting, 10.90 g kg⁻¹. This increase in grain N concentration can be associated in situ with the increase in grain yield for all starter band applied treatments since N was a non-limiting factor in 2009.

A significant ($p=0.05$) starter main effect was observed for grain P concentration in 2010 (Table 2.15). Starter band applied treatments exhibited less grain P concentration than no starter band applied treatments, with mean concentrations of 3.45 g kg⁻¹ and 3.60 g kg⁻¹, respectively. Plots without the starter band had greater grain K concentration than plots with the starter band at

planting. Nitrogen P, and K concentrations were greater in 2010, but no differences can be explained due to climatic conditions and treatment changes.

Grain phosphorus in 2010 significantly ($p=0.05$) affected grain yields (Figure 2.8). As grain P increased by one unit in 2010, grain yield increased at a rate of 1.00 Mg ha^{-1} . Grain P did not correlate to grain yield in 2009, due to greater variability in grain samples. Grain nitrogen varied greatly between years (Figure 2.9). A quadratic relationship between grain N and grain yield was found in 2009, 10.10 g kg^{-1} was deemed as the minimum grain N that needs to be in the grain to achieve adequate grain yields. 2010 was completely different, increased grain N led to a decrease in grain yield. This could be due to the N being a limiting factor or greater P getting into the kernel as a response to adequate P fertilization.

Nutrient Removal

Nutrient removal can play an important part in irrigated corn management in the Great Plains. It can help with overall nutrient management planning and help make recommendations in subsequent years following nutrient applications. In this study nutrient removal for N, P, and K was a function of grain yield and grain nutrient concentration, respectively. Therefore, the partitioning of differences in nutrient removal could either be due to grain yield or grain nutrient concentration. A significant ($p=0.05$) starter main effect was observed for N, P, and K removal in both years (Table 2.15). Nutrient removal was mostly affected by grain yield differences (Table 2.15). Nitrogen grain removal was significantly ($p=0.05$) greater for all starter band applied treatments, with a mean N removal of 123 kg N ha^{-1} for starter band applied and 110 kg N ha^{-1} for no starter band applied in 2009 (Table 2.17). In 2010, grain yields were lower; subsequently N removal rates were lower. Starter band applied treatments exhibited greater N removal rates, 106 kg N ha^{-1} and 99 kg N ha^{-1} , respectively. Similar to N, P grain removal was significantly ($p=0.05$) greater for all starter band applied treatments, $82 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$ and $77 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$ in 2009; and $70 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$ and $67 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$ in 2010, respectively (Table 2.18). Potassium grain removal was greater for starter band applied treatments ($p=0.05$), however the differences were minimal when compared with N and P in this study (Table 2.19). Using orthogonal contrasts can be a useful tool to compare control plots to all other treatments, either with starter applied, without starter applied, or by averaging both together. Within each year, control plots were different ($p=0.05$) than all other treatments when the starter and non-starter

plots were averaged with respect to N, P, and K grain removal rates. In 2009, control treatments applied with a starter band were significantly ($p=0.05$) different in grain P removal rates than all other treatments applied with a starter band (Table 2.18). This exemplifies when starter is applied along with fertigation applications, grain P removal rates increase, therefore making P replenishment very important in irrigated corn fields. When contrasting the control plots to all other treatments regardless of starter fertilizer, N, P, and K grain removal was less than all other treatments averaged together in both years, mostly due to grain yield differences.

Stover Nutrient Concentration

A significant ($p=0.05$) starter main effect was observed for stover N in 2010. Starter band applied treatments had greater amounts of N in the stover when compared with no starter band applied treatments (Table 2.20). Phosphorus content in the stover appeared to have no effects on starter and treatment in either year, except when the control plot was compared to all other treatments in 2009 (Table 2.21). Stover N concentration appeared to decrease in all control plots contrasted to all other treatments, regardless of starter band application in both years. In 2009, stover P concentration appeared to be less in control treatments than all other treatments regardless of starter band application. Potassium content in the stover appeared to have no effects on starter and treatment in either year.

Stover P in 2010 was linearly related to grain yield with a line equation of $y = 8.74 + 0.82x$ (Figure 2.10). This could be due to getting more P into the plant earlier in the season and the P translocated into the grain before maturation; nonetheless, some P can be left behind from the translocation and stored in the plant tissue. Better plant tissue testing throughout the vegetative growth stages in corn may lead to greater deviations in yield later in the season. Stover N samples in 2009, were linearly related to grain yield; and in 2010 a negative quadratic response was found (Figure 2.11). Similar to stover P in 2010, grain yield in 2009 increased as stover N increased with a line equation of $y = 10.9 + 0.72x$ (Figure 2.11). Conversely, in 2010 grain yield was greatest when stover N was 5.1 g kg^{-1} . Due to the loss of N through volatilization early in the season, thereby becoming limiting through the season, grain N decreased and stover N was best described by a quadratic relationship in 2010. In 2009, better growing conditions and greater yields were obtained by having better stabilization of N and P, so no major-limiting nutrients contributed to lessen yields.

A general trend of all stover nutrient concentrations being lower in 2009 than 2010 was observed. This was due to moisture content differences in the stover and random variability within the subsamples. Less than 25% of the N, <20% P, and <50% K in corn is partitioned to the stover at maturity; so simulation of nutrient partitioning is difficult at maturity (Ritchie et al., 1997). To simulate better nutrient uptake partitioning one should consider monitoring nutrient uptake throughout the growing season, in the important stages of vegetative growth.

Summary of Results

Due to the complexity of the split-plot design, summary tables of cumulative results for the starter main effect were created (Table 2.13 and Table 2.15). As stated earlier, in 2009, grain yield, individual seed weight, N in the stover, N in the kernel, grain N removal, grain P removal, and grain N removal were observed as significant ($p=0.05$) main effects. Higher grain yields were obtained due to heavier seed weights, greater N concentrations in the kernel; thereby increasing grain N, P, and K removal. 2010 exhibited lower grain yields, however many starter main effects were observed, including: grain yield, P in the kernel, grain N, P, and K removal. Increased yields were obtained by applying a starter band at planting, by increasing grain N, P, and K removal. However, P in the kernel was reduced when starter band applied grain yields were higher. Hypothetically, since P soil test levels were very high in 2010, N may have partitioned to a limiting factor and a N-P negative interaction in the soil may have contributed to significantly lower P kernel concentrations, even though grain yields were greater.

Nutrient response curves can help producers make very important decisions in their operation. In high yielding sub-surface drip irrigated corn fields, nutrients need to be replenished to obtain better growing environments in subsequent years. Phosphorus was applied at four different rates, and as P applied increases, grain yield increases and seemed to increase even at high rates of P (Figure 2.12). To increase yields above expectations, it seems that greater than 20 kg P_2O_5 ha⁻¹ is needed to achieve high irrigated corn yields, even when P levels in the soil are relatively high. Efficient placement of P, either near the seed or near actively growing roots throughout the growing season can help irrigated corn yields even at high P levels in the soil.

With the addition of P-enhancing products in the study, many conclusions and implications can be drawn. The effects of the P-enhancing polymers on yield can be found on Table 2.22 and Table 2.23. In many high pH, alkaline soils, magnesium and calcium are

abundant and tie up P from becoming available to the plant. The two products responded positively in both years; however due to the variability between plots only a significant ($p=0.05$) response to grain yield was observed with the Plen-T-Phos application to Assure Crop 5-20-5 (Table 2.22). In 2009, Plen-T-Phos increased grain yield from 12.7 to 14.1 Mg ha⁻¹. However, no other implications on nutrient content in grain or stover, or grain nutrient removal were observed in this study. The use of P-enhancing polymers can not only boost grain yields, but can also help important reactions with the fertilizer, and try and minimize precipitant formation when applied through SDI systems, which will be covered in the next chapter.

Conclusions

Many conclusions can be drawn from this study both quantitatively and hypothetically. A well documented response to starter band application at planting was observed in each year both visually and quantitatively. A 0.90 Mg ha⁻¹ grain yield increase was observed in starter band applied treatments at planting in each year. Improved early season growth and stimulation of deficient young plants led to well documented responses. Greater seed weight, stover nitrogen, grain nitrogen, and N, P, and K grain removal all contributed to higher yields with applications of starter banded P at planting. In high yielding irrigated corn environments, a starter band application is needed regardless of soil test P based on this information. Even though significant treatment responses were not found with fertigation in this experiment, in 2009 applying a starter banded fertilizer in combination with a fertigation application in the vegetative growing season created a significant interaction. Greater yields were obtained by applying starter at planting in combination with Nutra-Flo 6-24-6 and Avail in-season, Assure Crop 5-20-5 and Plen-T-Phos in-season, and Haifa 12-61-0 in-season, in 2009. The fertigation in-season applications were deemed appropriate in 2009 for the high yielding irrigated corn environment. Grain yields for the control treatment versus all other treatments averaged together were different in 2009, which warrants the decision to apply P nutrients as an in-season fertigation application. In 2010, very few differences were observed in this study, due to the hot and dry conditions during grain fill. A significant starter response was observed, very similar to 2009, in that starter band applied plots exhibited greater grain yields than plots with no starter band applied. Even though soil test P levels were relatively high in both years, significant starter band at planting responses were well documented. Placement and timing can be attributed to

these responses. By placing a starter band at planting below the soil surface and near the seed, early vegetative growth can accelerate the plants development. Placing an in-season fertigation application 38cm below the soil surface and next to actively growing corn roots can help “spoon” feed the crop. Efficiently placing P in an active growing environment can lead to greater P uptake into the plant by diffusion. An appropriate nutrient management decision in an irrigated SDI field based on this study would be to apply a starter band at planting every year in combination with appropriate fertilizers injected into the SDI system based on rainfall and soil test depending on the year.

Before applying nutrients through an conventional SDI system, many questions are of great concern such as, what fertilizer’s are deemed appropriate to apply, what concentration of fertilizer will “clog” up an irrigation system, how much precipitant will form as a result of mixing fertilizer, and what best management practices (BMPs) need to be implemented to minimize these important issues. The next chapter will cover a small laboratory study conducted to identify some of the important concepts of mixing fertilizer with irrigation water.

Tables

Table 2.1 Pre-plant soil test in 2009 & 2010 at Ashland Bottoms

| Year | Block | Depth | pH | P | K | NO ₃ -N | NH ₄ -N | OM |
|-------|-------|-------|-----|---------------------|---------------------|---------------------|---------------------|-----|
| | | cm | | mg kg ⁻¹ | mg kg ⁻¹ | mg kg ⁻¹ | mg kg ⁻¹ | % |
| 2009† | 1 | 0-15 | 8.0 | 47 | 282 | 6.2 | 4.2 | 1.1 |
| | 2 | 0-15 | 8.0 | 42 | 268 | 6.0 | 3.9 | 0.9 |
| | 3 | 0-15 | 8.2 | 32 | 257 | 6.1 | 4.3 | 1.3 |
| 2010‡ | 1 | 0-15 | 8.3 | 53 | 254 | 4.1 | 2.9 | 1.3 |
| | | 15-30 | 8.1 | 28 | 211 | 3.3 | 2.1 | 1.0 |
| | 2 | 0-15 | 8.3 | 51 | 239 | 3.2 | 2.4 | 1.2 |
| | | 15-30 | 8.3 | 28 | 206 | 1.9 | 1.6 | 0.9 |
| | 3 | 0-15 | 8.3 | 42 | 206 | 3.7 | 2.8 | 0.9 |
| | | 15-30 | 8.5 | 27 | 155 | 2.5 | 1.9 | 0.6 |

† Samples were taken 4 April 2009

‡ Samples were taken 28 April 2010

Table 2.2 Pre-plant secondary & micronutrient soil test in 2010 at Ashland Bottoms

| Block† | Depth† | CEC | Ca | Mg | S | Zn | Fe | Cl |
|--------|--------|------------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| | cm | meq 100g ⁻¹ | mg kg ⁻¹ | mg kg ⁻¹ | mg kg ⁻¹ | mg kg ⁻¹ | mg kg ⁻¹ | mg kg ⁻¹ |
| 1 | 0-15 | 13.7 | 2467 | 72 | 6.8 | 1.3 | 13.5 | 3.2 |
| | 15-30 | 14.1 | 2546 | 80 | 6.4 | 0.8 | 16.6 | 2.6 |
| 2 | 0-15 | 12.3 | 2181 | 51 | 6.5 | 1.1 | 9.3 | 5.7 |
| | 15-30 | 14.1 | 2544 | 81 | 6.8 | 0.8 | 9.5 | 3.9 |
| 3 | 0-15 | 11.6 | 2106 | 84 | 6.3 | 0.8 | 6.7 | 3.1 |
| | 15-30 | 13.2 | 2463 | 49 | 6.5 | 0.6 | 6.6 | 4.7 |

†Samples were taken 5 May 2010

Table 2.3 Planting and harvest dates and seeding & fertilizer rates in 2009 & 2010

| Year | Cultivar | Planting Date | Seeding Rate | 2x2 Fertilizer Rate† | Harvest Date‡ |
|------|---------------|---------------|------------------------|---|---------------|
| | | | seeds ha ⁻¹ | kg P ₂ O ₅ ha ⁻¹ | |
| 2009 | Pioneer 33T57 | 11 May | 74 100 | 17.1 | 27 October |
| 2010 | Pioneer 33T57 | 3 May | 74 100 | 17.1 | 9 October |

†2x2 Fertilizer applied with the planter only on starter split plots

‡In 2009 plots hand harvested 7m², 2010 machine harvested ~23m²

Table 2.4 In-season fertilizer dates and fertilizer rates in 2009 & 2010

| Year | Top Dress Nitrogen Rate† kg N ha ⁻¹ | Topdress Application Date | Fertigation Injection Rate‡ kg P ₂ O ₅ ha ⁻¹ | Fertigation Application Date |
|------|---|---------------------------|--|------------------------------|
| 2009 | 179 | 22 May | 34 | 12-13 June |
| 2010 | 179 | 26 May | 34 | 14-15 June |

†Applied as surface applied urea

‡Fertigation rates are not applicable on control plots

Table 2.5 List of treatments and amounts of P and N in 2009

| 2x2 Starter Applied† | Fertigation Treatment | Additive | Additive Rate % v/v | Fertigation Injection Rate kg P ₂ O ₅ ha ⁻¹ | Total Phosphorus Applied ‡ kg P ₂ O ₅ ha ⁻¹ | Total N Applied § kg N ha ⁻¹ |
|----------------------|-----------------------|-------------|------------------------|---|---|--|
| 1 | Control | - | - | - | 17.13 | 196.33 |
| 2 | NF 6-24-6 | - | - | 34 | 51.13 | 204.73 |
| 3 | NF 6-24-6 | Avail | 0.5 | 34 | 51.13 | 204.73 |
| 4 | Assure 5-20-5 | - | - | 34 | 51.13 | 204.72 |
| 5 | Assure 5-20-5 | Plen-T-Phos | 0.5 | 34 | 51.13 | 204.72 |
| 6 | Haifa 12-61-0 | - | - | 34 | 51.13 | 202.94 |
| 7 | NF 9-18-9 | Avail | 0.5 | 34 | 51.13 | 213.13 |
| 8 | NF 9-18-9 | - | - | 34 | 51.13 | 213.13 |
| Not Applied | | | | | | |
| 1 | Control | - | - | - | - | 179.20 |
| 2 | NF 6-24-6 | - | - | 34 | 34.00 | 187.60 |
| 3 | NF 6-24-6 | Avail | 0.5 | 34 | 34.00 | 187.60 |
| 4 | Assure 5-20-5 | - | - | 34 | 34.00 | 187.59 |
| 5 | Assure 5-20-5 | Plen-T-Phos | 0.5 | 34 | 34.00 | 187.59 |
| 6 | Haifa 12-61-0 | - | - | 34 | 34.00 | 185.81 |
| 7 | NF 9-18-9 | Avail | 0.5 | 34 | 34.00 | 195.99 |
| 8 | NF 9-18-9 | - | - | 34 | 34.00 | 195.99 |

† 2x2 Starter was applied to all split plots at a rate of 78.6 L ha⁻¹

‡ Total P applied equals amount of P fertigation plus 2x2 starter @ planting, if applicable

§ Total N applied equals the amount of N fertigation plus starter @planting, plus 179 kg N ha⁻¹ applied as urea

Table 2.6 List of treatments and amounts of P and N for 2010

| 2x2 Starter | Fertigation Treatment | Additive | Additive Rate | Fertigation Injection Rate | Total Phosphorus Applied ‡ | Total N Applied § |
|-------------|-----------------------|-------------|---------------|---|---|-----------------------|
| Applied† | | | % v/v | kg P ₂ O ₅ ha ⁻¹ | kg P ₂ O ₅ ha ⁻¹ | kg N ha ⁻¹ |
| 1 | Control | - | - | - | 17.13 | 196.33 |
| 2 | NF 6-24-6 | - | - | 34 | 51.13 | 204.73 |
| 3 | NF 6-24-6 | Avail | 0.5 | 34 | 51.13 | 204.73 |
| 4 | Assure 5-20-5 | - | - | 34 | 51.13 | 204.72 |
| 5 | Assure 5-20-5 | Plen-T-Phos | 0.5 | 34 | 51.13 | 204.72 |
| 6 | Haifa MAP | - | - | 34 | 51.13 | 202.94 |
| 7 | Rotem 0-60-20 | - | - | 34 | 51.13 | 196.33 |
| 8 | NF 9-18-9 | - | - | 34 | 51.13 | 213.13 |
| Not Applied | | | | | | |
| 1 | Control | - | - | - | - | 179.20 |
| 2 | NF 6-24-6 | - | - | 34 | 34.00 | 187.60 |
| 3 | NF 6-24-6 | Avail | 0.5 | 34 | 34.00 | 187.60 |
| 4 | Assure 5-20-5 | - | - | 34 | 34.00 | 187.59 |
| 5 | Assure 5-20-5 | Plen-T-Phos | 0.5 | 34 | 34.00 | 187.59 |
| 6 | Haifa MAP | - | - | 34 | 34.00 | 185.81 |
| 7 | Rotem 0-60-20 | - | - | 34 | 34.00 | 179.20 |
| 8 | NF 9-18-9 | - | - | 34 | 34.00 | 195.99 |

† 2x2 Starter was applied to all split plots at a rate of 78.6 L ha⁻¹

‡ Total P applied equals amount of P fertigation plus 2x2 starter @ planting, if applicable

§ Total N applied equals the amount of N fertigation plus starter @ planting, plus 179 kg N ha⁻¹ applied as urea.

Table 2.7 Fertigation injection treatment log for 2009 & 2010

| Year | Treatment | Fertilizer | Rec. Rate | Actual Rate Applied | Fertilizer Run Time | Water Flush Time |
|------|-----------|----------------|-------------------------------|-------------------------------|---------------------------|---------------------------|
| | | | L fertilizer ha ⁻¹ | L fertilizer ha ⁻¹ | sec 0.12 ha ⁻¹ | sec 0.12 ha ⁻¹ |
| 2009 | 1 | Control | — | — | — | — |
| | 2 | NF 6-24-6 | 104.5 | 109.1 | 1860 | 1440 |
| | 3 | NF 6-24-6† | 104.5 | 109.1 | 1860 | 2040 |
| | 4 | Assure 5-20-5 | 133.6 | 140.3 | 2520 | 2100 |
| | 5 | Assure 5-20-5‡ | 133.6 | 140.3 | 2460 | 2100 |
| | 6 | Haifa 12-61-0§ | 55.1§ | 56.0§ | 2640 | 1860 |
| | 7 | NF 9-18-9† | 141.7 | 140.3 | 2400 | 2040 |
| | 8 | NF 9-18-9 | 141.7 | 140.3 | 2340 | 2100 |
| 2010 | 1 | Control | — | — | — | — |
| | 2 | NF 6-24-6 | 104.5 | 109.1 | 1920 | 1980 |
| | 3 | NF 6-24-6† | 104.5 | 109.1 | 2220 | 2220 |
| | 4 | Assure 5-20-5 | 133.6 | 140.3 | 2400 | 2100 |
| | 5 | Assure 5-20-5‡ | 133.6 | 140.3 | 2460 | 2100 |
| | 6 | Haifa 12-61-0§ | 55.1§ | 56.0§ | 3060 | 2040 |
| | 7 | Rotem 0-60-20¶ | 56.0¶ | 56.0¶ | 2280 | 2100 |
| | 8 | NF 9-18-9 | 141.7 | 140.3 | 2640 | 1860 |

† Avail was added at 0.5 v/v

‡ Plen-T-Phos was added at 0.5 v/v

§ Granular product (kg ha⁻¹), was dissolved in 18.9L water prior to injecting

¶ Granular product (kg ha⁻¹), was dissolved in 15.1L water prior to injecting

Table 2.8 Herbicide Applications in 2009 & 2010

| Year | Burndown-herbicide and rate kg a.i. ha ⁻¹ | Date | PRE-herbicide and rate kg a.i. ha ⁻¹ | Date |
|------|--|----------|---|--------|
| 2009 | 1.1 glyphosate† | 28 April | 0.70 atrazine‡ + 1.9 S-Metolachlor§ + 0.2 mesotrione¶ | 05 May |
| 2010 | 0.3 2-ethylhexyl ester# + 1.2 glyphosate | 02 May | 1.5 atrazine + 1.5 S-Metolachlor + 0.2 mesotrione | 05 May |

† Glyphosate [N-(phosphonomethyl)glycine]

‡ Atrazine [2-chloro-4-(ethylamino-6-(isopropylamino)-s-triazine]

§ S-Metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-[(1S)-2-methoxy-1-methylethyl] acetamide]

¶ Mesotrione [2-[4-(methylsulfonyl)-2-nitrobenzoyl]-1,3-cyclohexanedione]

2-ethylhexyl ester [2,4-dichlorophenoxyacetic acid]

Table 2.9 In-season growing degree units and precipitation in 2009 & 2010

| Year† | Growing Degree Units‡ | Precipitation |
|--------|-----------------------|---------------|
| | GDU's | mm |
| 2009 | 3116 | 725 |
| 2010 | 4376 | 609 |
| Normal | 3403 | 690 |

† GDUs and Precipitation values from KSU Weather Data Library

‡ Growing season considered 1 April through 31 October in GDU calculation

Table 2.10 In-season precipitation and irrigation in 2009 & 2010

| Year | Precipitation† | Irrigation‡ |
|--------|----------------|-------------|
| | mm | mm |
| 2009 | 725 | 195 |
| 2010 | 609 | 290 |
| Normal | 690 | - |

† Precipitation values from KSU Weather Data Library

‡ Irrigation values downloaded from irrigation controller

Table 2.11 Well water analysis in 2010 at Ashland Bottoms

| Analysis | Result | Units |
|-------------------------|-------------------|------------------------|
| pH | 7.66 | — |
| Chloride | <2.5 | mg L ⁻¹ |
| Total Hardness | 402 | mg L ⁻¹ |
| Nitrate-N | <1.0 | mg L ⁻¹ |
| Calcium | 102 | mg L ⁻¹ |
| Magnesium | 10.9 | mg L ⁻¹ |
| Sodium | 6.3 | mg L ⁻¹ |
| Sulfate | 12.5 | mg L ⁻¹ |
| Sodium | 5.3 | % |
| Sodium Absorption Ratio | 0.16 | — |
| Iron | 2.60 | mg L ⁻¹ |
| Electrical Conductivity | 623 | µmhos cm ⁻¹ |
| Total Dissolved Solids | 442 | mg L ⁻¹ |
| Quality of Water | Excellent to Good | — |

Table 2.12 Grain yield results for 2009 & 2010

| Treatment | Grain Yield | | | | | |
|--|-------------|-------------|--------|---------|-------------|------|
| | 2009 | | | 2010 | | |
| | Starter | Non-Starter | | Starter | Non-Starter | |
| Mg ha ⁻¹ | | | | | | |
| Control | 12.3 | de† | 12.2 | de | 9.8 | 9.0 |
| NF 6-24-6 | 13.3 | bcde | 12.7 | de | 10.3 | 9.4 |
| + Avail | 14.2 | abc | 12.5 | de | 10.9 | 9.9 |
| AC 5-20-5 | 13.2 | bcd | 12.2 | de | 10.8 | 9.6 |
| + Plen-T-Phos | 14.8 | a | 13.4 | bcde | 10.7 | 9.9 |
| Haifa 12-61-0 | 14.2 | ab | 13.1 | cde | 10.3 | 9.9 |
| NF 9-18-9 | 13.2 | bcde | 12.8 | de | 10.5‡ | 9.7‡ |
| + Avail‡ | | | | | | |
| NF 9-18-9 | 12.5 | de | 12.2 | de | 10.3 | 9.4 |
| Mean | 13.5 | a | 12.6 | b | 10.5 | a |
| LSD _{start} | | | 0.24 | | 0.27 | |
| LSD _{trt*start} | | | 1.30 | | NA | |
| | | | Prob>F | | | |
| Treatment | | | 0.096 | | 0.4402 | |
| Starter | | | <.0001 | | <.0001 | |
| Treatment x Starter | | | 0.0442 | | .8349 | |
| Orthogonal Contrasts | | | | | | |
| §Control _{Start} vs. TRT _{Start} | | | 0.01 | | 0.09 | |
| ¶Control _{NS} vs. TRT _{NS} | | | 0.31 | | 0.07 | |
| #Control _{Both} vs. TRT _{Both} | | | 0.01 | | 0.01 | |

† Mean grain yields across both applications with the same letter aren't different, $\alpha=0.05$.

‡ Treatment was switched in 2010, Rotem 0-60-20.

§ Contrast included mean of starter control vs. all other treatments with starter.

¶ Contrast included mean of non-starter control vs. all other treatments of non-starter.

Contrast included mean of both starter and non-starter vs. all other treatments of both starter and non-starter.

Table 2.13 Starter band applied at planting yield determinates & stover nutrients

| Year | Starter | Grain Yield | Seed Weight | Moisture | Test Weight | N Stover | P Stover | K Stover |
|------|--------------|---------------------|-----------------------|--------------------|---------------------|--------------------|--------------------|--------------------|
| 2009 | | Mg ha ⁻¹ | mg seed ⁻¹ | g kg ⁻¹ | kg hL ⁻¹ | g kg ⁻¹ | g kg ⁻¹ | g kg ⁻¹ |
| | No Starter | 12.6 | 262 | 167 | 71.9 | 2.87 | 0.90 | 15.2 |
| | With Starter | 13.5*** | 280*** | 169 | 72.0 | 3.10* | 0.89 | 15.4 |
| | LSD | 0.24 | 7.94 | NA | NA | 0.207 | NA | NA |
| 2010 | | | | | | | | |
| | No Starter | 9.6 | 235 | 134 | 74.0 | 5.08 | 1.54 | 16.8 |
| | With Starter | 10.5*** | 243 | 133 | 74.1 | 5.30 | 1.60 | 17.5 |
| | LSD | 0.27 | NA | NA | NA | NA | NA | NA |

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 2.14 Individual seed weights in 2009 & 2010

| Treatment | Seed Weight | | | |
|--|-----------------------|-------------|---------|-------------|
| | 2009 | | 2010 | |
| | Starter | Non-Starter | Starter | Non-Starter |
| | mg seed ⁻¹ | | | |
| Control | 286 | 256 | 251 | 248 |
| NF 6-24-6 | 270 | 248 | 243 | 242 |
| + Avail | 274 | 266 | 230 | 239 |
| AC 5-20-5 | 284 | 264 | 247 | 235 |
| + Plen-T-Phos | 288 | 259 | 250 | 250 |
| Haifa 12-61-0 | 277 | 277 | 236 | 222 |
| NF 9-18-9 | 276 | 267 | 241† | 231† |
| + Avail† | | | | |
| NF 9-18-9 | 289 | 256 | 246 | 218 |
| Mean | 280 a‡ | 262 b | 243 | 235 |
| LSD _{start} | 7.94 | | NA | |
| LSD _{trt*start} | NA | | NA | |
| | Prob>F | | | |
| Treatment | .6341 | | .3783 | |
| Starter | .0001 | | .5534 | |
| Treatment x Starter | .2987 | | .8634 | |
| Orthogonal Contrasts | | | | |
| §Control _{Start} vs. TRT _{Start} | 0.50 | | 0.45 | |
| ¶Control _{NS} vs. TRT _{NS} | 0.44 | | 0.21 | |
| #Control _{Both} vs. TRT _{Both} | 0.02 | | 0.71 | |

† Treatment was switched in 2010, Rotem 0-60-20.

‡ Mean seed weights across both applications with the same letter aren't different, $\alpha=0.05$.

§ Contrast included mean of starter control vs. all other treatments with starter.

¶ Contrast included mean of non-starter control vs. all other treatments of non-starter.

Contrast included mean of both starter and non-starter vs. all other treatments of both starter and non-starter.

Table 2.15 Starter band applied at planting on nutrient removal

| Year | Starter | Grain Yield | N Kernel | P Kernel | K Kernel | Grain N Removal | Grain P Removal | Grain K Removal |
|------|--------------|---------------------|--------------------|--------------------|--------------------|-----------------------|---|--------------------------------------|
| | | Mg ha ⁻¹ | g kg ⁻¹ | g kg ⁻¹ | g kg ⁻¹ | kg N ha ⁻¹ | kg P ₂ O ₅ ha ⁻¹ | kg K ₂ O ha ⁻¹ |
| 2009 | No Starter | 12.6 | 10.2 | 3.15 | 3.63 | 110 | 77 | 46 |
| | With Starter | 13.5*** | 10.9** | 3.15 | 3.60 | 123*** | 82** | 49** |
| | LSD | 0.24 | 0.58 | NA | NA | 5.33 | 2.67 | 1.61 |
| | | | | | | | | |
| 2010 | No Starter | 9.6 | 12.2 | 3.60** | 4.07 | 99 | 67 | 40 |
| | With Starter | 10.5*** | 12.1 | 3.45 | 4.04 | 106*** | 70* | 43*** |
| | LSD | 0.27 | NA | 0.11 | NA | 3.55 | 2.88 | 1.22 |
| | | | | | | | | |

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Table 2.16 Grain nutrient concentration in 2009 & 2010

| Treatment | Kernel Nutrient Concentration | | | | | |
|-----------------------------|-------------------------------|----------|------|-------|-------|-------|
| | 2009 | | | 2010 | | |
| | N | P | K | N | P | K |
| | g kg ⁻¹ | | | | | |
| Control | 10.5 | 3.09 bc‡ | 3.52 | 12.0 | 3.52 | 4.06 |
| NF 6-24-6 | 10.5 | 3.25 ab | 3.66 | 12.3 | 3.67 | 4.11 |
| + Avail | 10.4 | 3.26 ab | 3.64 | 12.0 | 3.49 | 4.05 |
| AC 5-20-5 | 10.9 | 3.10 bc | 3.68 | 12.2 | 3.54 | 4.11 |
| + Plen-T-Phos | 10.6 | 3.01 c | 3.51 | 12.1 | 3.41 | 4.03 |
| Haifa 12-61-0 | 10.9 | 3.34 a | 3.72 | 12.2 | 3.56 | 4.08 |
| NF 9-18-9 | 10.4 | 3.00 c | 3.49 | 11.9† | 3.51† | 4.01† |
| + Avail† | | | | | | |
| NF 9-18-9 | 10.3 | 3.14 abc | 3.68 | 12.3 | 3.47 | 4.00 |
| LSD _{treat} | NA | 0.21 | NA | NA | NA | NA |
| | Prob>F | | | | | |
| Treatment | 0.79 | 0.03 | 0.34 | 0.87 | 0.75 | 0.98 |
| Orthogonal Contrasts | | | | | | |
| §Control vs. TRT | 0.10 | 0.48 | 0.43 | 0.92 | 0.21 | 0.68 |

† Treatment was switched in 2010, Rotem 0-60-20.

‡ Mean P concentrations with the same letter aren't different, $\alpha=0.05$.

§ Contrast included mean of control vs. all other treatments.

Table 2.17 Grain nitrogen removal in 2009 & 2010

| Treatment | Nitrogen Removal | | | |
|--|-----------------------|-------------|---------|-------------|
| | 2009 | | 2010 | |
| | Starter | Non-Starter | Starter | Non-Starter |
| | kg N ha ⁻¹ | | | |
| Control | 112 | 106 | 100 | 91 |
| NF 6-24-6 | 124 | 107 | 108 | 97 |
| + Avail | 123 | 111 | 112 | 100 |
| AC 5-20-5 | 122 | 111 | 109 | 100 |
| + Plen-T-Phos | 141 | 113 | 109 | 101 |
| Haifa 12-61-0 | 130 | 123 | 107 | 103 |
| NF 9-18-9 | 122 | 106 | 102‡ | 99‡ |
| + Avail‡ | | | | |
| NF 9-18-9 | 117 | 98 | 104 | 101 |
| Mean | 123 a† | 110 b | 106 a | 99 b |
| LSD _{start} | 5.33 | | 3.55 | |
| | Prob>F | | | |
| Treatment | 0.3203 | | 0.5895 | |
| Starter | <.0001 | | 0.0004 | |
| Treatment x Starter | 0.4682 | | 0.7804 | |
| Orthogonal Contrasts | | | | |
| §Control _{Start} vs. TRT _{Start} | 0.10 | | 0.16 | |
| ¶Control _{NS} vs. TRT _{NS} | 0.61 | | 0.06 | |
| #Control _{Both} vs. TRT _{Both} | 0.01 | | 0.01 | |

† Mean N removal across both applications with the same letter aren't different, $\alpha=0.05$.

‡ Treatment was switched in 2010, Rotem 0-60-20.

§ Contrast included mean of starter control vs. all other treatments with starter.

¶ Contrast included mean of non-starter control vs. all other treatments of non-starter.

Contrast included mean of both starter and non-starter vs. all other treatments of both starter and non-starter.

Table 2.18 Grain phosphorus removal in 2009 & 2010

| Treatment | Phosphorus Removal | | | |
|--|---|-------------|---------|-------------|
| | 2009 | | 2010 | |
| | Starter | Non-Starter | Starter | Non-Starter |
| | kg P ₂ O ₅ ha ⁻¹ | | | |
| Control | 74 | 73 | 66 | 62 |
| NF 6-24-6 | 85 | 79 | 70 | 69 |
| + Avail | 89 | 78 | 75 | 67 |
| AC 5-20-5 | 78 | 74 | 75 | 66 |
| + Plen-T-Phos | 86 | 77 | 69 | 68 |
| Haifa 12-61-0 | 89 | 88 | 69 | 71 |
| NF 9-18-9 | 77 | 73 | 70† | 67† |
| + Avail† | | | | |
| NF 9-18-9 | 77 | 74 | 67 | 66 |
| Mean | 82 a‡ | 77 b | 70 a | 67 b |
| LSD _{start} | 2.67 | | 2.88 | |
| | Prob>F | | | |
| Treatment | 0.1108 | | 0.5436 | |
| Starter | 0.0017 | | 0.0451 | |
| Treatment x Starter | 0.4091 | | 0.3931 | |
| Orthogonal Contrasts | | | | |
| §Control _{Start} vs. TRT _{Start} | 0.04 | | 0.21 | |
| ¶Control _{NS} vs. TRT _{NS} | 0.30 | | 0.10 | |
| #Control _{Both} vs. TRT _{Both} | 0.01 | | 0.01 | |

† Treatment was switched in 2010, Rotem 0-60-20.

‡ Mean P removal across both applications with the same letter aren't different, $\alpha=0.05$.

§ Contrast included mean of starter control vs. all other treatments with starter.

¶ Contrast included mean of non-starter control vs. all other treatments of non-starter.

Contrast included mean of both starter and non-starter vs. all other treatments of both starter and non-starter.

Table 2.19 Grain potassium removal in 2009 & 2010

| Treatment | Potassium Removal | | | |
|--|--------------------------------------|-------------|---------|-------------|
| | 2009 | | 2010 | |
| | Starter | Non-Starter | Starter | Non-Starter |
| | kg K ₂ O ha ⁻¹ | | | |
| Control | 43 | 44 | 41 | 36 |
| NF 6-24-6 | 51 | 46 | 42 | 40 |
| + Avail | 52 | 46 | 46 | 41 |
| AC 5-20-5 | 49 | 46 | 46 | 40 |
| + Plen-T-Phos | 52 | 48 | 43 | 42 |
| Haifa 12-61-0 | 52 | 51 | 42 | 42 |
| NF 9-18-9 | 47 | 45 | 43† | 39† |
| + Avail† | | | | |
| NF 9-18-9 | 47 | 46 | 40 | 40 |
| Mean | 49 a‡ | 46 b | 43 a | 40 b |
| LSD _{start} | 1.61 | | 1.22 | |
| | Prob>F | | | |
| Treatment | 0.1472 | | 0.3384 | |
| Starter | 0.0033 | | <.0001 | |
| Treatment x Starter | 0.3532 | | 0.1606 | |
| Orthogonal Contrasts | | | | |
| §Control _{Start} vs. TRT _{Start} | 0.01 | | 0.28 | |
| ¶Control _{NS} vs. TRT _{NS} | 0.31 | | 0.02 | |
| #Control _{Both} vs. TRT _{Both} | 0.01 | | 0.01 | |

† Treatment was switched in 2010, Rotem 0-60-20.

‡ Mean P removal across both applications with the same letter aren't different, $\alpha=0.05$.

§ Contrast included mean of starter control vs. all other treatments with starter.

¶ Contrast included mean of non-starter control vs. all other treatments of non-starter.

Contrast included mean of both starter and non-starter vs. all other treatments of both starter and non-starter.

Table 2.20 Stover nitrogen in 2009 & 2010

| Treatment | Stover Nitrogen | | | |
|--|--------------------|-------------|---------|-------------|
| | 2009 | | 2010 | |
| | Starter | Non-Starter | Starter | Non-Starter |
| | g kg ⁻¹ | | | |
| Control | 3.02 | 2.63 | 4.83 | 4.58 |
| NF 6-24-6 | 3.23 | 3.03 | 5.23 | 4.75 |
| + Avail | 3.22 | 3.02 | 5.34 | 5.31 |
| AC 5-20-5 | 3.00 | 2.73 | 5.74 | 5.10 |
| + Plen-T-Phos | 3.06 | 3.25 | 5.62 | 5.26 |
| Haifa 12-61-0 | 3.10 | 2.55 | 5.64 | 5.16 |
| NF 9-18-9 | 3.17 | 2.89 | 5.23† | 5.27† |
| + Avail† | | | | |
| NF 9-18-9 | 2.99 | 2.83 | 4.74 | 5.19 |
| Mean | 3.10 a‡ | 2.87 b | 5.30 | 5.08 |
| LSD _{start} | .2065 | | NA | |
| | Prob>F | | | |
| Treatment | 0.4574 | | 0.6435 | |
| Starter | 0.0278 | | 0.1044 | |
| Treatment x Starter | 0.7848 | | 0.4964 | |
| Orthogonal Contrasts | | | | |
| §Control _{Start} vs. TRT _{Start} | 0.70 | | 0.18 | |
| ¶Control _{NS} vs. TRT _{NS} | 0.22 | | 0.16 | |
| #Control _{Both} vs. TRT _{Both} | 0.03 | | 0.05 | |

† Treatment was switched in 2010, Rotem 0-60-20.

‡ Mean stover nitrogen across both applications with the same letter aren't different, $\alpha=0.05$.

§ Contrast included mean of starter control vs. all other treatments with starter.

¶ Contrast included mean of non-starter control vs. all other treatments of non-starter.

Contrast included mean of both starter and non-starter vs. all other treatments of both starter and non-starter.

Table 2.21 Stover phosphorus in 2009 & 2010

| Treatment | Stover Phosphorus | | | |
|--|--------------------|-------------|---------|-------------|
| | 2009 | | 2010 | |
| | Starter | Non-Starter | Starter | Non-Starter |
| | g kg^{-1} | | | |
| Control | 0.64 | 0.67 | 1.63 | 1.50 |
| NF 6-24-6 | 1.03 | 0.95 | 1.49 | 1.61 |
| + Avail | 0.97 | 1.11 | 1.74 | 1.56 |
| AC 5-20-5 | 0.89 | 0.83 | 1.91 | 1.68 |
| + Plen-T-Phos | 1.02 | 0.92 | 1.25 | 1.55 |
| Haifa 12-61-0 | 1.06 | 1.05 | 1.91 | 1.49 |
| NF 9-18-9 | 0.72 | 0.68 | 1.49† | 1.30† |
| + Avail† | | | | |
| NF 9-18-9 | 0.77 | 1.00 | 1.38 | 1.60 |
| Mean | 0.89 | 0.90 | 1.60 | 1.54 |
| | Prob>F | | | |
| Treatment | 0.0889 | | 0.7088 | |
| Starter | 0.8335 | | 0.4607 | |
| Treatment x Starter | 0.7611 | | 0.4923 | |
| Orthogonal Contrasts | | | | |
| ‡Control _{Start} vs. TRT _{Start} | 0.04 | | 0.89 | |
| §Control _{NS} vs. TRT _{NS} | 0.06 | | 0.86 | |
| ¶Control _{Both} vs. TRT _{Both} | 0.04 | | 0.74 | |

† Treatment was switched in 2010, Rotem 0-60-20.

‡ Contrast included mean of starter control vs. all other treatments with starter.

§ Contrast included mean of non-starter control vs. all other treatments of non-starter.

¶ Contrast included mean of both starter and non-starter vs. all other treatments of both starter and non-starter.

Table 2.22 Effect of P-enhancing polymers on yield & stover nutrient concentration

| Year | Fertilizer | Additive | Grain Yield | Seed Weight | N Stover | P Stover | K Stover |
|--------------------|------------|-------------|---------------------|-----------------------|--------------------|--------------------|--------------------|
| | | | Mg ha ⁻¹ | mg seed ⁻¹ | g kg ⁻¹ | g kg ⁻¹ | g kg ⁻¹ |
| 2009 | NF 6-24-6 | — | 13.0 | 259 | 3.13 | 0.99 | 15.6 |
| | NF 6-24-6 | Avail | 13.3 | 270 | 3.12 | 1.04 | 15.4 |
| | NF 9-18-9 | — | 12.4 | 272 | 2.91 | 0.89 | 15.4 |
| | NF 9-18-9 | Avail | 13.0 | 273 | 3.03 | 0.70 | 15.8 |
| | AC 5-20-5 | — | 12.7 | 274 | 2.87 | 0.86 | 15.9 |
| | AC 5-20-5 | Plen-T-Phos | 14.1 | 273 | 3.15 | 0.97 | 14.3 |
| 2010 | NF 6-24-6 | — | 9.9 | 243 | 4.99 | 1.55 | 17.2 |
| | NF 6-24-6 | Avail | 10.4 | 234 | 5.33 | 1.65 | 17.3 |
| | AC 5-20-5 | — | 10.2 | 241 | 5.42 | 1.81 | 17.5 |
| | AC 5-20-5 | Plen-T-Phos | 10.3 | 250 | 5.44 | 1.40 | 18.1 |
| Contrasts | | | | | | | |
| ————— Prob>F ————— | | | | | | | |
| 2009 | NF 6-24-6 | Avail | 0.60 | 0.22 | 0.96 | 0.73 | 0.77 |
| 2009 | NF 9-18-9 | Avail | 0.30 | 0.92 | 0.55 | 0.20 | 0.64 |
| 2009 | AC 5-20-5 | Plen-T-Phos | 0.03 | 0.96 | 0.16 | 0.45 | 0.09 |
| 2010 | NF 6-24-6 | Avail | 0.22 | 0.44 | 0.45 | 0.70 | 0.88 |
| 2010 | AC 5-20-5 | Plen-T-Phos | 0.87 | 0.37 | 0.97 | 0.13 | 0.52 |

Table 2.23 Effect of P-enhancing polymers on kernel & nutrient removal

| Year | Fertilizer | Additive | N | P | K | N | P | K |
|------|------------|----------|--------------------|--------------------|--------------------|---------------------|---------------------|---------------------|
| | | | Kernel | Kernel | Kernel | Removal | Removal | Removal |
| | | | g kg ⁻¹ | g kg ⁻¹ | g kg ⁻¹ | kg ha ⁻¹ | kg ha ⁻¹ | kg ha ⁻¹ |
| 2009 | NF 6-24-6 | — | 10.5 | 3.25 | 3.66 | 115 | 82.1 | 48.5 |
| | NF 6-24-6 | Avail | 10.4 | 3.26 | 3.64 | 117 | 83.7 | 49.0 |
| | NF 9-18-9 | — | 10.3 | 3.14 | 3.68 | 107 | 75.1 | 46.1 |
| | NF 9-18-9 | Avail | 10.4 | 3.00 | 3.49 | 114 | 75.3 | 46.1 |
| | AC 5-20-5 | — | 10.9 | 3.10 | 3.68 | 116 | 76.2 | 47.3 |
| | AC 5-20-5 | PTP† | 10.6 | 3.01 | 3.51 | 127 | 81.8 | 49.9 |
| 2010 | NF 6-24-6 | — | 12.3 | 3.67 | 4.11 | 102 | 69.8 | 41.1 |
| | NF 6-24-6 | Avail | 12.0 | 3.49 | 4.05 | 106 | 71.3 | 43.2 |
| | AC 5-20-5 | — | 12.2 | 3.54 | 4.11 | 105 | 70.6 | 42.8 |
| | AC 5-20-5 | PTP | 12.1 | 3.41 | 4.03 | 105 | 68.4 | 42.3 |
| | | | Contrasts | | | | | |
| | | | ————— Prob>F ————— | | | | | |
| 2009 | NF 6-24-6 | Avail | 0.85 | 0.95 | 0.83 | 0.85 | 0.75 | 0.82 |
| 2009 | NF 9-18-9 | Avail | 0.75 | 0.16 | 0.13 | 0.44 | 0.97 | 0.99 |
| 2009 | AC 5-20-5 | PTP | 0.56 | 0.33 | 0.15 | 0.25 | 0.28 | 0.31 |
| 2010 | NF 6-24-6 | Avail | 0.46 | 0.22 | 0.65 | 0.51 | 0.69 | 0.27 |
| 2010 | AC 5-20-5 | PTP | 0.86 | 0.35 | 0.55 | 0.93 | 0.54 | 0.77 |

† Plen-T-Phos was added with fertilizer

Figures

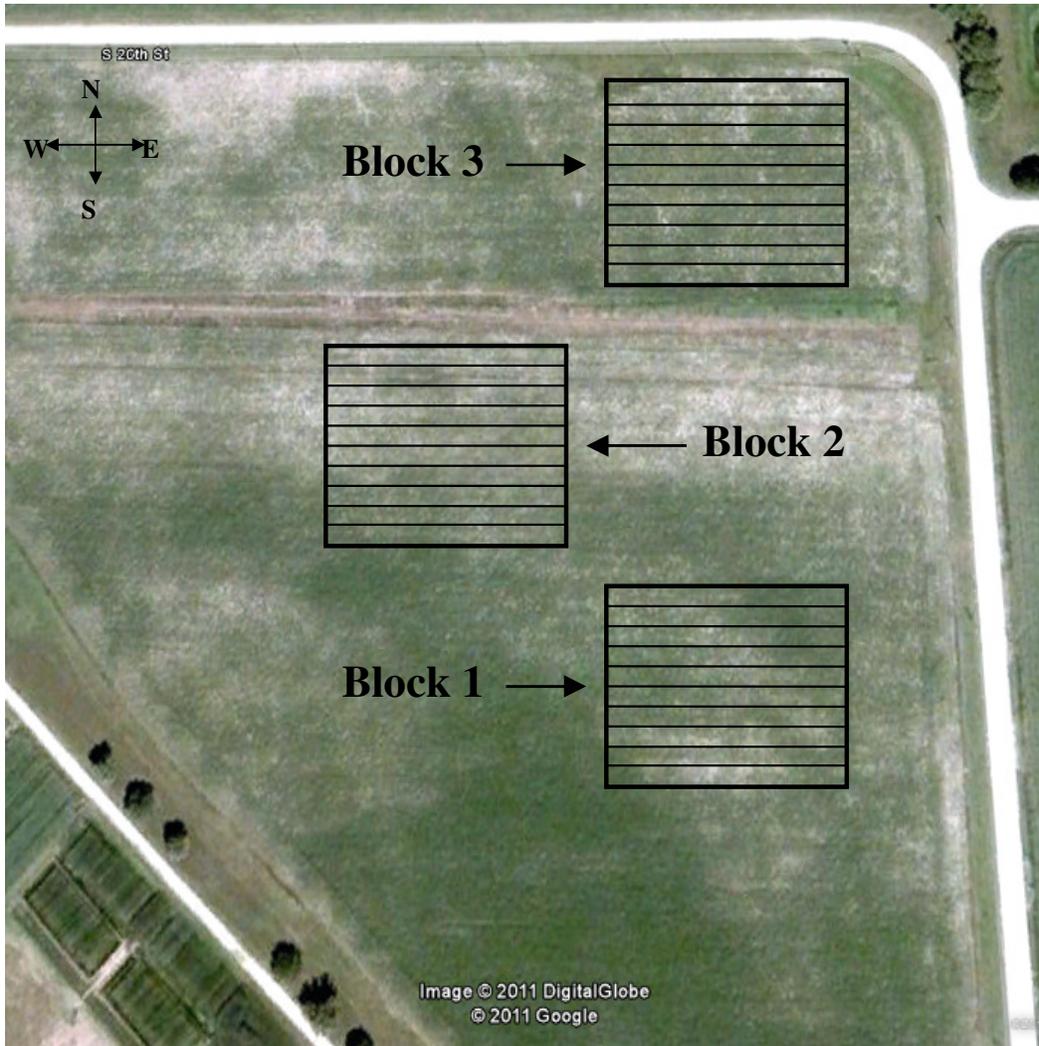


Figure 2.1 Ashland Bottom Field Layout

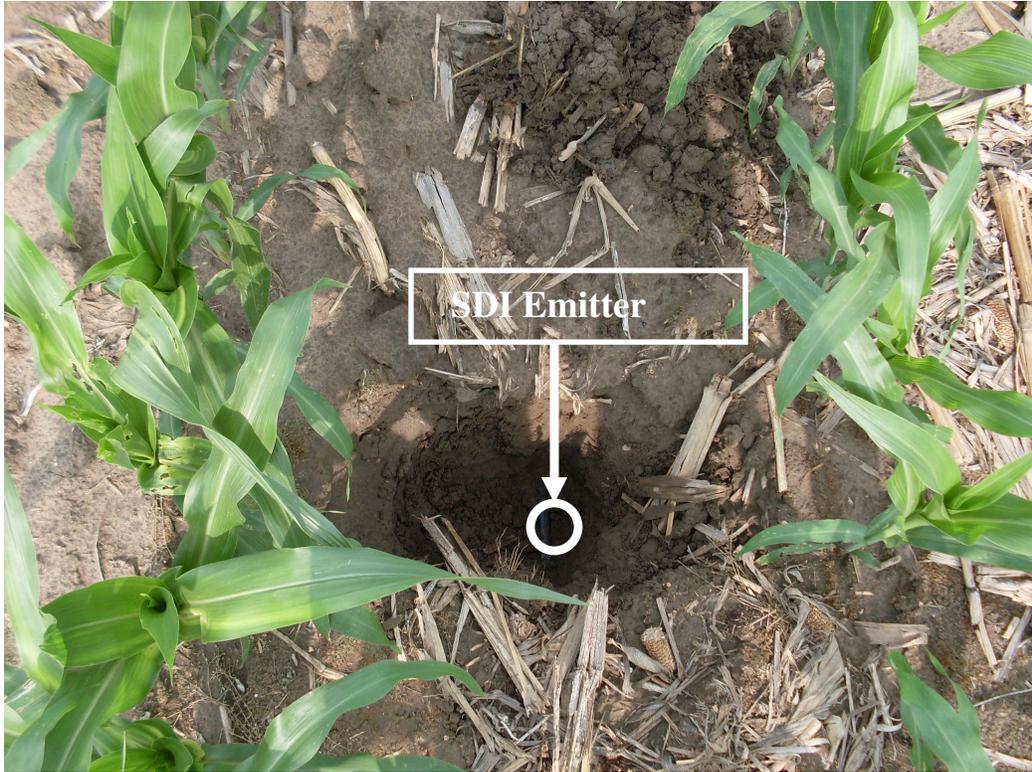


Figure 2.2 Corn spaced between SDI laterals

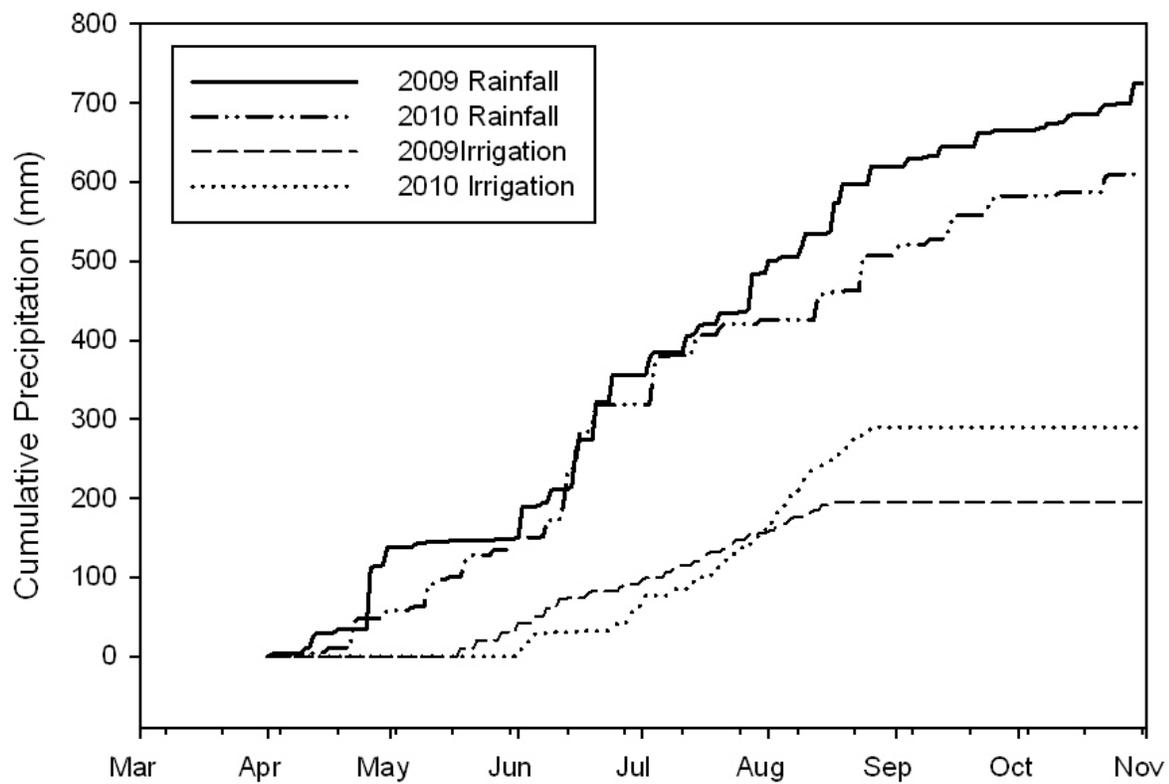


Figure 2.3 Cumulative Rainfall and Irrigation in 2009 and 2010



Figure 2.4 Starter band applied at planting affects early growth



Figure 2.5 Starter band at planting affects actively growing V5 corn plants



Figure 2.6 R2 corn with Avail applied (4 rows on left w/o Avail, 4 rows on right w/ Avail)



Figure 2.7 Avail affects stalk diameter (Avail applied on left, no Avail applied on right)

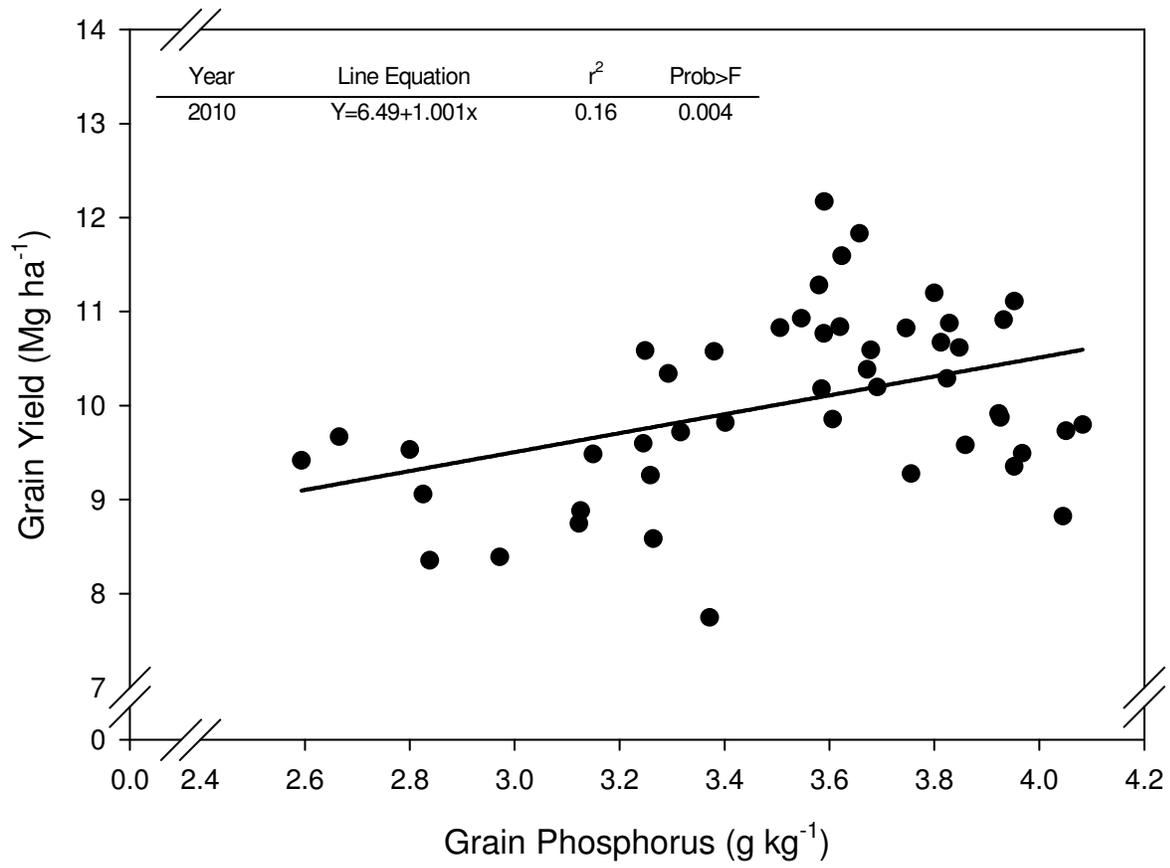


Figure 2.8 Grain yield as function of grain phosphorus in 2010

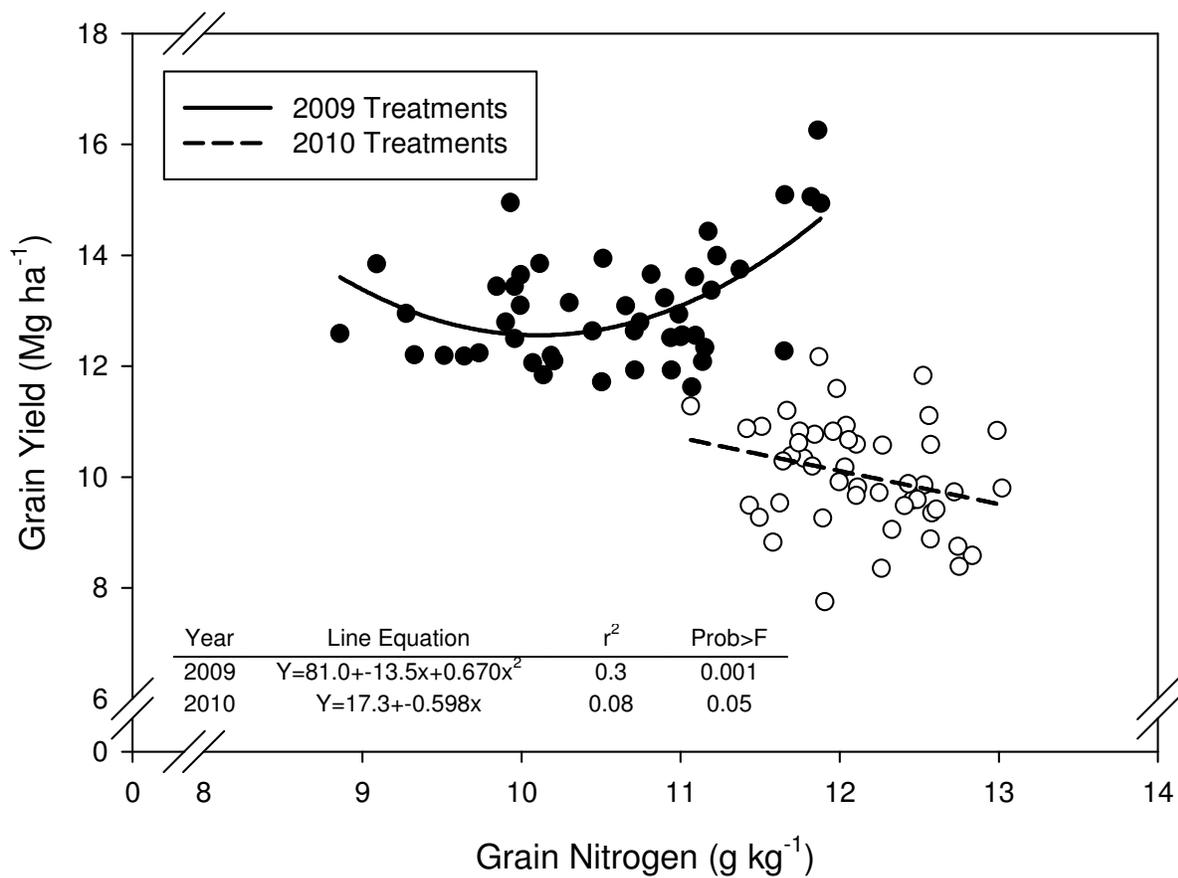


Figure 2.9 Grain yield as a function of grain nitrogen in 2009 & 2010

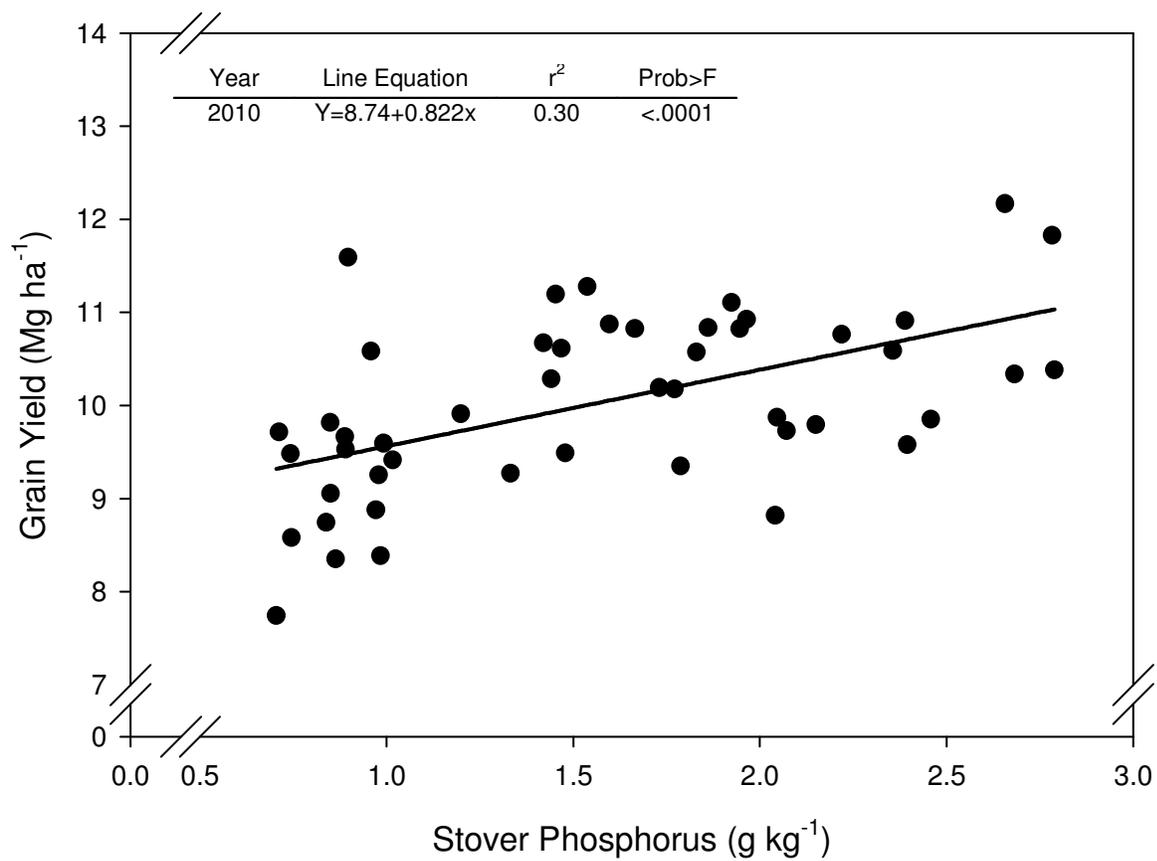


Figure 2.10 Grain yield as a function of stover phosphorus in 2010

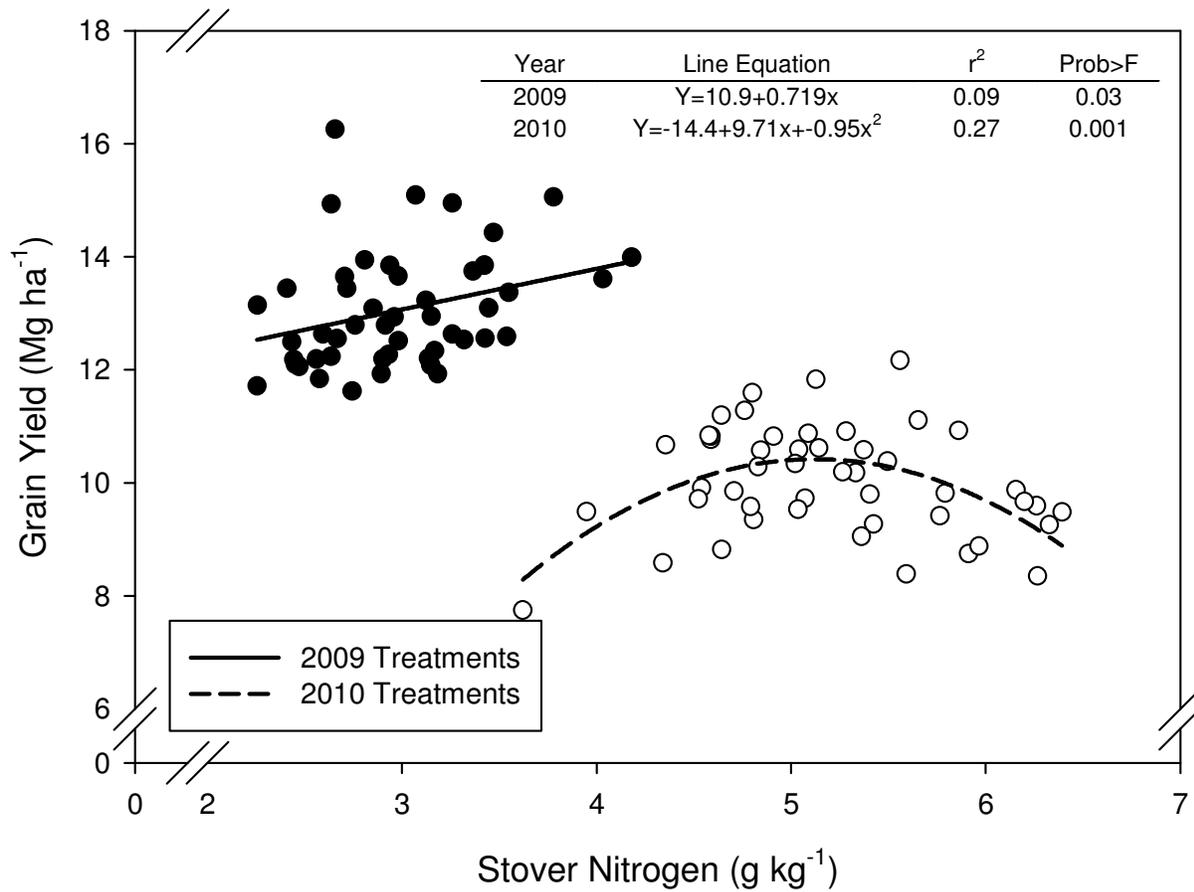


Figure 2.11 Grain yield as a function of stover nitrogen in 2009 & 2010

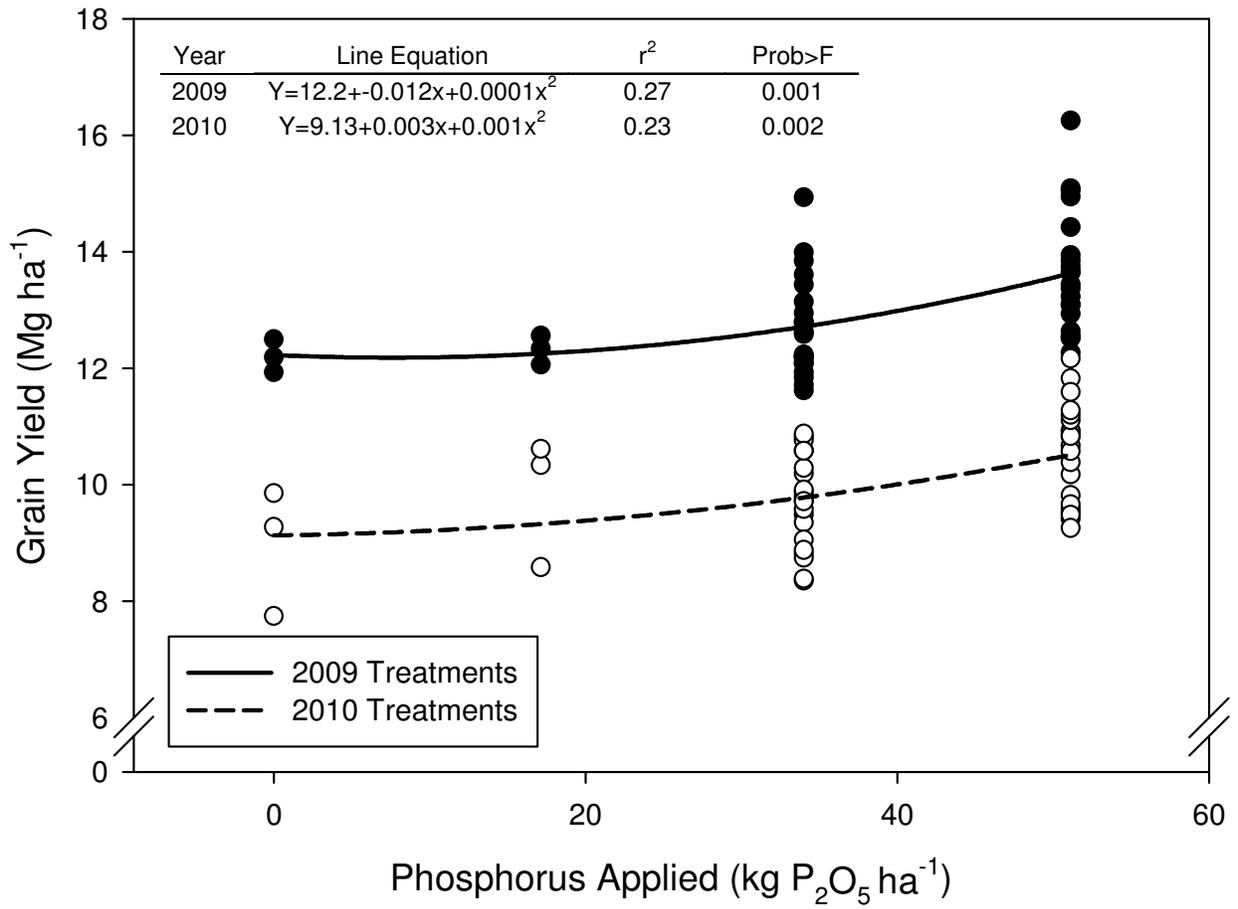


Figure 2.12 Grain yield as a function of P applied

Chapter 3 - Water and Fertilizer Precipitant Testing

Introduction

Few methodologies exist to evaluate phosphorus fertilizer and irrigation water compatibility in SDI systems. The most common nutrients used in SDI systems are nitrogen (N) and potassium (K), and indeed do not cause the problems that phosphorus (P) fertilizers do. The major problems with P fertigation are dissolution of the fertilizer, which depends on the quality and solubility of the fertilizer, and the precipitation of P as insoluble compounds within the lines and emitters, which is a function of water pH and cationic amounts (Ryan and Saleh, 1998). Water quality, fertilizer solubility, fertilizer compatibility, and fertilizer source are a few key points to consider prior to applying P fertilizer through a SDI system. Many acidic water soluble P sources are deemed acceptable for injecting P into a SDI system; however some acidic liquid formulations need to be evaluated for solubility and compatibility with the irrigation water. Fertilizers that are readily dissolved, or have high solubility are the best and easiest fertilizers to inject in most SDI systems. The solubility of a fertilizer depends on its physical properties, water temperature, and irrigation water quality. There are many factors to consider, avoiding precipitation of minerals that result in the clogging of SDI emitters (Bar-Yosef, 1999). For example, mixing two fertilizers together, such as a calcium salt with a phosphate, may form precipitants of calcium phosphate or calcium sulfate, even at low pH (Kafkafi, 2005). A fertilizer compatibility test in combination with a simulated filtration test with the irrigation water and fertilizer should be conducted before injecting soluble P products into a drip irrigation system. The objectives of this study are:

- 1.) Evaluate and create methodologies to simulate P fertilizer and irrigation water compatibility tests for SDI systems.
- 2.) Determine which P fertilizers may be suitable in a SDI system.
- 3.) Determine if P-enhancing products can help decrease precipitant formation.

Materials and Methods

A laboratory study was conducted in the KSU Soil Testing Laboratory in Manhattan, KS. To simulate field conditions, a small scale filtration system was created to quantify precipitant amounts. In this study, precipitant is defined as the amount of insoluble solid that occurred from mixing irrigation water and fertilizer. Irrigation water was pumped from the fertigation well at the Kansas State University (KSU) Research Farm (39°8'16"N, 96°38'12"W) near Manhattan, KS. To simulate field conditions, fertilizers were added to irrigation water at rates equivalent to 34 kg P₂O₅ ha⁻¹ in 1185 L of irrigation water,

Irrigation water was chilled to 15°C before adding fertilizer to replicate well water conditions. The pH of each fertilizer individually and the pH of the irrigation water were measured before mixing with a Corning pH meter (Corning, Inc, Corning, NY). The appropriate amount of fertilizer were added to 500 mL of irrigation water and mixed before filtering. After mixing the fertilizer and water homogeneously, pH and electrical conductivity (Corning, Inc, Corning, NY) were measured for the fertilizer/water solution.

The small scale filtration system was created to capture precipitants is shown in Figure 3.1. An Erlenmeyer flask coupled with a filtration funnel was used to filter samples. A Fisherbrand Q8 filter (Fisher Scientific, Pittsburgh, PA) was used for filtration, it had a coarse porosity, 20-25 µm particle retention, and a fast flow rate. This filter was deemed appropriate to simulate field conditions due to the fast flow rates and particle retention; however filter size calculated was approximately 400 mesh. Before filtration, all filter papers were dried for one hour at 50°C and weighed with a precision micro-balance for tare weight. A small vacuum line applied a small vacuum to each sample to increase filter times. Filtration time was measured as the time from when the fertilizer/water mix was added to the completion of the filtration. After filtration was complete, the filter was removed from the filtration funnel and dried for one hour at 50°C to evaporate any water, leaving behind the precipitants. Weights were taken of the filter and precipitant with a precision micro-balance after drying to determine precipitant mass in each treatment. Photos of the fertilizer/water mixture and the filter paper were taken to visually quantify the differences in treatments. In the first replication, precipitants were analyzed separately for calcium, phosphorus, and iron concentration. A nitric/perchloric digest (Gieseking

et al., 1935) was performed and then analyzed by an inductively coupled plasma (ICP), model 720-ES (Varian Australia Pty Ltd., Mulgrave, Vic Australia). Later replications were not measured for these minerals due to cost restraints.

Three different studies were conducted by mixing fertilizer with irrigation water, a simple study of mixing sixteen common fertilizers individually, a study of mixing five common fertilizers with and without P-enhancing additives, and a study of mixing three common fertilizers with four rates of Avail (Specialty Fertilizer Products, LLC, Belton, MO¹). All studies were analyzed separately but were performed at the same time.

All of the fertilizers used in this study are listed in Table 3.1 with their respective analysis, state, mass, pH, and solubility. Masses, pH, and solubility's were taken from the respective fertilizers label or MSDS sheet. The sixteen fertilizers were organized in a randomized complete block design, replicated three times through time with treatment as the main effect. Eleven different fluid fertilizers, with five being clear and six being colored, along with five high-grade granular fertilizers were added at rates equivalent to 34 kg P₂O₅ ha⁻¹ in 1185 L of irrigation water (Table 3.2). All fertilizers analyzed were added to 500mL of irrigation water. Treatment 16, a potassium nitrate fertilizer was added at rates of 22.4 kg K₂O ha⁻¹ since phosphorus wasn't part of the N-P-K analysis. Fluid fertilizers were added to irrigation water with syringes and granular fertilizers were added by weighing the mass on a precision micro-balance and applying with a spoon. Clear fertilizers were defined as fertilizers with no color or "see through". On the other hand, colored fertilizers were simply defined as fertilizers that were not clear fertilizers. Results were analyzed using PROC Mixed in SAS version 9.1 (SAS Institute, Cary, NC). Replication was used as the random factor and treatment as the model variable, the Satterthwaite method of determining degrees of freedom was used to correctly identify degrees of freedom with a random factor. Fishers protected LSD test in combination with pdmix800 was used for mean separations. A coefficient of variation (C.V.) was calculated for each variable by dividing the standard error by the mean of the respective variable. Orthogonal contrasts were used to compare fluids versus solids, colored fluids versus clear fluids, and clear fluids versus solids. Variables measured were water pH, fertilizer pH, mixture pH, mixture temperature, mixture electrical conductivity, filtration time, and precipitant mass.

¹ Kansas State University does not endorse any commercial providers or their products.

In the second study, five fertilizers were treated without and with P-enhancing products to determine if these products had an effect on precipitant formation. Treatment structure with fertilizer and additive rates are listed in Table 3.3. Treatments include, Nutra-Flo Goldstart 6-24-6 (Nutra-Flo Company, Sioux City, IA¹) treated without and with Avail (Specialty Fertilizer Products, LLC, Belton, MO¹), Assure Crop 5-20-5 (Assure Crop Liquid Fertilizer, Seneca, KS¹) treated without and with Plen-T-Phos (Nano Chem Solutions, Inc, Bedford Park, IL¹), Nutra-Flo Goldstart 9-18-9 (Nutra-Flo Company, Sioux City, IA¹) treated without and with Avail, Geary Grain 10-34-0 (Geary Grain, Inc., Junction City, KS¹) treated without and with Avail, and Rotem 12-61-0 (ICL Fertilizers, Beer Sheva, Israel¹) treated without and with Avail, respectively. The P-enhancing polymers of Avail and Plen-T-Phos with their respective characteristics are noted in Table 3.4.

The ten treatments were organized in a randomized complete block design replicated three times through time with treatment as the main effect. The five fertilizers were added at rates equivalent to 34 kg P₂O₅ ha⁻¹ in 1185 L of irrigation water (Table 3.3). All fertilizers analyzed were added to 500mL of irrigation water. Rates of the P-enhancing polymers were added a rate of 1% (v/v). Fluid fertilizers were added to irrigation water with syringes and granular fertilizers were added by weighing the mass on a precision micro-balance and applying with a spoon. Results were analyzed using PROC Mixed in SAS version 9.1 (SAS Institute, Cary, NC). Replication was used as the random factor and treatment as the model variable, the Satterthwaite method of determining degrees of freedom was used to correctly identify degrees of freedom with a random factor. Fishers protected LSD test in combination with pdmix800 was used for mean separations. A coefficient of variation (C.V.) was calculated for each variable by dividing the standard error by the mean of the respective variable. Orthogonal contrasts were used to compare treatments without and with the P-enhancing polymers. Variables measured were water pH, fertilizer pH, mixture pH, mixture temperature, mixture electrical conductivity, filtration time, and precipitant mass.

In the third study, three common fertilizers were applied with four rates of Avail. Treatments include, Nutra-Flo Goldstart 6-24-6, Geary Grain 10-34-0, and Rotem 12-61-0 all combined with 0, 0.5, 1.0, and 2.0% (v/v) of Avail. The Nutra-Flo 6-24-6 and Geary Grain 10-

¹ Kansas State University does not endorse any commercial providers or their products.

34-0 are fluid fertilizers; Rotem 12-61-0 is a highly soluble granular fertilizer (Table 3.5). The three fertilizers were added at rates equivalent to 34 kg P₂O₅ ha⁻¹ in 1185 L of irrigation water (Table 3.5). All fertilizers analyzed were added to 500mL of irrigation water. Fluid fertilizers were added to irrigation water with syringes and granular fertilizers were added by weighing the mass on a precision micro-balance and applying with a spoon.

Results were analyzed using PROC Mixed in SAS version 9.1 (SAS Institute, Cary, NC). Replication was used as the random factor and product and rate as main effect model variables and product by rate as the interaction variable, the Satterthwaite method of determining degrees of freedom was used to correctly identify degrees of freedom with a random factor. Fishers protected LSD test in combination with pdmix800 was used for mean separation. A coefficient of variation (C.V.) was calculated for each variable by dividing the standard error by the mean of the respective variable. Subsequently, after results were analyzed using PROC Mixed PROC Reg and PROC Nlin were used to analyze both linear and non-linear relationships. All regression lines were tested with linear, quadratic, and linear plateau models and were fit to the model with the lowest root mean square error and highest r². Variables measured were water pH, fertilizer pH, mixture pH, mixture temperature, mixture electrical conductivity, filtration time, and precipitant mass.

Results and Discussion

An irrigation water quality test and individual samples were taken from the irrigation well during the growing season to be used for the laboratory study. Irrigation water quality was tested and was deemed good to excellent based on quality reports (Table 3.6). The only concerns were iron, with a high level of concern at 2.60 mg L⁻¹ and pH with a moderate level of concern at 7.66 (Rogers et al., 2003). Overall the filtration setup worked very well with no major concerns and simulated field conditions very well on a smaller basis. Results in this study will be presented as tables, graphs, and photos based on results from the measured variables of water pH, fertilizer pH, mixture pH, mixture electrical conductivity, mixture temperature, filtration time, and precipitant amount. Results will be split up into the three sub studies and conclusions will be made on each sub study and the study as a whole.

Fertilizer Only Study

A significant ($p=0.05$) treatment main effect was observed for fertilizer pH, mixture pH, mixture electrical conductivity, filtration time, and precipitant mass (Table 3.7 and Table 3.8). Clearly the treatment main effect did not affect water pH and mixture temperature. Hypothetically, the water pH and mixture temperature should stay constant throughout the experiment.

Fertilizer pH ranged from 2.13 to 7.71 and clearly an identifiable difference was observed across treatments (Table 3.7). Na-Churs 3-18-18 (NaChurs Alpine Solutions, Marion, OH¹), a clear fluid fertilizer had the greatest pH and Rotem 0-60-20 (ICL Fertilizers, Beer Sheva, Israel¹), a highly acidic granular fertilizer had the lowest pH. Fluid fertilizers versus granular fertilizers exhibited a significant ($p=0.05$) differences in pH with mean fertilizer pH of 7.04 and 3.92, respectively. Clear fertilizers tended to have higher fertilizer pH than colored fertilizers, with mean pH values of 7.40 and 6.73, respectively. Granular fertilizers were more acidic than clear fluid fertilizers ($p=0.05$). Hypothesized, fertilizer pH can help develop management decisions on which fertilizer to use in a given situation and help to make better conclusions on the amount of fertilizer that is trapped in the filter before entering the irrigation system. In general, mixture pH followed the same trend as fertilizer pH ($r^2 = 0.78$) (Table 3.7). When granular fertilizers were mixed with the irrigation water, the mixture pH increased above the respective fertilizer pH due to slightly alkaline irrigation water.

Electrical conductivity (EC) is a measure of the total salinity or total dissolved solids in a given solution (Rogers et al., 2003). Electrical conductivity can help quantify the amount of solids in the fertilizer/water mixture. A significant ($p=0.05$) treatment effect was observed for EC; treatments ranged from 0.451 S m^{-1} in the granular treatment of Rotem 0-60-20 to 0.950 S m^{-1} in the fluid treatment of Geary Grain 17-17-0 (Geary Grain, Inc., Junction City, KS). All fluid fertilizers had the same EC with the exception of Nutra-Flo 6-24-6 which had an EC of 0.627 S m^{-1} and Geary Grain 17-17-0 which had an EC of 0.950 S m^{-1} (Table 3.7). Granular fertilizers generally had lower ECs than fluid fertilizers, with means of 0.528 S m^{-1} and 0.754 S m^{-1} , respectively. Granular fertilizers tended to have lower EC than both clear and colored fluid fertilizers. This could be due to the high solubility of the pure grade granular fertilizers, with the

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ability to get fertilizer well dissolved in irrigation water, total dissolved solids will be lower and greater amounts of fertilizer can pass through the filter.

Filtration time varied greatly among treatments, ranging from 26.67 to 1120 sec 500mL⁻¹ (Table 3.8). Nutra-Flo Goldstart 9-18-9 exhibited the highest filtration time of 1120 sec 500mL⁻¹. Too high of a filtration time could lead to further problems in a SDI system such as decreased flow rates and pressure fluctuations. Minimizing the filtration time will help not only the injection timing, but will keep flow rates and system pressures within optimal ranges. Fluid fertilizers had greater filtration times than granular fertilizers; this could be attributed to the solubility and dissolving issues. However, granular fertilizers had the same filtration time as clear fluid fertilizers nonetheless; colored fertilizers had much greater filtration times than granular fertilizers. This demonstrates that filtration times may be reduced by using clear fluid fertilizers or pure grade granular fertilizers.

A significant ($p=0.05$) treatment main effect was observed for precipitant mass, which was expected with amounts ranging from 0.011 g 500mL⁻¹ for the Rotem 0-60-20 granular treatment to 0.385 g 500mL⁻¹ for the Na-Churs 6-24-6 (NaChurs Alpine Solutions, Marion, OH¹) fluid treatment (Table 3.8). The granular treatments of Rotem 0-60-20, Rotem 12-61-0 (ICL Fertilizers, Beer Sheva, Israel¹), Rotem 0-52-34 (ICL Fertilizers, Beer Sheva, Israel¹), Haifa 12-61-0 (Haifa Chemicals, Ltd., Haifa Bay, Israel¹), and Haifa 13.5-0-46.2 (Haifa Chemicals, Ltd., Haifa Bay, Israel¹) all performed similarly with precipitant masses all less than 0.025 g 500mL⁻¹. Fluid fertilizers varied based on clearness, with means of 0.135 g 500mL⁻¹ for clear fluid fertilizers and 0.245 g 500mL⁻¹ for colored fluid fertilizers. Clearly granular fertilizers performed better than any fluid fertilizer, regardless of clearness of the fertilizer.

Some visual interpretations were observed in this study. Once mixed with irrigation water, clear fluid fertilizers tended to create a homogenous clear solution, as shown in Figure 3.2 with the 4 beakers on the left having clear fluid fertilizers added. In contrast, when colored fertilizers were added to the irrigation water, a dark brown, heterogeneous solution was formed, as shown in Figure 3.2 with the eight beakers to the left having colored fluid fertilizers added. Figure 3.3 depicts the visual difference after filtration that occurred in a colored fluid fertilizer (on left) and a clear fluid fertilizer (on right). In most cases clear fertilizers had less brown color

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after filtration than did colored fluid fertilizers. All other visual differences were minimal between different fertilizers.

Based on these results, using a pure grade granular fertilizer will reduce filtration times and precipitant masses. However one management questions comes to mind, “Do the benefits outweigh the costs?” Using clear fluid fertilizers can be a very effective way, in terms of filtration time and precipitant mass, to apply P fertilizer through a SDI system. Yet, using colored fluid fertilizers can lead to high amounts of precipitant formation and slowed filtration times. So even if the cost of the colored fertilizers are low, many maintenance issues such as plugged filters, plugged emitters, reduced flow rates, and reduced pressures hinder the use of these fertilizers.

Adding P-Enhancing Products to Fertilizers Study

It was hypothesized that, adding P-enhancing products to fertilizer/irrigation water mixtures may reduce precipitant formation when filtered. A significant ($p=0.05$) treatment main effect was observed for fertilizer pH, mixture pH, mixture EC, filtration time and precipitant amount (Table 3.9). However, these differences were attributed mainly to the five different fertilizers used, not by the addition of P-enhancing products. In only two cases did the use of P-enhancing products affect the variables listed above. By adding Plen-T-Phos to Assure Crop 5-20-5, precipitant mass decreased from $0.126 \text{ g } 500\text{mL}^{-1}$ to $0.027 \text{ g } 500\text{mL}^{-1}$. This could be attributed to the breakdown of the insoluble precipitants, which means it slowed the formation of insoluble precipitates due to the interaction of important cations in the water, such as calcium, magnesium, and iron. By adding Avail to Nutra-Flo 6-24-6, filtration time decreased from $514.7 \text{ sec } 500 \text{ mL}^{-1}$ to $357.0 \text{ sec } 500 \text{ mL}^{-1}$. As the Avail technology surrounds P in a water-soluble barrier, this barrier expanded to block the elements that tie up P in the solution such as calcium, iron, and magnesium in this case of high pH, to speed up filtration time when Avail was added. The use of P-enhancing products can help increase filtration time and decrease precipitant formation in some cases; however more research is needed to justify any further conclusions.

Rate of Avail Study

If and when Avail can be used in a commercial irrigation situation to decrease precipitant levels, strong evidence of the rate needs to be well implemented. The recommended rate of Avail on the market for starter fertilizers is 0.50% (v/v). In other words the Avail concentration

needs to be 0.50 percent of the total tank mix. By adding greater rates of Avail to the mixture, it is possible that precipitant rates will decrease and filtration time will increase.

A significant ($p=0.05$) product main effect was observed between the three common fertilizers for precipitant amount, filtration time, mixture EC, mixture pH, and fertilizer pH (Table 3.10). Nutra-Flo 6-24-6 had the greatest precipitant mass, slowest filtration time, most alkaline mixture pH, and most alkaline fertilizer pH (Table 3.11). Rotem 12-61-0 exhibited the lowest precipitant amount at $0.021 \text{ g } 500\text{mL}^{-1}$, fastest filtration time at $44.6 \text{ sec } 500\text{mL}^{-1}$, and the most acidic mixture pH and fertilizer pH, at 5.60 and 4.18, respectively. Geary Grain 10-34-0 fell in between the other two products for all variables, except mixture EC, which was the greatest, at 0.635 S m^{-1} .

The three products in this study performed very different from one another, however, a significant ($p=0.05$) rate main effect was observed for precipitant mass. After plotting the precipitant amounts for each fertilizer, a decreasing linear plateau model was fit for each fertilizer (Figure 3.4 and Figure 3.5). Both fertilizers followed the same trend, however, Geary Grain 10-34-0 exhibited a tighter fit than Nutra-Flo 6-24-6 ($r^2 = 0.48$ and 0.29 , respectively). Increasing the rate of Avail to 0.50 % decreased the precipitant amount considerably; nevertheless further increasing to 1.0 or 2.0 % did not additionally decrease the precipitant mass in either mixture. According to the linear plateau line, Nutra-Flo 6-24-6 and Geary Grain 10-34-0 both applied with 0.50 percent Avail, the minimum precipitant mass of $0.195 \text{ g } 500\text{mL}^{-1}$ and $0.120 \text{ g } 500\text{mL}^{-1}$, respectively. By applying the recommended rate of Avail, 0.50 %, to two common fluid fertilizers, minimum precipitant amounts were achieved and no additional benefit of applying greater amounts of Avail would be deemed necessary.

Similarly, in the pure grade granular fertilizer of Rotem 12-61-0, the recommended rate of Avail (0.50 %) did seem to minimize precipitant mass (Figure 3.5). Adding greater amounts of Avail did not further decrease the precipitant amount. Similar to the fluid fertilizers, the r^2 was 0.44. According to the linear plateau line equation for Rotem 12-61-0, the precipitant mass was $0.019 \text{ g } 500\text{mL}^{-1}$ when 0.50 % of Avail was applied and no additional benefit was achieved when greater amounts of Avail were added. Applying the recommended rate of Avail is important from a cost and also an agronomic standpoint. In this study, applying the recommended rate of 0.50 % did effectively decrease precipitant amounts in each of the three common fertilizers. Applying greater amounts of Avail will not further decrease or increase

precipitant amounts. As always before mixing Avail with any other fertilizer and irrigation water in an entire tank mix; put small amounts in a jar or beaker and mix together with the fertilizer/water solution to see if any antagonistic reactions occur.

Additional Results

As stated earlier, many factors can effect the precipitant amounts in a fertilizer/water solution, factors measured in this experiment include, fertilizer pH, mixture pH, mixture EC, filtration time, and phosphorus, calcium, and iron concentrations contained in the actual precipitant. All of these were plotted with precipitant mass to determine which factors had greater influence on precipitant amount.

Fertilizer pH increased as precipitant amounts increased only in granular fertilizer treatments, conversely fluid fertilizer treatments did not follow this trend (Figure 3.6). Granular fertilizer pH increased with a line equation of $y = 0.0012 + 0.005x$ and a r^2 of 0.43, as precipitant mass increased. Similar to fertilizer pH, mixture pH increased as precipitant mass increased only in the granular fertilizer treatments (Figure 3.7). Granular mixture pH increased with a line equation of $y = 0.0057 + 0.0025x$ and a r^2 of 0.30. As the pH becomes more alkaline in fertilizer/water mixtures, more calcium and magnesium cations are present, leading to greater precipitation of the fertilizer and/or water minerals. Conversely, in more acidic fertilizer/water mixtures, less calcium and magnesium cations are present, therefore less antagonistic reactions with the important cations lead to decrease precipitant amounts. The fertilizer/water mixtures electrical conductivity was directly proportional to the precipitant mass in all treatments studied, with a r^2 of 0.21 and a line equation of $y = -0.087 + 0.34x$ (Figure 3.8). With greater amounts of total dissolved solids and salts present in the mixture, precipitant masses increase proportionally. Similar to the other variables, filtration times were linearly related to precipitant mass with a line equation of $y = 0.063 + 0.0003x$ and a r^2 of 0.61 (Figure 3.9). This can be attributed to the greater amount of precipitants getting stuck in the filter during filtration, thereby slowing filtration rates linearly.

Filters were digested and analyzed for calcium, iron, and phosphorus concentrations and plotted with precipitant amount (Figure 3.10). The three concentrations of Ca, Fe, and P showed positive linear responses to precipitant amounts. Greater concentrations of P were found in the precipitant than both calcium and iron. Greater amounts of P were found in filter papers, which

was expected with high concentrations of P fertilizer added to the water, however calcium and iron in the water reacted with the P fertilizer and precipitated heavily to form calcium and iron deposits. When in solution together, calcium and phosphorus form di- and tricalcium phosphates which will cause the insoluble precipitates in the solution, which will cause filter or emitter plugging potential to increase (Burt et al., 1995). Similarly, when mixed in solution together, iron and phosphorus can form iron phosphates, which are deemed insoluble as well (Burt et al., 1995). With relatively high amounts of iron in the water and very alkaline pH, the potential for precipitation in the filter and emitters is very high.

Conclusions

Some best management practices (BMPs) for fertigation can be developed from these results. Many differences were observed between fertilizer treatments, both visually and quantitatively in all three studies. Many dissimilar fertilizers were used in the fertilizer only study and many differences were observed between treatments. When highly soluble granular fertilizers were added to irrigation water, minimal precipitants were observed when compared with fluid fertilizers. Conversely, when colored fluid fertilizers were added to irrigation water, high precipitant masses were found when compared with clear fluid fertilizers. However, a balance between cost and benefit needs to be well evaluated within the management system. Water quality plays an important role in fertigation management; if water pH values are high, acidifying the water to a neutral state before adding fertilizers could be a potential solution. When extremely hard water, with large amounts of calcium, magnesium, and iron are used as the irrigation source, precautions need to be taken so insoluble substances are not formed from the combination of calcium, magnesium, iron, and phosphate ions. Using an acidic P source, such as PekaAcid (0-60-20) or MAP (12-61-0) could potentially balance the pH in the water. As a general rule, many clear fluid fertilizers can be added to irrigation water without any problems, however, by performing simple jar tests and acidifying procedures prior to injection, reducing the potential of precipitant formation can help lead to better system life and better performance of the overall system. The use of colored fluid fertilizer is not a good BMP for fertigation, however threshold values need to be implemented for precipitant masses so producers have a better understanding of how individual fertilizers will work in their own situation. More research is needed to quantify the base threshold values for precipitant formation.

The use of P-enhancing products can help reduce precipitant formation in some cases; nonetheless recommended rates are appropriate for fertigation applications. If the water is high in antagonistic cations at high pHs, such as calcium and magnesium, a P-enhancing product is deemed appropriate at a rate of 0.50 %. Fertilizer pH, mixture pH, and mixture EC can be great predictors in determining precipitant amount. Decreased pH and EC values can lead to lower precipitant amounts in the water/fertilizer mixture.

Testing the water quality and determining how the water will affect the individual fertilizers will help minimize potential precipitant formation. Overall, performing a filtration test and analyzing pH, EC, and concentration of calcium, iron, and phosphorus in the filter can be great tools to help determine which P fertilizer products will work in a given situation.

Tables

Table 3.1 Names & Analysis of Fertilizers

| Name | Brand | N-P-K Analysis | State | Weight g L ⁻¹ | pH | Solubility @20°C g L ⁻¹ |
|-----------|-------------|-------------------|----------|-----------------------------|-----|--|
| Goldstart | Nutra-Flo | 6-24-6 | liquid | 1341.0 | 6.4 | - |
| Start | Assure Crop | 5-20-5 | liquid | 1259.4 | 6.2 | - |
| Goldstart | Nutra-Flo | 9-18-9 | liquid | 1333.8 | 7.2 | - |
| Diamond | Nutra-Flo | 9-18-9 | liquid | 1327.8 | 7.3 | - |
| Diamond | Nutra-Flo | 10-10-10 | liquid | 1266.6 | 8.0 | - |
| Goldstart | Nutra-Flo | 10-10-10 | liquid | 1270.2 | 7.5 | - |
| Liquid | Na-Churs | 3-18-18 | liquid | 1403.4 | 7.4 | - |
| Liquid | Na-Churs | 9-18-9 | liquid | 1325.4 | 7.3 | - |
| Liquid | Na-Churs | 6-24-6 | liquid | 1331.4 | 6.3 | - |
| APP | Geary Grain | 10-34-0 | liquid | 1403.4 | 5.8 | - |
| Pop-Up | Geary Grain | 17-17-0 | liquid | 1284.6 | 5.7 | - |
| Pek Acid | Rotem | 0-60-20 | granular | - | 2.2 | 670 |
| MAP | Rotem | 12-61-0 | granular | - | 4.7 | 382 |
| MKP | Rotem | 0-52-34 | granular | - | 4.5 | NA |
| MAP | Haifa | 12-61-0 | granular | - | 4.2 | 374 |
| PK | Haifa | 13.5-0-46.2 | granular | - | 4.6 | NA |

Table 3.2 Fertilizer rates for sixteen common fertilizers

| Treatment | Brand | Analysis | State | Clearness | Fertilizer Rate |
|-----------|-------------|-------------|----------|-----------|------------------------|
| | | | | | mL 500mL ⁻¹ |
| 1 | Nutra-Flo | 6-24-6 | Fluid | Colored | 5.35 |
| 2 | Assure Crop | 5-20-5 | Fluid | Clear | 6.83 |
| 3 | Nutra-Flo | 9-18-9 | Fluid | Colored | 7.17 |
| 4 | Nutra-Flo | 9-18-9 | Fluid | Clear | 7.20 |
| 5 | Nutra-Flo | 10-10-10 | Fluid | Clear | 13.60 |
| 6 | Nutra-Flo | 10-10-10 | Fluid | Colored | 13.60 |
| 7 | Na-Churs | 3-18-18 | Fluid | Clear | 6.81 |
| 8 | Na-Churs | 9-18-9 | Fluid | Clear | 7.21 |
| 9 | Na-Churs | 6-24-6 | Fluid | Colored | 5.36 |
| 10 | Geary Grain | 10-34-0 | Fluid | Colored | 3.61 |
| 11 | Geary Grain | 17-17-0 | Fluid | Colored | 7.88 |
| | | | | | g 500mL ⁻¹ |
| 12 | Rotem | 0-60-20 | Granular | None | 2.87 |
| 13 | Rotem | 12-61-0 | Granular | None | 2.82 |
| 14 | Rotem | 0-52-34 | Granular | None | 3.31 |
| 15 | Haifa | 12-61-0 | Granular | None | 2.82 |
| 16 | Haifa | 13.5-0-46.2 | Granular | None | 2.48† |

† Treatment 16, fertilizer rates were based on 22.4 kg K₂O ha⁻¹, all other on 34.0 kg P₂O₅ ha⁻¹

Table 3.3 The use of P-enhancing polymers with five common fertilizers

| Treatment | Brand | Analysis | State | Additive | Fertilizer Rate | |
|-----------|----------------|----------|----------|-------------|--------------------------|------------------------|
| | | | | | Additive Rate % (v/v) | mL 500mL ⁻¹ |
| 1 | Nutra-Flo | 6-24-6 | Fluid | — | — | 5.35 |
| 2 | Nutra-Flo | 6-24-6 | Fluid | Avail | 1.0 | 5.35 |
| 3 | Assure Crop | 5-20-5 | Fluid | — | — | 6.83 |
| 4 | Assure Crop | 5-20-5 | Fluid | Plen-T-Phos | 1.0 | 6.83 |
| 5 | Nutra-Flo | 9-18-9 | Fluid | — | — | 7.17 |
| 6 | Nutra-Flo | 9-18-9 | Fluid | Avail | 1.0 | 7.17 |
| 7 | Geary Grain | 10-34-0 | Fluid | — | — | 3.61 |
| 8 | Geary Grain | 10-34-0 | Fluid | Avail | 1.0 | 3.61 |
| | | | | | | g 500mL ⁻¹ |
| 9 | Rotem | 12-61-0 | Granular | — | — | 2.82 |
| 10† | Rotem | 12-61-0 | Granular | Avail | 1.0 | 2.82 |

† Granular fertilizer product was used with the fluid Avail additive.

Table 3.4 P-enhancing polymers and their characteristics

| Additive | Brand | Rec. Rate | A.I. | Amino Acid Group | pH |
|-------------|---------------------|----------------------------|------------------------------|---------------------|------|
| Avail | SFP, Inc. | ^{% (v/v)} 0.50 | maleic-itaconic copolymer | carboxyl | 2.00 |
| Plen-T-Phos | Nano- Chem, Inc. | 1.00 | polyaspartic acid | carboxyl | 7.50 |

Table 3.5 Rate of Avail in three common fertilizers

| Treatment | Brand | Analysis | State | Avail Rate | Fertilizer Rate |
|-----------|-------------|----------|----------|------------|------------------------|
| | | | | % (v/v) | mL 500mL ⁻¹ |
| 1 | Nutra-Flo | 6-24-6 | Fluid | 0.00 | 5.35 |
| 2 | Nutra-Flo | 6-24-6 | Fluid | 0.50 | 5.35 |
| 3 | Nutra-Flo | 6-24-6 | Fluid | 1.00 | 5.35 |
| 4 | Nutra-Flo | 6-24-6 | Fluid | 2.00 | 5.35 |
| 5 | Geary Grain | 10-34-0 | Fluid | 0.00 | 3.61 |
| 6 | Geary Grain | 10-34-0 | Fluid | 0.50 | 3.61 |
| 7 | Geary Grain | 10-34-0 | Fluid | 1.00 | 3.61 |
| 8 | Geary Grain | 10-34-0 | Fluid | 2.00 | 3.61 |
| | | | | | g 500mL ⁻¹ |
| 9 | Rotem | 12-61-0 | Granular | 0.00 | 2.82 |
| 10 | Rotem | 12-61-0 | Granular | 0.50 | 2.82 |
| 11 | Rotem | 12-61-0 | Granular | 1.00 | 2.82 |
| 12 | Rotem | 12-61-0 | Granular | 2.00 | 2.82 |

Table 3.6 Irrigation water quality test

| Analysis | Result | Units |
|-------------------------|-------------------|------------------------|
| pH [†] | 7.66 | — |
| Chloride | <2.5 | mg L ⁻¹ |
| Total Hardness | 402 | mg L ⁻¹ |
| Nitrate-N | <1.0 | mg L ⁻¹ |
| Calcium | 102 | mg L ⁻¹ |
| Magnesium | 10.90 | mg L ⁻¹ |
| Sodium | 6.32 | mg L ⁻¹ |
| Sulfate | 12.50 | mg L ⁻¹ |
| Sodium | 5.30 | % |
| Sodium Absorption Ratio | 0.159 | — |
| Iron [‡] | 2.60 | mg L ⁻¹ |
| Electrical Conductivity | 623 | µmhos cm ⁻¹ |
| Total Dissolved Solids | 442 | mg L ⁻¹ |
| Quality of Water | Excellent to Good | — |

[†] pH was considered a moderate level of concern (Rogers et al. 2003)

[‡] Iron was considered a high level of concern (Rogers et al. 2003)

Table 3.7 Sixteen common fertilizers pH & EC

| Brand | Analysis | State | Clearness | Fertilizer pH | Mixture pH | Mixture EC S m ⁻¹ |
|------------------------------|-------------|----------|-----------|------------------|---------------|------------------------------------|
| Nutra-Flo | 6-24-6 | Fluid | Colored | 6.70 c† | 7.00 bc | 0.627 cd |
| Assure Crop | 5-20-5 | Fluid | Clear | 6.75 c | 7.06 bc | 0.735 bc |
| Nutra-Flo | 9-18-9 | Fluid | Colored | 7.26 b | 7.15 bc | 0.705 bc |
| Nutra-Flo | 9-18-9 | Fluid | Clear | 7.30 b | 7.19 ab | 0.787 b |
| Nutra-Flo | 10-10-10 | Fluid | Clear | 7.56 a | 7.21 ab | 0.782 b |
| Nutra-Flo | 10-10-10 | Fluid | Colored | 7.67 a | 7.23 ab | 0.719 bc |
| Na-Churs | 3-18-18 | Fluid | Clear | 7.71 a | 7.22 ab | 0.791 b |
| Na-Churs | 9-18-9 | Fluid | Clear | 7.70 a | 7.44 a | 0.802 b |
| Na-Churs | 6-24-6 | Fluid | Colored | 6.70 c | 7.03 bc | 0.712 bc |
| Gearly Grain | 10-34-0 | Fluid | Colored | 6.12 d | 6.90 cd | 0.681 bc |
| Gearly Grain | 17-17-0 | Fluid | Colored | 5.94 d | 6.67 d | 0.950 a |
| Rotem | 0-60-20 | Granular | None | 2.13 h | 2.56 f | 0.451 e |
| Rotem | 12-61-0 | Granular | None | 4.41 f | 5.76 e | 0.487 e |
| Rotem | 0-52-34 | Granular | None | 4.14 g | 5.78 e | 0.521 de |
| Haifa | 12-61-0 | Granular | None | 4.22 fg | 5.79 e | 0.489 e |
| Haifa | 13.5-0-46.2 | Granular | None | 4.69 e | 7.04 bc | 0.693 bc |
| LSD (p=0.05) | | | | 0.26 | 0.26 | 0.132 |
| Coefficient of Variation (%) | | | | 1.70 | 1.53 | 7.27 |
| | | | | —————Prob>F————— | | |
| Treatment | | | | <0.001 | <0.001 | <0.001 |
| Orthogonal Contrasts | | | | | | |
| Fluid vs. Granular | | | | <0.001 | <0.001 | <0.001 |
| Colored vs. Clear | | | | <0.001 | <0.001 | 0.101 |
| Granular vs. Clear | | | | <0.001 | <0.001 | <0.001 |

† Mean values for each variable with the same letter aren't different (p=0.05)

Table 3.8 Sixteen common fertilizers precipitant & filtration time

| Brand | Analysis | State | Clearness | Filtration | Precipitant |
|------------------------------|-------------|----------|-----------|-------------------------|-----------------------|
| | | | | Time | Mass |
| | | | | sec 500mL ⁻¹ | g 500mL ⁻¹ |
| Nutra-Flo | 6-24-6 | Fluid | Colored | 514.7 c† | 0.253 bc |
| Assure Crop | 5-20-5 | Fluid | Clear | 104.3 e | 0.126 d |
| Nutra-Flo | 9-18-9 | Fluid | Colored | 1120 a | 0.290 b |
| Nutra-Flo | 9-18-9 | Fluid | Clear | 98.67 e | 0.123 d |
| Nutra-Flo | 10-10-10 | Fluid | Clear | 65.00 e | 0.149 d |
| Nutra-Flo | 10-10-10 | Fluid | Colored | 458.3 c | 0.235 c |
| Na-Churs | 3-18-18 | Fluid | Clear | 56.33 e | 0.138 d |
| Na-Churs | 9-18-9 | Fluid | Clear | 65.00 e | 0.141 d |
| Na-Churs | 6-24-6 | Fluid | Colored | 719.3 b | 0.385 a |
| Geary Grain | 10-34-0 | Fluid | Colored | 276.7 d | 0.161 d |
| Geary Grain | 17-17-0 | Fluid | Colored | 138.3 e | 0.143 d |
| Rotem | 0-60-20 | Granular | None | 34.67 e | 0.011 e |
| Rotem | 12-61-0 | Granular | None | 53.00 e | 0.025 e |
| Rotem | 0-52-34 | Granular | None | 39.33 e | 0.018 e |
| Haifa | 12-61-0 | Granular | None | 56.00 e | 0.020 e |
| Haifa | 13.5-0-46.2 | Granular | None | 26.67 e | 0.020 e |
| LSD (p=0.05) | | | | 121.1 | 0.049 |
| Coefficient of Variation (%) | | | | 17.57 | 12.14 |
| | | | | —————Prob>F————— | |
| Treatment | | | | <0.001 | <0.001 |
| Orthogonal Contrasts | | | | | |
| Fluid vs. Granular | | | | <0.001 | <0.001 |
| Colored vs. Clear | | | | <0.001 | <0.001 |
| Granular vs. Clear | | | | 0.186 | <0.001 |

† Mean values for each variable with the same letter aren't different (p=0.05)

Table 3.9 P-enhancing polymers added to five fertilizers

| Fertilizer | Additive | Precipitant Mass | Filtration Time | Mixture EC | Mixture pH | Fertilizer pH |
|-----------------------------|----------|-----------------------|-----------------------|-------------------|---------------|------------------|
| | | g 500mL ⁻¹ | s 500mL ⁻¹ | S m ⁻¹ | | |
| NF 6-24-6 | — | 0.253 | 514.7* | 0.609 | 6.92 | 6.73 |
| NF 6-24-6 | Avail | 0.202 | 357.0 | 0.653 | 6.91 | 6.77 |
| AC 5-20-5 | — | 0.126** | 104.3 | 0.717 | 6.98 | 6.79 |
| AC 5-20-5 | PTP† | 0.027 | 156.3 | 0.711 | 6.98 | 6.80 |
| NF 9-18-9 | — | 0.290 | 1120.0 | 0.687 | 7.07 | 7.30 |
| NF 9-18-9 | Avail | 0.264 | 1053.0 | 0.670 | 6.99 | 7.31 |
| GG 10-34-0 | — | 0.161 | 276.7 | 0.663 | 6.82 | 6.15 |
| GG 10-34-0 | Avail | 0.126 | 302.7 | 0.628 | 6.75 | 6.15 |
| Rotem 12-61-0 | — | 0.025 | 53.0 | 0.469 | 5.69 | 4.45 |
| Rotem 12-61-0 | Avail | 0.020 | 37.3 | 0.459 | 5.60 | 4.46 |
| Prob>F _{treatment} | | <0.001 | <0.001 | 0.008 | <0.001 | <0.001 |
| CV (%) | | 13.68 | 11.49 | 7.73 | 1.35 | 1.83 |

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively for additive treatments.

†Plen-T-Phos was added to the fertilizer

Table 3.10 Classic ANOVA table for rate of Avail study

| Variable | Product | Rate | Product*Rate | CV | LSD _{product} | LSD _{rate} |
|-----------------|---------|--------|--------------|------|------------------------|---------------------|
| | Prob>F | Prob>F | Prob>F | % | | |
| Precipitant | <.0001 | 0.007 | 0.405 | 14.2 | 0.019 | 0.022 |
| Filtration Time | <.0001 | 0.082 | 0.211 | 18.9 | 63.09 | NA |
| Mixture EC | <.0001 | 0.969 | 0.917 | 6.95 | 0.046 | NA |
| Mixture pH | <.0001 | 0.219 | 0.997 | 1.54 | 0.124 | NA |
| Fertilizer pH | <.0001 | 0.994 | 0.999 | 2.69 | 0.010 | NA |

Table 3.11 Product main effect in rate of Avail study

| Product | Precipitant Mass | Filtration Time | Mixture EC | Mixture pH | Fertilizer pH |
|------------------------|-----------------------|-------------------------|-------------------|---------------|------------------|
| | g 500mL ⁻¹ | sec 500mL ⁻¹ | S m ⁻¹ | | |
| Nutra-Flo 6-24-6 | 0.211 a† | 384.8 a | 0.630 a | 6.90 a | 6.48 a |
| Geary Grain 10-34-0 | 0.131 b | 262.6 b | 0.635 a | 6.76 b | 5.88 b |
| Rotem 12-61-0‡ | 0.021 c | 44.6 c | 0.464 b | 5.60 c | 4.18 c |
| LSD _{product} | 0.020 | 63.1 | 0.462 | 0.12 | 0.10 |

† Significant at the 0.05 level of confidence.

Figures

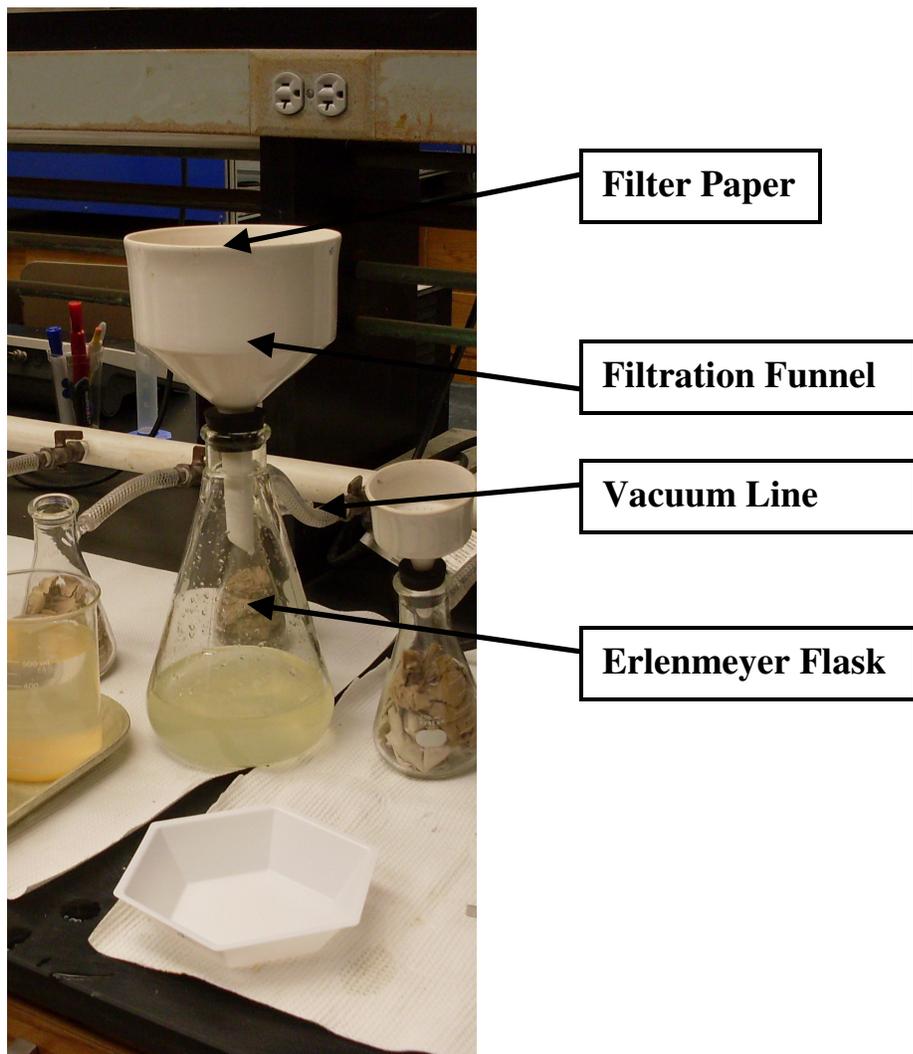


Figure 3.1 Photo of filtration setup



Figure 3.2 Clear Fluid Fertilizer vs. Colored Fluid Fertilizer

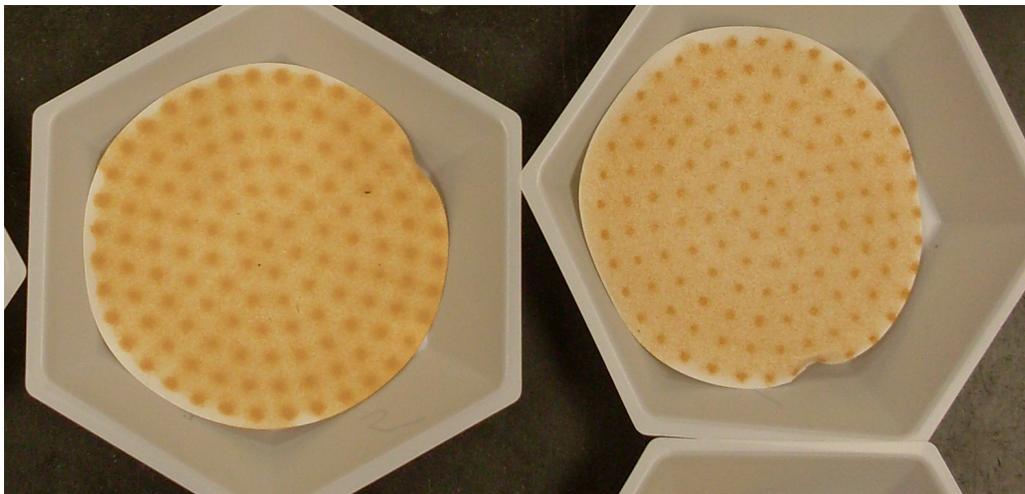


Figure 3.3 Colored Fluid Fertilizer vs. Clear Fluid Fertilizer

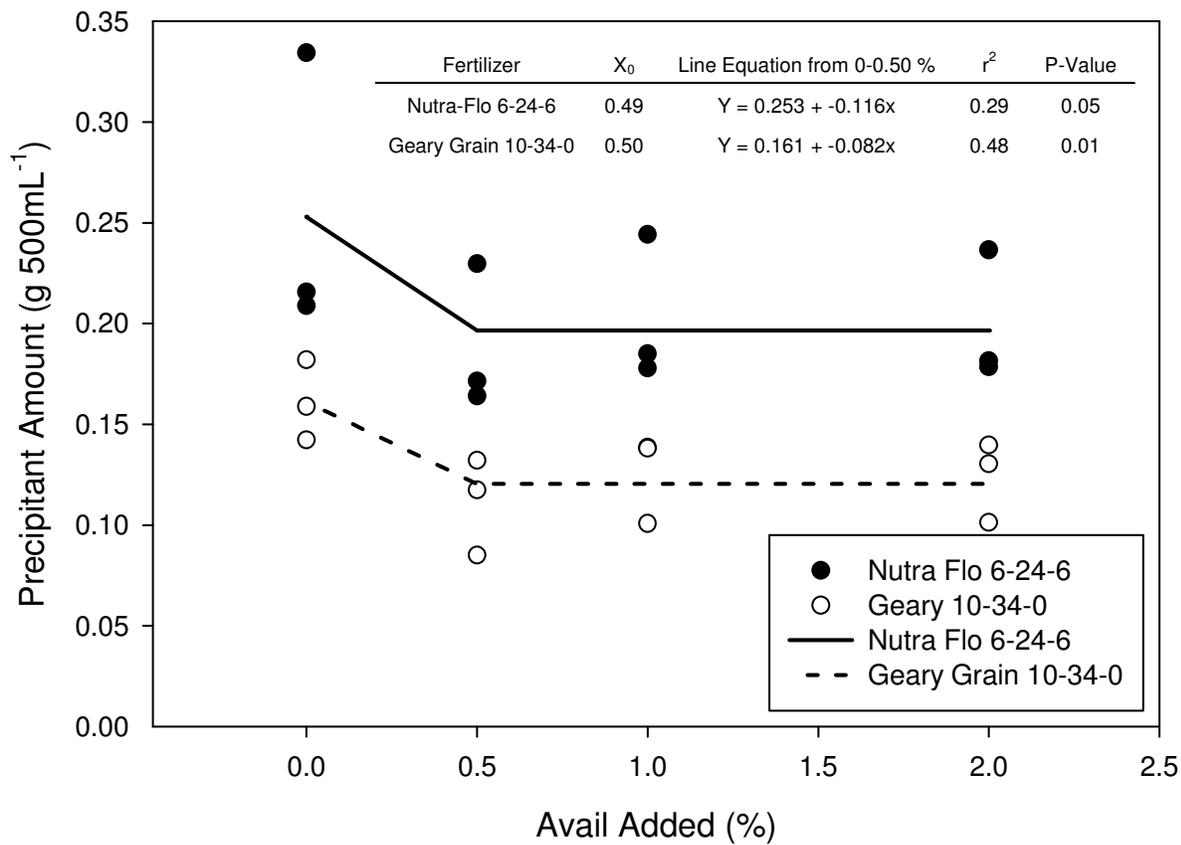


Figure 3.4 Rate of Avail in two Common Fluid Fertilizers

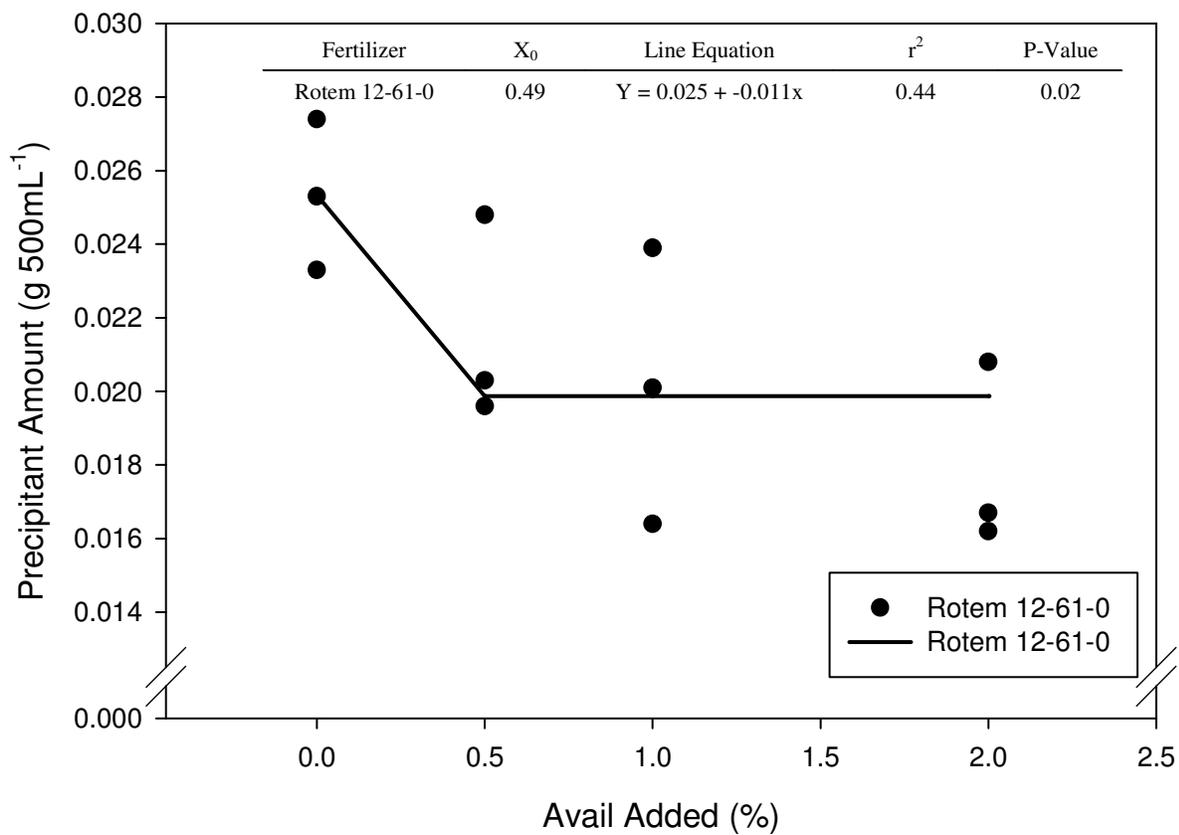


Figure 3.5 Rate of Avail in Rotem 12-61-0 Granular Fertilizer

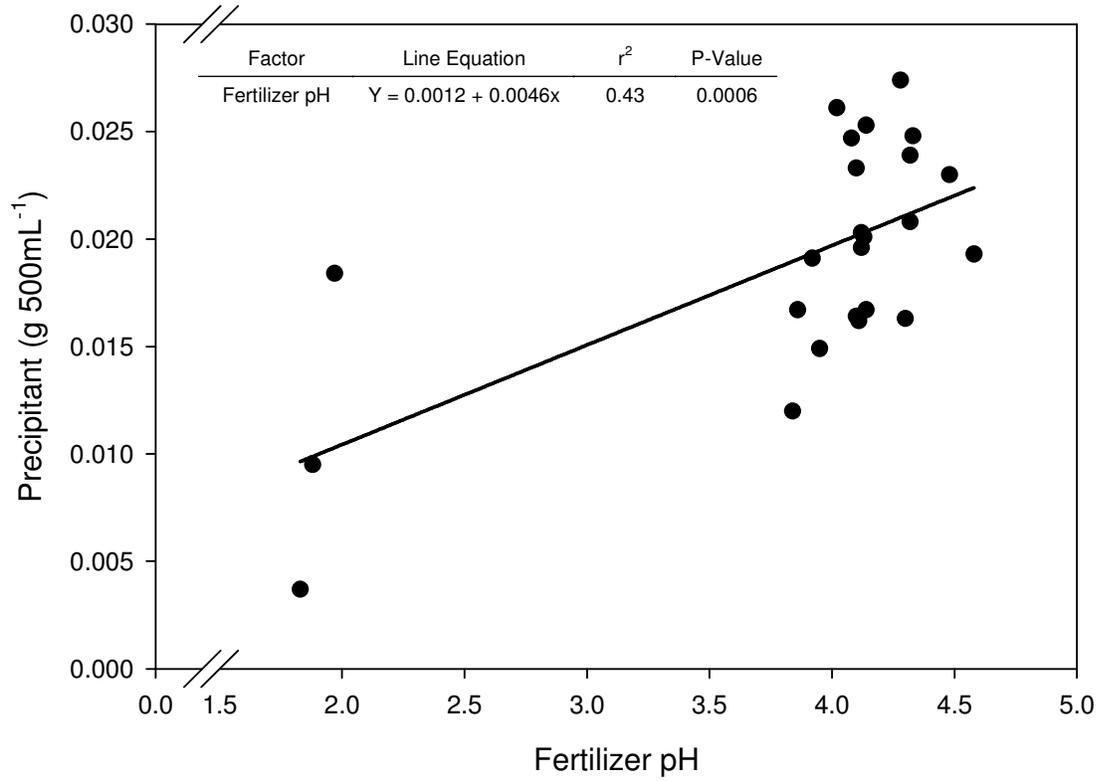


Figure 3.6 Granular fertilizer pH and precipitant mass

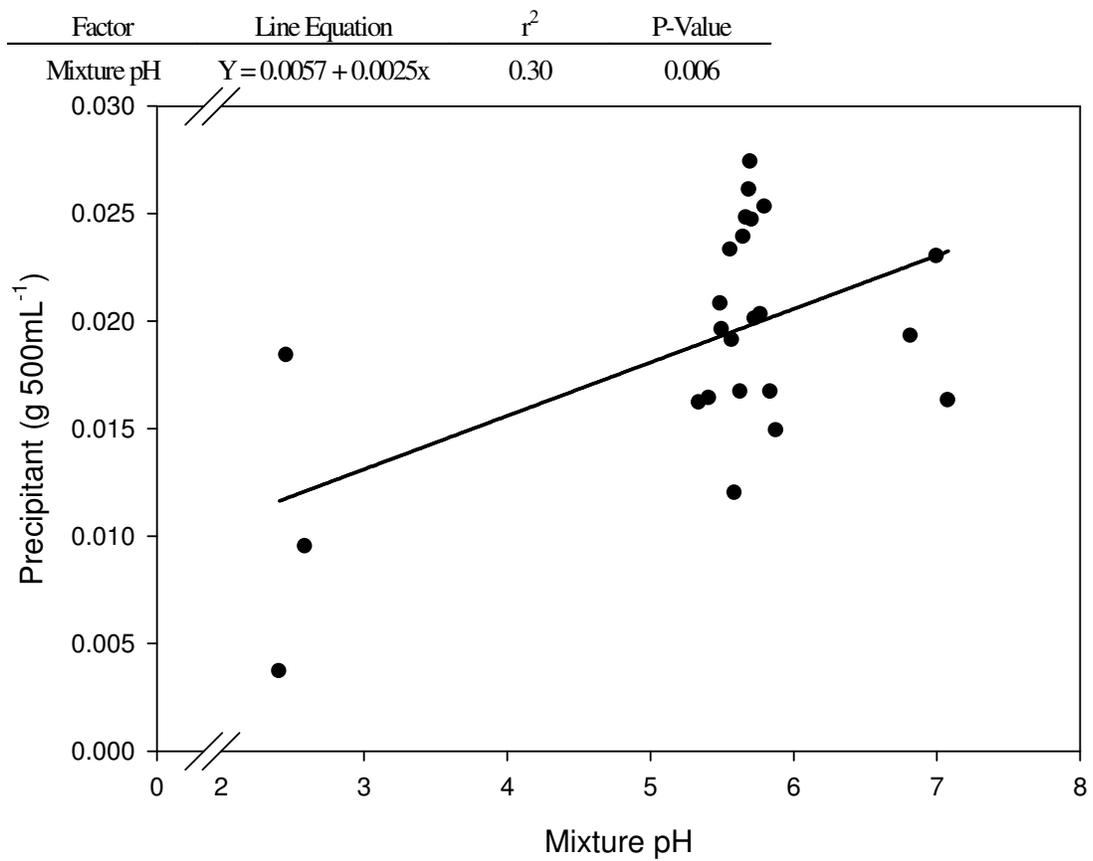


Figure 3.7 Granular mixture pH and precipitant mass

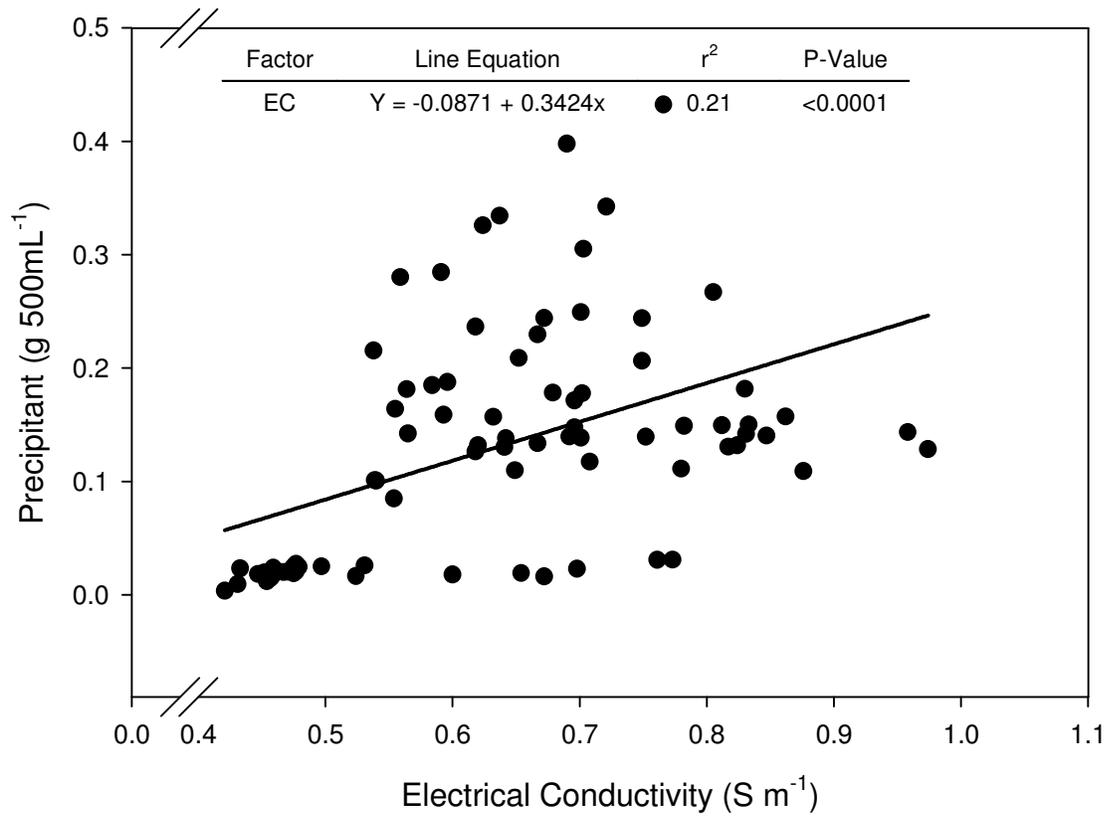


Figure 3.8 All treatments precipitant mass as a function of EC

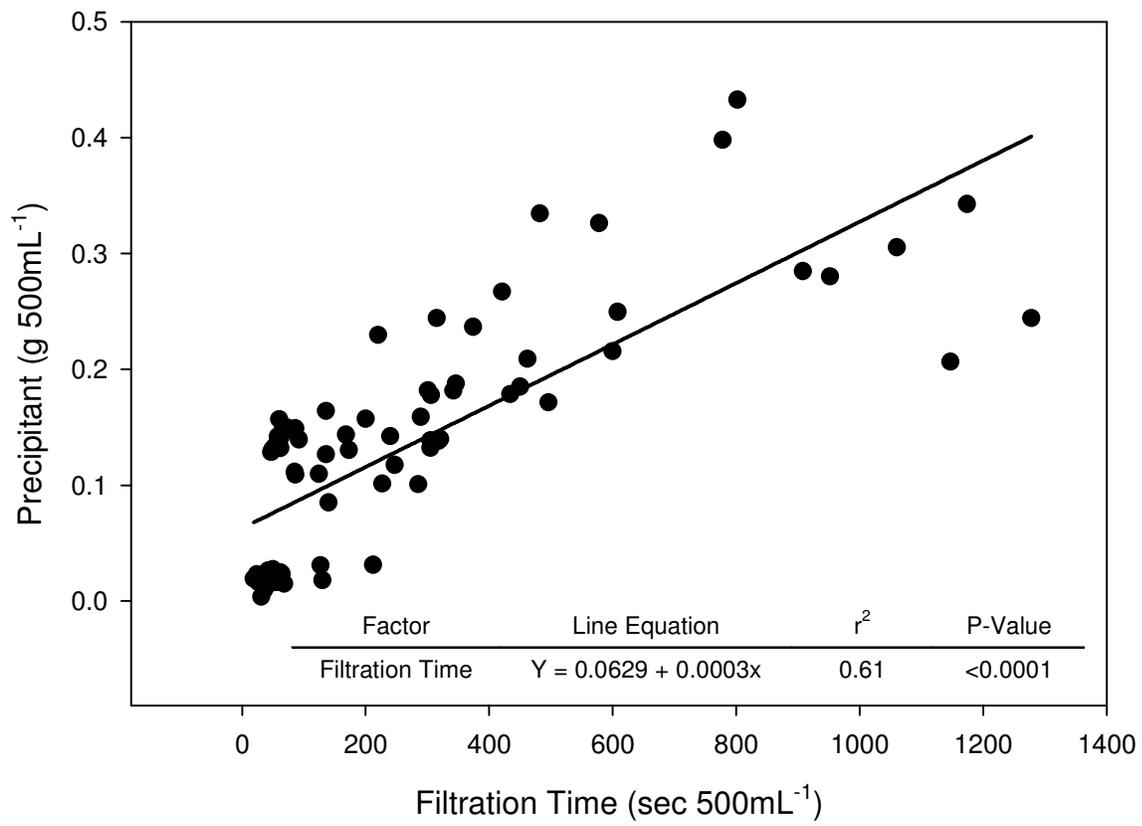


Figure 3.9 All treatments precipitant mass as a function of filtration time

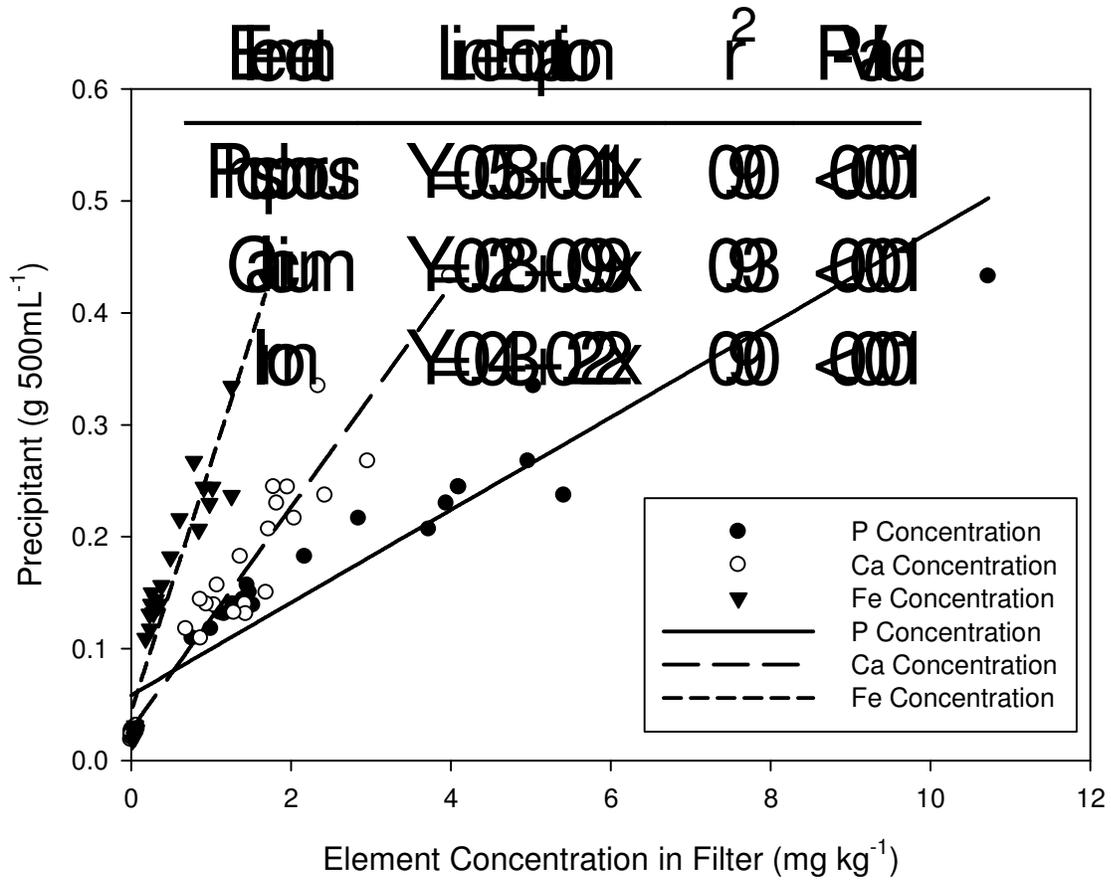


Figure 3.10 P, Ca, and Fe composition in precipitant filters

Chapter 4 - Phosphorus Soil Sampling Near SDI Emitter

Introduction

Phosphorus (P) plays an important role in sub-surface drip (SDI) corn production. Fertigation with SDI can provide many advantages to the producer. Nutrients can be applied directly to the root zone at the right time of growth, thus, optimizing plant uptake and nutrient availability, and minimizing nutrient losses through leaching. Other advantages include, the flexibility of applying nutrients throughout the growing season, convenient use of balanced liquid fertilizers with micronutrients, precise application of nutrients according to crop demand, maximize fertilizer use efficiency, and the application of nutrients into a portion of the wetted soil area by actively growing roots (Bar-Yosef, 1999, Lamm and Camp, 2007, and Burt et al., 1995). Applications of P via SDI are very efficient, due to the direct placement of P in the actively growing root zone, which allows immediate uptake by the plant before it undergoes drying and fixation in the soil (Kafkafi, 2005). Many times when P fertilizers are applied via SDI, P concentrations are concentrated within 7-10 cm of the emitter. Phosphorus movement in the soil is directly related to soil texture in that P will move further in a sandy soil when compared with a clay soil. Researchers found that P moved 20 cm in a loamy sand and less than 3 cm in a clay loam soil with a similar application of P in both studies (Burt et al., 1995 and Goldberg et al., 1971). In a similar SDI study, when P was applied as orthophosphate on a clay loam soil the P moved downward vertically 30 cm and 25 cm horizontally from the emitter (Rauschkolb et al., 1976). Phosphorus is considered very immobile in most soils; however more research is needed to quantify P concentrations around emitters when P fertilizers are added via SDI. The objectives of this study are:

- 1.) Assess the movement and concentration of P near the SDI emitter.
- 2.) Compare P concentrations around the emitter on a control treatment and a fertilized treatment.
- 3.) Evaluate P movement near the emitter to make P fertilizer recommendations in an SDI system.

Materials and Methods

A secondary field study to evaluate soil P movement around the emitter was conducted in 2009 and 2010 near Manhattan, KS at the Kansas State University (KSU) Ashland Bottom Farm (39°8'16"N, 96°38'12"). Soil types for this area include a Belvue silt loam [course-silty, mixed, superactive, nonacid, mesic Typic Udifluvents] and a Eudora silt loam [course-silty, mixed, superactive, mesic Fluventic Hapludolls]. A 1.2 ha SDI system was installed at the KSU Ashland Bottoms Research Farm in 2008. There are eight treatment zones replicated three times, therefore each block is 0.4 ha, or 60.8 m by 63.8 m (Figure 2.1). A border plot on each block edge was installed to encompass bordering effects. Each plot is 6.1 m wide and 63.8 m long (8 rows wide on 76 cm row spacing). The SDI laterals were installed 38 to 46 cm deep with every lateral centered between 76 cm row spacing in the plot. Pressure compensating emitters are evenly spaced on the laterals at 0.5m with a 0.6 L hr⁻¹ discharge rate. Sequentially, flow meter, pressure transducer, and filtration systems were installed, all managed by a NMC-64L Netafim irrigation controller (Netafim USA, Fresno, CA¹).

Corn (*Zea Mays L.*) was no-till planted in all plots both years. Pioneer '33T57' (Bt), a 113 day corn hybrid (Pioneer Hi-Bred International Johnston, IA) was planted at 74 100 seeds ha⁻¹ in early May with a four-row no-till planter (White Model 5100, AGCO Corp., Duluth, GA) (Table 2.3). Each eight row treatment was sub-divided into four rows of corn for split-plots (3.05 m wide), one with starter band applied and one without starter band applied at planting. Each year, corn was planted so each row of corn would fall between a SDI lateral (Figure 2.2). Starter fertilizer, 17-17-0, a blend of urea ammonium nitrate and ammonium polyphosphate, was band applied with the planter at rates of 78.6 L ha⁻¹ to all starter split plots (Table 2.3). Starter fertilizer was applied 5 cm below the soil surface and 5 cm to the side of the seed, commonly referred to as "2x2" starter band application (Mengel, 2010). Nitrogen was applied as surface-applied urea (46-0-0) to all plots as a top dress application at rates of 179 kg N ha⁻¹, 10-20 days after planting (Table 2.4). Two treatments were selected to be soil sampled for P movement after the fertigation application, a control treatment and a Nutra-Flo Goldstart 6-24-6 (Nutra-Flo Company, Sioux City, IA¹) with Avail (Specialty Fertilizer Products, LLC, Belton, MO¹) in both 2009 and 2010 (Table 4.1). Both sample treatments were from the starter band at planting main

¹ Kansas State University does not endorse any commercial providers or their products.

plot treatment. Due to time and financial restraints, only two treatments were sampled. Three randomly selected sites within each treatment were selected in each year to be the sub-samples. Samples were not taken from the same spot in each year, respectively.

Sampling sites were adjacent to each emitter in a 30.5 cm by 30.5 cm square. Each square was sub-divided into sixteen 7.6 cm by 7.6 cm grids that were separately sampled for P concentration (Figure 4.1). The emitter was spaced in the center of each square horizontally with 15.2 cm on each side of the emitter. Vertically, the emitter was placed 7.6 cm below the square top and 22.8 cm above the square bottom as shown field sampling in Figure 4.2. Samples were taken 32 days after the fertigation application in 2009, and 43 days after the fertigation application in 2010; which corresponded to the silk and milk reproductive stages in corn, respectively in each year (Ritchie et al., 1997). Samples were taken from between the row of corn adjacent to the drip line laterals. Sixteen individual soil cores were taken from each sub-sample treatment, with the letters corresponding to the rows horizontally around the emitter and the numbers corresponding to the columns vertically around the emitter (Figure 4.1). Each of the letters and numbers correspond to individual grid numbers. In each sub-sample treatment, soil was excavated 0.61 m downward to create a vertical face adjacent to the emitter where the sixteen individual soil cores were taken. All soil samples were air dried prior to submitting to the lab for P analysis (KSU Soil Testing Laboratory).

All sub-samples from each grid position were analyzed together to separate means. The three separate sub-samples within each treatment were averaged together to get a mean P concentration for each grid point within each treatment in each year. Sample standard deviations were calculated to estimate variability across the three sub-samples. Confidence intervals (95%) were calculated using 1.96 (95% z-score) multiplied by the sample standard deviation. Contour plots were created for each treatment in each year to smooth data using Sigma Plot 11 (Systat Software, San Jose, CA). Phosphorus concentrations were plotted using the horizontal distance from the emitter as the x-axis and vertical distance from the emitter as the y-axis.

Results and Discussion

In-season precipitation was above average in 2009, and below average in 2010 (Figure 2.2). In 2009, dry periods in May caused earlier initiation of irrigation in mid-May. Dry stages

in late-June and early-August in 2010 caused greater irrigation needs throughout the latter part of the growing season.

Samples taken in 2009 and 2010 from both the control treatment and the P applied treatment illustrated many differences in soil test P near the emitter. In 2009, the control treatment had soil test P values ranging from 6.09 to 9.87 mg kg⁻¹, which averaged 8.24 mg kg⁻¹ (Figure 4.3). Grid A4, which had a position of 11.4 cm from the emitter horizontally and 3.8 cm from the emitter vertically, had a mean soil test P of 6.09 mg kg⁻¹, which was the lowest P concentration within the entire grid. Grid C2, which had a position of -3.8 cm from the emitter horizontally and -11.4 cm from the emitter vertically, had a mean soil test P of 9.87 mg kg⁻¹, which was the highest P concentration within the entire control treatment grid. All grid samples had similar soil test P concentrations, which would be expected since P fertilizer was not applied as an in-season fertigation application. The treatment of Nutra-Flo 6-24-6 with Avail had dissimilar soil test P results compared with the control treatment (Figure 4.4). Five grid positions were identified as “hot” spots, with respect to high soil test P concentrations. Grids B1, B2, B3, and B4, all sampled 3.8 cm below the emitter vertically and -11.4 cm, -3.81 cm, 3.81 cm, and 11.43 cm horizontally from the emitter, respectively had soil test P concentrations greater than 20 mg kg⁻¹. Grid A2, which was -3.8 cm from the emitter horizontally and 3.8 cm from the emitter vertically, had a mean soil test P of 19.17 mg kg⁻¹. This upward movement could be explained by active corn roots and translocating the P upward in the profile. The greatest soil test P concentration was found in the B4 grid position, with a mean soil test P of 53.07 mg kg⁻¹. Hypothetically, this demonstrates that P moved laterally from the emitter 11.4 cm, however greater variability was found within this grid position. All grid positions labeled C and D had minimal soil test P concentrations compared with the positions labeled A and B. Other comparisons between grid positions in both treatments can be compared by using the 95 % confidence intervals listed in Figure 4.3 and Figure 4.4. These results indicate that by applying P as an in-season fertigation application, P movement was limited to 3.81 cm below the emitter and 11.4 cm to either side of the emitter horizontally. Placing P next to actively growing corn roots with an in-season application via SDI can be a great nutrient management tool in irrigated corn production. The availability of P in the soil largely depends on soil and fertilizer reactions, P goes through chemical reactions in the soil and can be deemed less available to the plant. Placing P near the roots at the correct time of growth can help steady this reaction. Phosphorus

applied in a SDI system can provide a residual benefit for upcoming years similar to row bands (Mikkelsen, 1989).

In 2010, greater variability was observed in the control treatment grid (Figure 4.5). This variability can be attributed to the previous management of the field. The last five years, a starter band was applied in this treatment, so hypothetically a starter banded layer could have formed due to the previous management of the field. Samples ranged from 27.47 mg kg⁻¹ to 40.30 mg kg⁻¹ in the grids above the emitter vertically. All samples below the emitter vertically were the same and ranged from 9.78 mg kg⁻¹ in the B2 grid to 14.03 mg kg⁻¹ in the B3 grid. The treatment of Nutra-Flo 6-24-6 with Avail in 2010 had similar trends to 2009, however greater concentrations of P were evident near the emitter (Figure 4.6). Eight grids, four grids 3.8 cm above the emitter vertically, and four grids -3.8 cm below the emitter vertically were observed as the “hot” spots, with P concentrations ranging from 31.70 mg kg⁻¹ in the A1 grid to 65.43 mg kg⁻¹ in the A3 grid. All samples below -11.4 cm vertically in the soil profile were the same. Other comparisons between grid positions in both treatments can be compared by using the 95 % confidence intervals listed in Figure 4.5 and Figure 4.6. The higher concentrations moving upward in the soil profile in 2010 were largely due to the second year of P fertilizer application through the emitter.

Contour plots were made to visualize and smooth the soil test P concentrations data for each treatment in each year. The control treatment in 2009 showed minimal contours, however the soil test P decreased in the upper-right profile to 6.50 mg kg⁻¹(Figure 4.7). Two major “hot” spots were observed on the fertigation treatment of Nutra-Flo 6-24-6 with Avail (Figure 4.8). The contour lines of 25 mg kg⁻¹ and 30 mg kg⁻¹ were observed directly on the emitter. Phosphorus was concentrated in the top 7.62 cm of the control treatment in 2010 even though P fertilizer was not applied in this treatment (Figure 4.9). The Nutra-Flo 6-24-6 with Avail treatment showed contour lines from 10 to 60 mg kg⁻¹, with the major “hot” spot being within 3.8 cm in either direction away from the emitter (Figure 4.10).

Conclusions

The movement and concentration of soil test P contrasted between the control and fertigation treatments, as expected in both years. However in 2009, the first year of fertigation with the SDI system, greater differences between treatments were observed. In the control

treatment, no differences were observed between grid samples. However, the fertigation treatment of Nutra-Flo 6-24-6 with Avail had concentrated regions of soil test P directly below and to the side of the emitter, all within 3.8 cm below the emitter vertically and 11.4 cm to either side of the emitter horizontally. In the second year of the study, similar concentrations were found, however P movement increased due to the second year of application to the same treatments. The control plot had greater concentrations of P in the top 7.62 cm of the grid, converse of the control plot in the previous year, due to previous management of the field stated previously. The fertigation treatment in 2010 showed similar trends to 2009, still the soil test P concentrations were expanded to 3.8 cm above and below the emitter vertically and 11.4 cm to either side of the emitter horizontally. In order to deliver P recommendations in a SDI system, sufficient evidence of P concentration and movement around the emitter need to be well documented. Based on these results, injecting P fertilizer in a SDI system can be a beneficial tool to deliver P and to make recommendations based on the concentration and movement of P.

Tables

Table 4.1 P sampling on two different starter banded treatments

| | Treatment | Total P Applied [†] | Total N Applied [‡] | Fertigation Rate | Fertigation Date | Sampling Date |
|------|-------------------|---|------------------------------|---|------------------|---------------|
| Year | | kg P ₂ O ₅ ha ⁻¹ | kg N ha ⁻¹ | kg P ₂ O ₅ ha ⁻¹ | | |
| 2009 | Control | 17.13§ | 196.3 | 0 | 12 June | 14 July |
| | NF 6-24-6 w/Avail | 51.13 | 204.7 | 34 | 12 June | 14 July |
| 2010 | Control | 17.13§ | 196.3 | 0 | 14 June | 27 July |
| | NF 6-24-6 w/Avail | 51.13 | 204.7 | 34 | 14 June | 27 July |

[†] Total P applied = starter band + fertigation application

[‡] Total N applied = starter band + fertigation application + broadcast urea

[§] Treatments were only starter band applied with no fertigation application

Figures

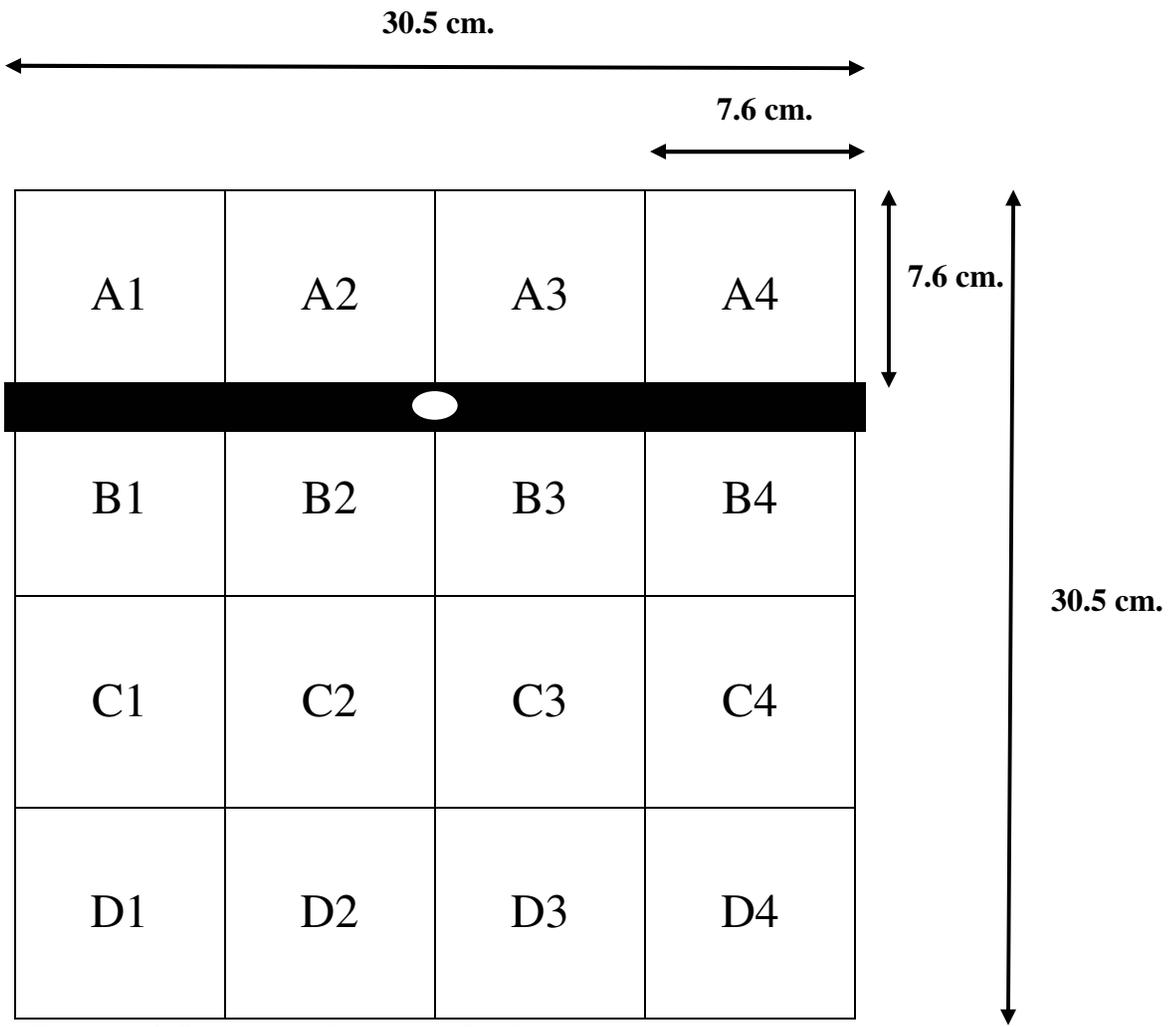


Figure 4.1 Schematic diagram of soil sampling around emitter



Figure 4.2 Photo of grid sample being taken around emitter

| | | | |
|---|---------|----------|---------|
| A1 | A2 | A3 | A4 |
| 8.33† | 7.20 | 9.43 | 6.09 |
| (±4.50)‡ | (±0.35) | (±10.60) | (±3.64) |
|  | | | |
| B1 | B2 | B3 | B4 |
| 7.87 | 8.10 | 7.70 | 7.79 |
| (±3.38) | (±4.20) | (±3.11) | (±2.77) |
| C1 | C2 | C3 | C4 |
| 9.25 | 9.87 | 8.21 | 9.46 |
| (±5.70) | (±7.15) | (±3.19) | (±4.75) |
| D1 | D2 | D3 | D4 |
| 9.19 | 8.18 | 7.56 | 7.58 |
| (±6.01) | (±5.31) | (±3.39) | (±4.22) |
| † Mean soil test P levels for the given position ‡ 95 % confidence interval (1.96* sample standard deviation) from the three sub-samples | | | |

Figure 4.3 2009 soil test P in control treatment

| | | | |
|---|----------|----------|----------|
| A1 | A2 | A3 | A4 |
| 10.37† | 19.17 | 9.63 | 9.77 |
| (±4.35)‡ | (±27.10) | (±6.80) | (±6.38) |
|  | | | |
| B1 | B2 | B3 | B4 |
| 20.47 | 44.70 | 31.31 | 53.07 |
| (±8.71) | (±15.44) | (±12.69) | (±34.73) |
| C1 | C2 | C3 | C4 |
| 8.59 | 12.00 | 12.55 | 9.59 |
| (±7.46) | (±0.67) | (±3.22) | (±2.23) |
| D1 | D2 | D3 | D4 |
| 9.42 | 8.56 | 8.89 | 8.46 |
| (±8.00) | (±3.25) | (±4.83) | (±2.88) |
| † Mean soil test P levels for the given position ‡ 95 % confidence interval (1.96* sample standard deviation) from the three sub-samples | | | |

Figure 4.4 2009 soil test P in NF 6-24-6 w/ Avail treatment

| | | | |
|---|----------|----------|----------|
| A1 | A2 | A3 | A4 |
| 27.47† | 38.73 | 40.30 | 33.03 |
| (±27.29)‡ | (±25.30) | (±15.39) | (±22.94) |
| ○ | | | |
| B1 | B2 | B3 | B4 |
| 11.56 | 9.78 | 14.03 | 13.42 |
| (±5.10) | (±1.46) | (±6.36) | (±10.43) |
| C1 | C2 | C3 | C4 |
| 11.43 | 11.59 | 11.36 | 11.64 |
| (±3.11) | (±3.78) | (±2.96) | (±3.71) |
| D1 | D2 | D3 | D4 |
| 13.20 | 12.30 | 12.27 | 12.57 |
| (±6.44) | (±4.04) | (±3.67) | (±3.13) |
| † Mean soil test P levels for the given position ‡ 95 % confidence interval (1.96* sample standard deviation) from the three sub-samples | | | |

Figure 4.5 2010 soil test P in control treatment

| | | | |
|---|----------|----------|----------|
| A1 | A2 | A3 | A4 |
| 31.70† | 61.27 | 65.43 | 37.97 |
| (±15.12)‡ | (±19.42) | (±37.40) | (±37.72) |
|  | | | |
| B1 | B2 | B3 | B4 |
| 65.07 | 62.47 | 59.37 | 56.70 |
| (±55.02) | (±41.26) | (±3.41) | (±53.76) |
| C1 | C2 | C3 | C4 |
| 10.01 | 10.03 | 11.03 | 9.15 |
| (±2.78) | (±2.06) | (±5.07) | (±0.92) |
| D1 | D2 | D3 | D4 |
| 10.42 | 10.97 | 10.84 | 12.10 |
| (±3.27) | (±0.92) | (±1.76) | (±1.93) |
| † Mean soil test P levels for the given position ‡ 95 % confidence interval (1.96* sample standard deviation) from the three sub-samples | | | |

Figure 4.6 2010 soil test P in NF 6-24-6 w/ Avail treatment

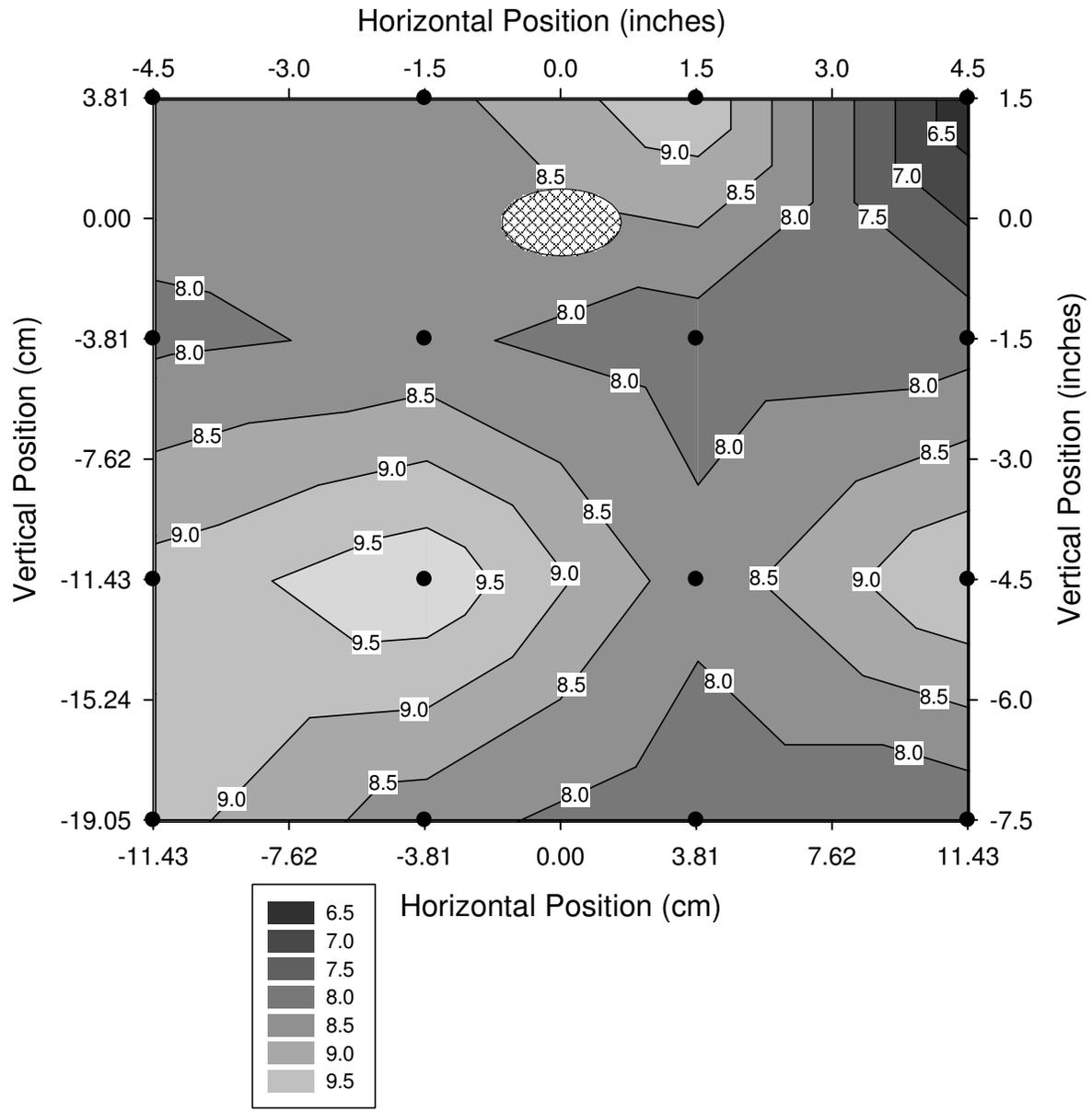


Figure 4.7 Control Treatment P Concentration (mg kg⁻¹) near emitter in 2009

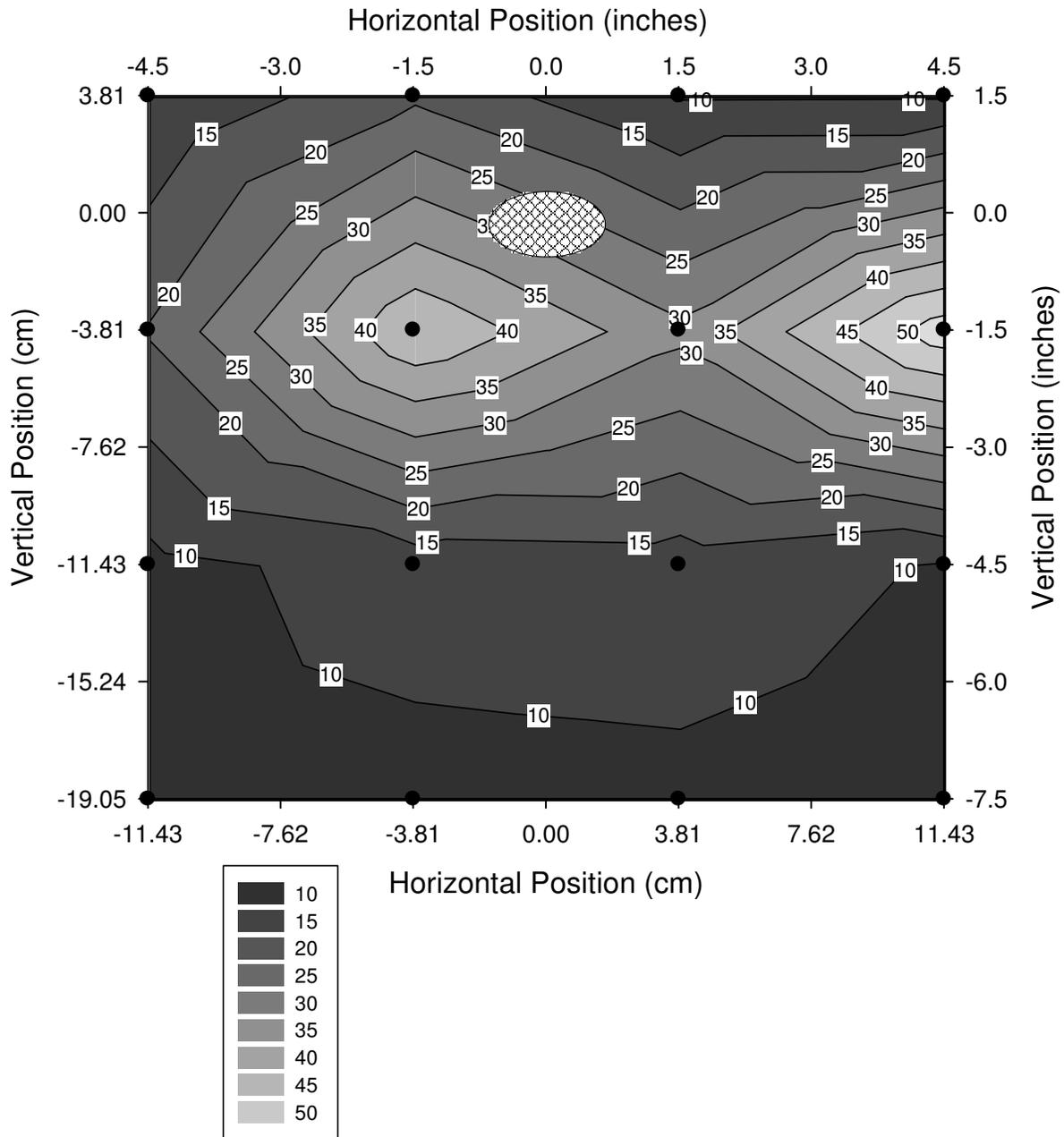


Figure 4.8 NF 6-24-6 w/ Avail Treatment P Concentration (mg kg⁻¹) near emitter in 2009

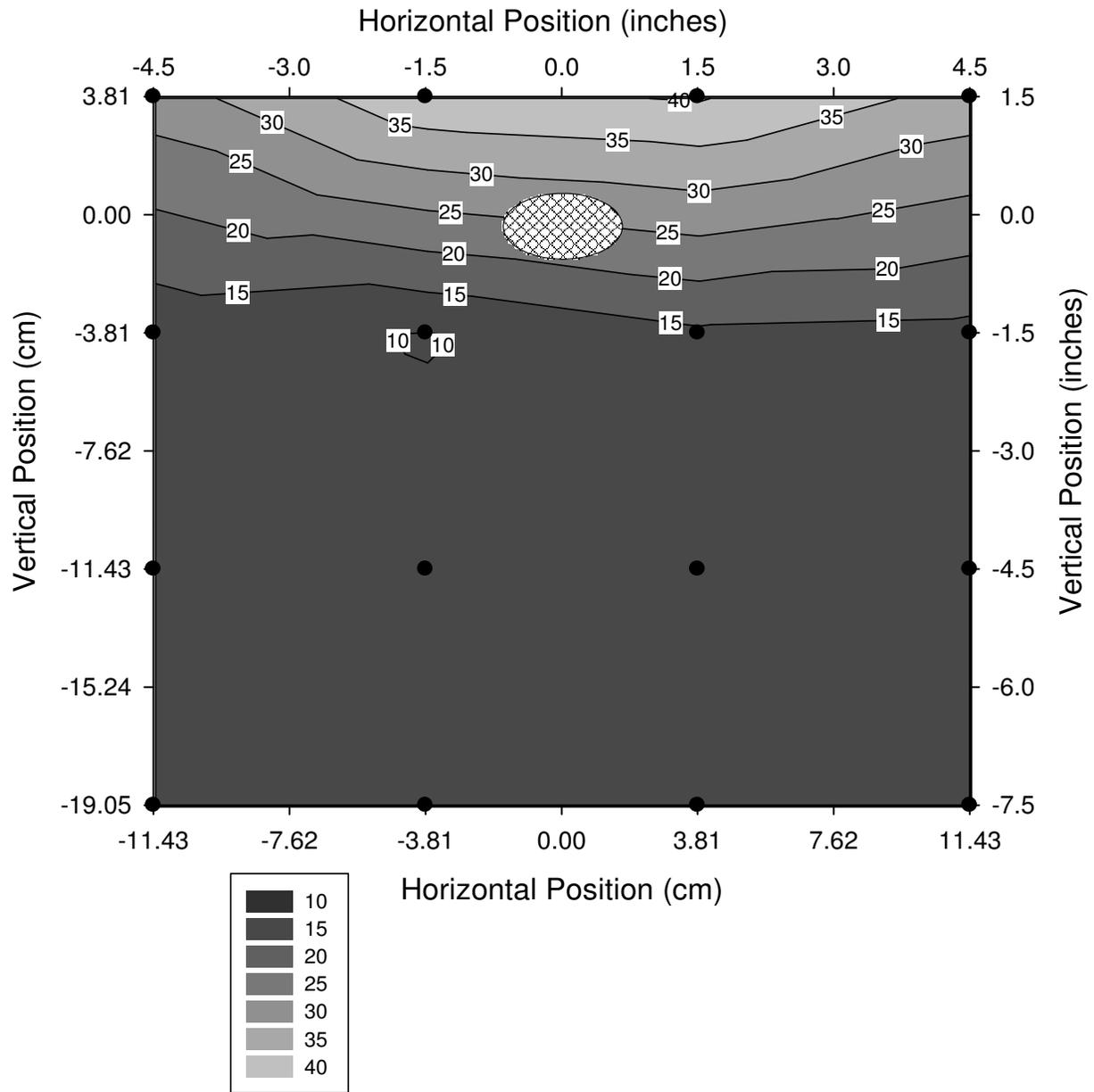


Figure 4.9 Control Treatment P Concentration (mg kg^{-1}) near emitter in 2010

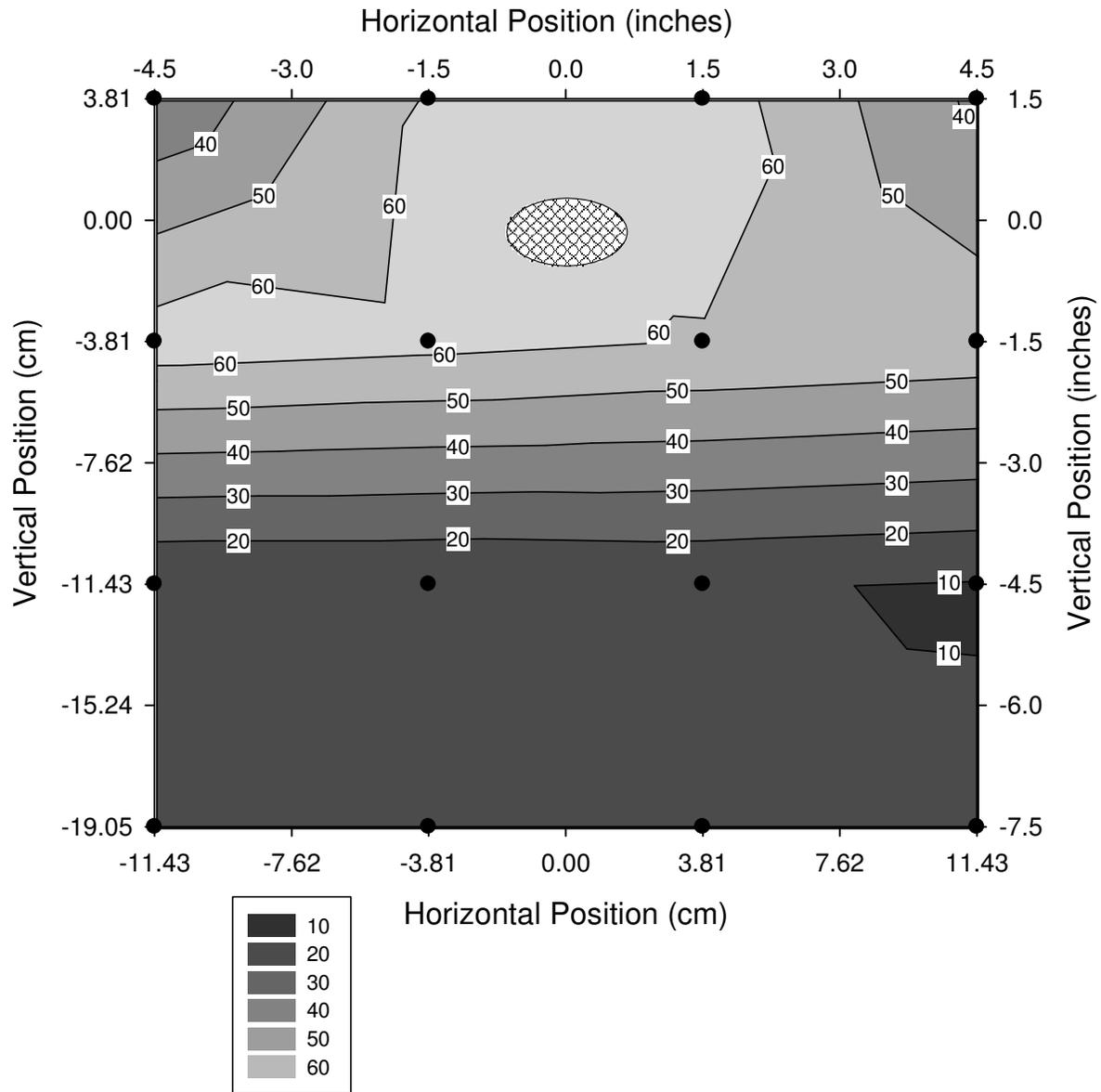


Figure 4.10 NF 6-24-6 w/ Avail Treatment P Concentration (mg kg⁻¹) near emitter in 2010

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Appendix A: KanSched 2 Output

A.1: KanSched 2 Output in 2009

| Day | Ref ET | Crop ET | Rainfall | Gross Irrigation | Available Soil Water Content | Root Zone Water Deficit | Effective Rain |
|--------|--------|---------|----------|------------------|------------------------------|-------------------------|----------------|
| | mm | mm | mm | mm | mm | mm | mm |
| 18-May | 9.14 | 1.78 | 0.00 | 10.67 | 30.48 | 0.00 | 0.00 |
| 19-May | 12.19 | 2.54 | 0.00 | 0.00 | 30.48 | 2.54 | 0.00 |
| 20-May | 11.18 | 2.29 | 0.00 | 0.00 | 30.48 | 4.57 | 0.00 |
| 21-May | 9.65 | 2.03 | 0.00 | 0.00 | 30.73 | 6.60 | 0.00 |
| 22-May | 10.16 | 2.03 | 0.00 | 10.41 | 39.62 | 0.00 | 0.00 |
| 23-May | 9.40 | 1.78 | 0.00 | 0.00 | 40.13 | 1.78 | 0.00 |
| 24-May | 7.62 | 1.52 | 0.00 | 0.00 | 40.89 | 3.30 | 0.00 |
| 25-May | 6.35 | 1.27 | 0.00 | 0.00 | 41.91 | 4.57 | 0.00 |
| 26-May | 3.81 | 0.76 | 0.76 | 0.00 | 44.45 | 4.57 | 0.76 |
| 27-May | 2.29 | 0.51 | 2.54 | 0.00 | 48.77 | 2.54 | 2.54 |
| 28-May | 7.37 | 1.52 | 0.00 | 10.16 | 53.59 | 0.00 | 0.00 |
| 29-May | 8.89 | 1.78 | 0.00 | 0.00 | 54.10 | 1.78 | 0.00 |
| 30-May | 9.91 | 2.03 | 0.00 | 0.00 | 54.61 | 3.81 | 0.00 |
| 31-May | 12.19 | 2.54 | 0.00 | 0.00 | 54.36 | 6.10 | 0.00 |
| 1-Jun | 11.18 | 2.29 | 0.51 | 10.67 | 62.99 | 0.00 | 0.51 |
| 2-Jun | 2.79 | 0.51 | 40.13 | 0.00 | 65.28 | 0.00 | 0.51 |
| 3-Jun | 6.10 | 1.27 | 0.00 | 0.00 | 66.29 | 1.27 | 0.00 |
| 4-Jun | 5.08 | 1.02 | 0.00 | 0.00 | 67.56 | 2.29 | 0.00 |
| 5-Jun | 8.13 | 1.52 | 0.00 | 9.65 | 72.14 | 0.00 | 0.00 |
| 6-Jun | 11.68 | 2.29 | 0.76 | 0.00 | 72.90 | 1.52 | 0.76 |
| 7-Jun | 11.68 | 2.29 | 3.81 | 0.00 | 76.71 | 0.00 | 3.81 |
| 8-Jun | 5.59 | 1.02 | 0.76 | 10.41 | 79.25 | 0.00 | 0.76 |
| 9-Jun | 2.29 | 0.51 | 14.99 | 0.00 | 81.53 | 0.00 | 0.51 |
| 10-Jun | 2.54 | 0.51 | 0.76 | 0.00 | 83.82 | 0.00 | 0.51 |
| 11-Jun | 3.05 | 0.76 | 0.25 | 10.41 | 86.11 | 0.00 | 0.25 |
| 12-Jun | 5.59 | 1.52 | 0.00 | 0.00 | 86.87 | 1.52 | 0.00 |

| | | | | | | | |
|--------|------|------|-------|------|--------|-------|-------|
| 13-Jun | 5.84 | 1.78 | 0.00 | 1.78 | 88.90 | 1.78 | 0.00 |
| 14-Jun | 5.08 | 1.52 | 4.06 | 0.25 | 92.96 | 0.00 | 3.30 |
| 15-Jun | 7.37 | 2.54 | 44.96 | 0.00 | 95.25 | 0.00 | 2.54 |
| 16-Jun | 6.86 | 2.54 | 14.48 | 0.00 | 97.79 | 0.00 | 2.54 |
| 17-Jun | 7.62 | 3.05 | 0.00 | 0.00 | 97.03 | 3.05 | 0.00 |
| 18-Jun | 9.91 | 4.06 | 0.00 | 5.59 | 100.08 | 2.29 | 0.00 |
| 19-Jun | 8.38 | 3.56 | 0.00 | 3.05 | 101.35 | 3.30 | 0.00 |
| 20-Jun | 2.79 | 1.27 | 46.74 | 0.00 | 106.93 | 0.00 | 4.57 |
| 21-Jun | 9.40 | 4.57 | 0.00 | 0.00 | 104.65 | 4.57 | 0.00 |
| 22-Jun | 8.89 | 4.57 | 0.00 | 0.00 | 102.62 | 9.14 | 0.00 |
| 23-Jun | 9.91 | 5.33 | 34.80 | 0.00 | 113.79 | 0.00 | 14.22 |
| 24-Jun | 8.89 | 4.83 | 0.00 | 0.00 | 111.25 | 4.83 | 0.00 |
| 25-Jun | 8.38 | 4.83 | 0.00 | 0.00 | 108.71 | 9.65 | 0.00 |
| 26-Jun | 7.11 | 4.32 | 0.00 | 5.33 | 111.25 | 9.40 | 0.00 |
| 27-Jun | 8.38 | 5.33 | 0.00 | 2.54 | 110.74 | 12.45 | 0.00 |
| 28-Jun | 9.14 | 5.84 | 0.00 | 0.00 | 106.93 | 18.54 | 0.00 |
| 29-Jun | 9.65 | 6.35 | 0.00 | 0.00 | 102.87 | 24.89 | 0.00 |
| 30-Jun | 8.13 | 5.59 | 0.00 | 0.00 | 99.57 | 30.48 | 0.00 |
| 1-Jul | 7.87 | 5.59 | 0.00 | 6.10 | 101.35 | 30.99 | 0.00 |
| 2-Jul | 6.35 | 4.83 | 0.00 | 3.05 | 101.60 | 33.27 | 0.00 |
| 3-Jul | 6.35 | 4.83 | 21.84 | 0.00 | 120.90 | 16.26 | 21.84 |
| 4-Jul | 5.59 | 4.32 | 6.86 | 0.00 | 125.73 | 13.72 | 6.86 |
| 5-Jul | 6.60 | 5.33 | 0.00 | 0.00 | 122.68 | 19.05 | 0.00 |
| 6-Jul | 7.62 | 6.35 | 0.00 | 0.00 | 118.62 | 25.40 | 0.00 |
| 7-Jul | 8.13 | 6.86 | 0.00 | 6.86 | 119.63 | 26.67 | 0.00 |
| 8-Jul | 7.87 | 6.86 | 0.00 | 0.00 | 115.06 | 33.53 | 0.00 |
| 9-Jul | 8.38 | 7.62 | 0.00 | 5.84 | 114.81 | 36.07 | 0.00 |
| 10-Jul | 5.33 | 5.08 | 0.25 | 3.05 | 115.06 | 38.35 | 0.25 |
| 11-Jul | 6.86 | 6.60 | 0.00 | 0.00 | 110.74 | 44.70 | 0.00 |
| 12-Jul | 4.83 | 4.83 | 20.32 | 0.00 | 128.78 | 29.21 | 20.32 |
| 13-Jul | 6.35 | 6.35 | 0.00 | 0.00 | 124.71 | 35.56 | 0.00 |
| 14-Jul | 7.37 | 7.37 | 3.30 | 5.84 | 128.02 | 34.54 | 3.30 |
| 15-Jul | 6.10 | 6.10 | 9.40 | 0.00 | 131.32 | 31.24 | 9.40 |
| 16-Jul | 5.08 | 5.08 | 1.27 | 3.05 | 130.05 | 32.51 | 1.27 |
| 17-Jul | 6.60 | 6.60 | 0.00 | 5.59 | 128.02 | 34.54 | 0.00 |
| 18-Jul | 7.11 | 7.11 | 0.00 | 3.05 | 123.70 | 38.86 | 0.00 |

| | | | | | | | |
|--------|-------|-------|-------|------|--------|-------|-------|
| 19-Jul | 8.13 | 8.13 | 0.00 | 0.00 | 115.57 | 46.99 | 0.00 |
| 20-Jul | 3.30 | 3.30 | 14.22 | 0.00 | 126.49 | 36.07 | 14.22 |
| 21-Jul | 3.81 | 3.81 | 0.00 | 3.05 | 125.22 | 37.34 | 0.00 |
| 22-Jul | 7.62 | 7.62 | 0.00 | 2.79 | 119.89 | 42.67 | 0.00 |
| 23-Jul | 7.62 | 7.62 | 0.00 | 3.05 | 114.81 | 47.75 | 0.00 |
| 24-Jul | 8.89 | 8.89 | 0.00 | 5.84 | 111.00 | 51.56 | 0.00 |
| 25-Jul | 7.37 | 7.37 | 1.52 | 0.00 | 105.16 | 57.40 | 1.52 |
| 26-Jul | 6.35 | 6.35 | 0.00 | 0.00 | 98.81 | 63.75 | 0.00 |
| 27-Jul | 7.11 | 7.11 | 3.30 | 5.84 | 99.82 | 62.74 | 3.30 |
| 28-Jul | 2.79 | 2.79 | 44.20 | 3.05 | 144.02 | 18.54 | 44.20 |
| 29-Jul | 5.08 | 5.08 | 0.00 | 0.00 | 138.94 | 23.62 | 0.00 |
| 30-Jul | 5.84 | 5.84 | 1.78 | 0.00 | 134.87 | 27.69 | 1.78 |
| 31-Jul | 8.38 | 8.38 | 0.00 | 0.00 | 126.49 | 36.07 | 0.00 |
| 1-Aug | 7.11 | 7.11 | 16.51 | 3.05 | 138.43 | 24.13 | 16.51 |
| 2-Aug | 8.13 | 8.13 | 0.00 | 0.00 | 130.30 | 32.26 | 0.00 |
| 3-Aug | 8.38 | 8.38 | 0.00 | 5.59 | 126.75 | 35.81 | 0.00 |
| 4-Aug | 6.86 | 6.86 | 3.81 | 3.05 | 126.24 | 36.32 | 3.81 |
| 5-Aug | 5.59 | 5.59 | 0.00 | 0.00 | 120.65 | 41.91 | 0.00 |
| 6-Aug | 4.57 | 4.57 | 0.00 | 5.33 | 120.65 | 41.91 | 0.00 |
| 7-Aug | 9.40 | 9.40 | 0.00 | 3.05 | 113.79 | 48.77 | 0.00 |
| 8-Aug | 10.41 | 10.41 | 0.00 | 0.00 | 103.38 | 59.18 | 0.00 |
| 9-Aug | 9.40 | 9.40 | 12.95 | 0.00 | 106.93 | 55.63 | 12.95 |
| 10-Aug | 5.33 | 5.33 | 17.27 | 3.05 | 121.41 | 41.15 | 17.27 |
| 11-Aug | 7.37 | 7.37 | 0.00 | 3.05 | 116.59 | 45.97 | 0.00 |
| 12-Aug | 7.11 | 7.11 | 0.00 | 3.05 | 112.01 | 50.55 | 0.00 |
| 13-Aug | 7.87 | 7.87 | 0.00 | 0.25 | 104.39 | 58.17 | 0.00 |
| 14-Aug | 7.62 | 7.62 | 0.00 | 6.10 | 102.11 | 60.45 | 0.00 |
| 15-Aug | 5.84 | 5.84 | 0.00 | 0.00 | 96.27 | 66.29 | 0.00 |
| 16-Aug | 5.33 | 5.33 | 2.29 | 0.00 | 93.22 | 69.34 | 2.29 |
| 17-Aug | 4.57 | 4.57 | 36.32 | 3.30 | 127.76 | 34.80 | 36.32 |
| 18-Aug | 4.83 | 4.83 | 0.00 | 0.00 | 122.94 | 39.62 | 0.00 |
| 19-Aug | 5.84 | 5.84 | 23.11 | 0.00 | 140.21 | 22.35 | 23.11 |
| 20-Aug | 7.11 | 7.11 | 0.00 | 0.00 | 133.10 | 29.46 | 0.00 |
| 21-Aug | 6.35 | 6.35 | 0.00 | 0.00 | 126.75 | 35.81 | 0.00 |
| 22-Aug | 5.84 | 5.84 | 0.00 | 0.00 | 120.90 | 41.66 | 0.00 |
| 23-Aug | 6.60 | 6.35 | 0.00 | 0.00 | 114.55 | 48.01 | 0.00 |

| | | | | | | | |
|--------|------|------|-------|------|--------|-------|-------|
| 24-Aug | 7.87 | 7.37 | 0.00 | 0.00 | 107.19 | 55.37 | 0.00 |
| 25-Aug | 7.11 | 6.60 | 0.00 | 0.00 | 100.58 | 61.98 | 0.00 |
| 26-Aug | 3.05 | 2.79 | 22.86 | 0.00 | 120.65 | 41.91 | 22.86 |
| 27-Aug | 3.05 | 2.79 | 0.00 | 0.00 | 117.86 | 44.70 | 0.00 |
| 28-Aug | 4.57 | 4.06 | 0.00 | 0.00 | 114.05 | 48.51 | 0.00 |
| 29-Aug | 3.81 | 3.30 | 0.00 | 0.00 | 110.74 | 51.82 | 0.00 |
| 30-Aug | 5.33 | 4.57 | 0.00 | 0.00 | 106.17 | 56.39 | 0.00 |
| 31-Aug | 3.56 | 2.79 | 0.00 | 0.00 | 103.38 | 59.18 | 0.00 |
| 1-Sep | 4.57 | 3.56 | 0.00 | 0.00 | 99.82 | 62.74 | 0.00 |
| 2-Sep | 3.56 | 2.79 | 0.00 | 0.00 | 97.03 | 65.53 | 0.00 |
| 3-Sep | 4.06 | 3.05 | 0.25 | 0.00 | 94.23 | 68.33 | 0.25 |
| 4-Sep | 3.05 | 2.29 | 9.91 | 0.00 | 101.85 | 60.71 | 9.91 |
| 5-Sep | 4.83 | 3.56 | 0.00 | 0.00 | 98.30 | 64.26 | 0.00 |
| 6-Sep | 4.83 | 3.30 | 0.00 | 0.00 | 95.00 | 67.56 | 0.00 |
| 7-Sep | 5.08 | 3.56 | 0.00 | 0.00 | 91.44 | 71.12 | 0.00 |
| 8-Sep | 2.79 | 1.78 | 0.76 | 0.00 | 90.42 | 72.14 | 0.76 |
| 9-Sep | 3.05 | 2.03 | 2.03 | 0.00 | 90.42 | 72.14 | 2.03 |
| 10-Sep | 4.32 | 2.79 | 0.00 | 0.00 | 87.63 | 74.93 | 0.00 |
| 11-Sep | 4.83 | 3.05 | 0.00 | 0.00 | 84.84 | 77.72 | 0.00 |
| 12-Sep | 4.32 | 2.54 | 11.68 | 0.00 | 93.73 | 68.83 | 11.68 |
| 13-Sep | 4.83 | 2.79 | 0.00 | 0.00 | 91.19 | 71.37 | 0.00 |
| 14-Sep | 4.32 | 2.29 | 0.00 | 0.00 | 88.65 | 73.91 | 0.00 |
| 15-Sep | 5.08 | 2.79 | 0.00 | 0.00 | 85.85 | 76.71 | 0.00 |
| 16-Sep | 5.59 | 2.79 | 0.00 | 0.00 | 83.06 | 79.50 | 0.00 |
| 17-Sep | 5.33 | 2.79 | 0.00 | 0.00 | 80.26 | 82.30 | 0.00 |

A.2: KanSched 2 Output in 2010

| Day | Ref ET | Crop ET | Rainfall | Gross Irrigation | Available Soil Water Content | Root Zone Water Deficit | Effective Rainfall |
|--------|--------|---------|----------|------------------|------------------------------|-------------------------|--------------------|
| | mm | mm | mm | mm | mm | mm | mm |
| 28-May | 7.62 | 1.52 | 0.00 | 0.00 | 30.48 | 0.00 | 0.00 |
| 29-May | 6.60 | 1.27 | 0.00 | 0.00 | 32.51 | 1.27 | 0.00 |
| 30-May | 6.35 | 1.27 | 16.51 | 0.00 | 37.08 | 0.00 | 2.54 |
| 31-May | 6.10 | 1.27 | 0.00 | 0.00 | 39.12 | 1.27 | 0.00 |
| 1-Jun | 8.38 | 1.78 | 0.00 | 9.14 | 43.69 | 0.00 | 0.00 |
| 2-Jun | 6.60 | 1.27 | 0.00 | 0.00 | 45.72 | 1.27 | 0.00 |
| 3-Jun | 7.87 | 1.78 | 0.00 | 9.14 | 50.29 | 0.00 | 0.00 |
| 4-Jun | 9.65 | 2.29 | 0.00 | 1.02 | 52.07 | 1.52 | 0.00 |
| 5-Jun | 8.64 | 2.29 | 0.00 | 0.00 | 53.09 | 3.81 | 0.00 |
| 6-Jun | 7.87 | 2.29 | 0.00 | 0.00 | 54.10 | 6.10 | 0.00 |
| 7-Jun | 5.08 | 1.52 | 0.51 | 0.00 | 56.13 | 7.37 | 0.51 |
| 8-Jun | 4.57 | 1.52 | 20.83 | 1.27 | 66.80 | 0.00 | 8.89 |
| 9-Jun | 6.60 | 2.29 | 0.00 | 0.76 | 68.33 | 1.78 | 0.00 |
| 10-Jun | 7.37 | 2.79 | 0.00 | 0.00 | 68.83 | 4.57 | 0.00 |
| 11-Jun | 5.33 | 2.29 | 0.00 | 0.00 | 69.85 | 6.86 | 0.00 |
| 12-Jun | 4.57 | 2.03 | 19.56 | 0.00 | 80.01 | 0.00 | 8.89 |
| 13-Jun | 5.08 | 2.29 | 44.45 | 0.00 | 83.31 | 0.00 | 2.29 |
| 14-Jun | 4.06 | 2.03 | 0.51 | 0.25 | 85.34 | 1.27 | 0.51 |
| 15-Jun | 5.84 | 3.05 | 6.86 | 0.76 | 89.92 | 0.00 | 4.32 |
| 16-Jun | 6.86 | 3.56 | 40.64 | 0.76 | 93.22 | 0.00 | 3.56 |
| 17-Jun | 8.89 | 4.83 | 0.00 | 0.00 | 91.69 | 4.83 | 0.00 |
| 18-Jun | 9.65 | 5.59 | 0.00 | 0.00 | 89.41 | 10.41 | 0.00 |
| 19-Jun | 7.87 | 4.83 | 11.43 | 0.00 | 99.31 | 3.81 | 11.43 |
| 20-Jun | 7.11 | 4.32 | 22.10 | 0.00 | 106.43 | 0.00 | 8.13 |
| 21-Jun | 7.87 | 5.08 | 0.51 | 0.00 | 105.16 | 4.57 | 0.51 |
| 22-Jun | 10.16 | 6.86 | 0.00 | 0.00 | 101.60 | 11.43 | 0.00 |
| 23-Jun | 7.87 | 5.59 | 0.00 | 0.00 | 99.57 | 16.76 | 0.00 |
| 24-Jun | 7.11 | 5.08 | 0.00 | 6.10 | 102.87 | 16.76 | 0.00 |
| 25-Jun | 9.14 | 6.86 | 0.00 | 2.79 | 101.85 | 21.08 | 0.00 |
| 26-Jun | 8.89 | 6.86 | 0.00 | 0.00 | 98.30 | 27.94 | 0.00 |

| | | | | | | | |
|--------|-------|-------|-------|------|--------|-------|-------|
| 27-Jun | 8.64 | 6.86 | 0.76 | 0.00 | 95.50 | 34.04 | 0.76 |
| 28-Jun | 8.13 | 6.60 | 0.00 | 8.89 | 99.82 | 33.02 | 0.00 |
| 29-Jun | 7.87 | 6.60 | 0.00 | 8.89 | 104.14 | 32.00 | 0.00 |
| 30-Jun | 7.87 | 6.86 | 0.00 | 0.00 | 100.58 | 38.86 | 0.00 |
| 1-Jul | 7.62 | 6.60 | 0.00 | 8.89 | 104.65 | 38.10 | 0.00 |
| 2-Jul | 7.87 | 7.11 | 0.00 | 8.89 | 108.46 | 37.59 | 0.00 |
| 3-Jul | 5.84 | 5.33 | 0.00 | 0.00 | 106.43 | 42.93 | 0.00 |
| 4-Jul | 2.54 | 2.54 | 47.24 | 0.00 | 152.65 | 0.00 | 45.47 |
| 5-Jul | 3.81 | 3.81 | 13.46 | 0.00 | 155.96 | 0.00 | 3.81 |
| 6-Jul | 6.35 | 6.35 | 0.00 | 0.00 | 152.91 | 6.35 | 0.00 |
| 7-Jul | 4.32 | 4.32 | 0.51 | 0.00 | 152.40 | 10.16 | 0.51 |
| 8-Jul | 3.81 | 3.81 | 0.25 | 5.59 | 153.67 | 8.89 | 0.25 |
| 9-Jul | 7.37 | 7.37 | 0.00 | 2.79 | 148.59 | 13.97 | 0.00 |
| 10-Jul | 7.62 | 7.62 | 0.00 | 0.00 | 140.97 | 21.59 | 0.00 |
| 11-Jul | 7.62 | 7.62 | 0.00 | 0.00 | 133.35 | 29.21 | 0.00 |
| 12-Jul | 5.33 | 5.33 | 0.00 | 0.00 | 128.02 | 34.54 | 0.00 |
| 13-Jul | 7.62 | 7.62 | 0.00 | 8.89 | 128.02 | 34.54 | 0.00 |
| 14-Jul | 8.64 | 8.64 | 18.29 | 0.00 | 137.67 | 24.89 | 18.29 |
| 15-Jul | 7.37 | 7.37 | 7.62 | 0.00 | 137.92 | 24.64 | 7.62 |
| 16-Jul | 7.37 | 7.37 | 0.00 | 8.89 | 138.18 | 24.38 | 0.00 |
| 17-Jul | 7.62 | 7.62 | 0.00 | 0.00 | 130.56 | 32.00 | 0.00 |
| 18-Jul | 8.38 | 8.38 | 0.00 | 0.00 | 122.17 | 40.39 | 0.00 |
| 19-Jul | 9.14 | 9.14 | 0.00 | 9.14 | 120.65 | 41.91 | 0.00 |
| 20-Jul | 7.37 | 7.37 | 8.64 | 0.00 | 121.92 | 40.64 | 8.64 |
| 21-Jul | 5.84 | 5.84 | 5.08 | 3.05 | 123.70 | 38.86 | 5.08 |
| 22-Jul | 10.41 | 10.41 | 0.00 | 8.89 | 120.90 | 41.66 | 0.00 |
| 23-Jul | 10.16 | 10.16 | 0.00 | 0.00 | 110.74 | 51.82 | 0.00 |
| 24-Jul | 7.87 | 7.87 | 0.00 | 9.14 | 110.74 | 51.82 | 0.00 |
| 25-Jul | 6.60 | 6.60 | 0.00 | 0.00 | 104.14 | 58.42 | 0.00 |
| 26-Jul | 7.37 | 7.37 | 0.00 | 9.14 | 104.39 | 58.17 | 0.00 |
| 27-Jul | 8.13 | 8.13 | 0.00 | 0.00 | 96.27 | 66.29 | 0.00 |
| 28-Jul | 8.64 | 8.64 | 0.00 | 0.00 | 87.63 | 74.93 | 0.00 |
| 29-Jul | 8.64 | 8.64 | 0.00 | 9.14 | 86.61 | 75.95 | 0.00 |
| 30-Jul | 8.13 | 8.13 | 5.33 | 0.00 | 83.82 | 78.74 | 5.33 |
| 31-Jul | 6.60 | 6.60 | 0.00 | 9.14 | 85.09 | 77.47 | 0.00 |
| 1-Aug | 7.37 | 7.37 | 0.25 | 0.00 | 77.98 | 84.58 | 0.25 |

| | | | | | | | |
|--------|-------|-------|-------|-------|--------|--------|-------|
| 2-Aug | 11.43 | 10.92 | 0.00 | 11.94 | 76.96 | 85.60 | 0.00 |
| 3-Aug | 11.18 | 10.67 | 0.00 | 9.14 | 74.17 | 88.39 | 0.00 |
| 4-Aug | 6.35 | 5.84 | 0.00 | 9.14 | 76.20 | 86.36 | 0.00 |
| 5-Aug | 8.13 | 7.62 | 0.00 | 0.00 | 68.58 | 93.98 | 0.00 |
| 6-Aug | 7.87 | 6.60 | 0.00 | 9.14 | 69.60 | 92.96 | 0.00 |
| 7-Aug | 9.14 | 7.87 | 0.00 | 9.14 | 69.60 | 92.96 | 0.00 |
| 8-Aug | 9.65 | 8.38 | 0.00 | 0.00 | 61.21 | 101.35 | 0.00 |
| 9-Aug | 10.16 | 7.62 | 0.00 | 9.14 | 61.21 | 101.35 | 0.00 |
| 10-Aug | 10.16 | 7.62 | 0.00 | 8.89 | 61.21 | 101.35 | 0.00 |
| 11-Aug | 10.16 | 7.62 | 0.00 | 8.89 | 60.96 | 101.60 | 0.00 |
| 12-Aug | 9.40 | 7.11 | 0.00 | 0.00 | 54.10 | 108.46 | 0.00 |
| 13-Aug | 11.94 | 7.87 | 31.24 | 4.83 | 81.53 | 81.03 | 31.24 |
| 14-Aug | 7.37 | 7.37 | 0.76 | 2.03 | 76.45 | 86.11 | 0.76 |
| 15-Aug | 6.86 | 6.35 | 0.00 | 0.00 | 70.36 | 92.20 | 0.00 |
| 16-Aug | 6.10 | 4.83 | 0.00 | 4.83 | 69.60 | 92.96 | 0.00 |
| 17-Aug | 3.05 | 2.29 | 3.56 | 9.40 | 78.49 | 84.07 | 3.56 |
| 18-Aug | 5.33 | 4.57 | 0.00 | 0.00 | 74.17 | 88.39 | 0.00 |
| 19-Aug | 7.11 | 5.33 | 0.00 | 0.00 | 68.83 | 93.73 | 0.00 |
| 20-Aug | 5.59 | 3.81 | 0.76 | 9.14 | 73.66 | 88.90 | 0.76 |
| 21-Aug | 6.35 | 4.32 | 0.25 | 9.14 | 77.22 | 85.34 | 0.25 |
| 22-Aug | 7.62 | 5.33 | 0.00 | 0.00 | 71.88 | 90.68 | 0.00 |
| 23-Aug | 8.89 | 5.59 | 0.00 | 0.00 | 66.29 | 96.27 | 0.00 |
| 24-Aug | 6.60 | 3.56 | 43.94 | 8.38 | 113.79 | 48.77 | 43.94 |
| 25-Aug | 5.84 | 3.81 | 0.00 | 0.00 | 109.98 | 52.58 | 0.00 |
| 26-Aug | 5.59 | 3.30 | 0.00 | 7.37 | 113.03 | 49.53 | 0.00 |
| 27-Aug | 7.62 | 4.32 | 0.00 | 0.00 | 108.71 | 53.85 | 0.00 |
| 28-Aug | 9.40 | 5.08 | 0.00 | 0.00 | 103.63 | 58.93 | 0.00 |
| 29-Aug | 10.41 | 5.33 | 0.00 | 0.00 | 98.55 | 64.01 | 0.00 |

Appendix B: Field Study Raw Data

B.1: 2009 Field Study Raw Data

| Rep | TRT | Avail | Starter | Grain Yield | Seed Wt. | Moisture | N Stover | P Stover | K Stover | N Kernel | P Kernel | K Kernel | Grain N Removal | Grain P Removal | Grain K Removal |
|-----|-----|-------|---------|---------------------|-----------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-----------------------|---|--------------------------------------|
| | | | | Mg ha ⁻¹ | mg seed ⁻¹ | g kg ⁻¹ | g kg ⁻¹ | g kg ⁻¹ | g kg ⁻¹ | g kg ⁻¹ | g kg ⁻¹ | g kg ⁻¹ | kg N ha ⁻¹ | kg P ₂ O ₅ ha ⁻¹ | kg K ₂ O ha ⁻¹ |
| 1 | 5 | 1 | 1 | 13.10 | 254.60 | 164.00 | 3.45 | 1.79 | 12.90 | 9.99 | 3.32 | 4.00 | 110.58 | 84.26 | 53.09 |
| 1 | 5 | 1 | 0 | 12.24 | 259.20 | 165.00 | 2.64 | 1.39 | 11.93 | 9.73 | 3.19 | 3.60 | 100.66 | 75.56 | 44.69 |
| 1 | 1 | 0 | 1 | 12.56 | 286.70 | 175.00 | 3.43 | 0.90 | 14.92 | 11.01 | 3.41 | 3.77 | 116.86 | 82.88 | 47.96 |
| 1 | 1 | 0 | 0 | 12.50 | 252.50 | 167.00 | 2.43 | 0.87 | 13.41 | 9.96 | 3.34 | 3.94 | 105.16 | 80.82 | 49.88 |
| 1 | 4 | 0 | 1 | 12.27 | 295.10 | 168.00 | 2.93 | 1.16 | 15.66 | 11.65 | 3.46 | 3.98 | 120.83 | 82.22 | 49.51 |
| 1 | 4 | 0 | 0 | 11.62 | 272.90 | 169.00 | 2.74 | 1.28 | 14.52 | 11.07 | 3.40 | 3.86 | 108.72 | 76.57 | 45.46 |
| 1 | 2 | 0 | 1 | 12.94 | 257.90 | 172.00 | 2.96 | 1.35 | 13.47 | 10.99 | 3.41 | 3.81 | 120.13 | 85.33 | 49.97 |
| 1 | 2 | 0 | 0 | 12.08 | 227.90 | 166.00 | 3.15 | 1.13 | 15.96 | 11.14 | 3.48 | 3.92 | 113.72 | 81.34 | 48.02 |
| 1 | 3 | 1 | 1 | 13.66 | 272.30 | 169.00 | 2.98 | 1.12 | 15.78 | 10.81 | 3.50 | 3.96 | 124.84 | 92.51 | 54.91 |
| 1 | 3 | 1 | 0 | 11.84 | 270.10 | 171.00 | 2.58 | 1.38 | 15.50 | 10.14 | 3.40 | 3.65 | 101.44 | 77.88 | 43.79 |
| 1 | 6 | 0 | 1 | 13.94 | 262.50 | 169.00 | 2.81 | 1.42 | 15.04 | 10.51 | 3.41 | 3.73 | 123.87 | 91.93 | 52.72 |
| 1 | 6 | 0 | 0 | 12.79 | 255.00 | 173.00 | 2.76 | 1.57 | 15.88 | 10.75 | 3.50 | 3.85 | 116.18 | 86.74 | 50.01 |
| 1 | 8 | 0 | 1 | 12.53 | 289.40 | 166.00 | 3.32 | 1.05 | 15.22 | 11.00 | 3.31 | 3.70 | 116.53 | 80.29 | 47.03 |
| 1 | 8 | 0 | 0 | 12.19 | 255.75 | 166.00 | 2.90 | 0.95 | 15.92 | 9.51 | 3.28 | 3.70 | 98.03 | 77.40 | 45.77 |
| 1 | 7 | 1 | 1 | 13.23 | 276.15 | 167.00 | 3.12 | 1.16 | 15.30 | 10.90 | 3.29 | 3.50 | 121.86 | 84.23 | 46.96 |
| 1 | 7 | 1 | 0 | 12.79 | 267.30 | 168.00 | 2.92 | 0.95 | 15.12 | 9.90 | 3.25 | 3.50 | 107.02 | 80.45 | 45.40 |
| 2 | 8 | 0 | 1 | 12.55 | 272.90 | 161.00 | 2.67 | 0.81 | 16.89 | 11.09 | 3.43 | 4.04 | 117.67 | 83.24 | 51.42 |
| 2 | 8 | 0 | 0 | 12.18 | 250.80 | 162.00 | 2.44 | 1.64 | 16.73 | 9.64 | 3.34 | 4.12 | 99.24 | 78.63 | 50.92 |
| 2 | 4 | 0 | 1 | 13.44 | 270.60 | 162.00 | 2.72 | 0.94 | 18.06 | 9.84 | 3.40 | 4.03 | 111.80 | 88.41 | 54.94 |
| 2 | 4 | 0 | 0 | 13.14 | 254.90 | 161.00 | 2.26 | 0.72 | 18.23 | 10.30 | 3.50 | 4.09 | 114.40 | 88.97 | 54.56 |
| 2 | 2 | 0 | 1 | 14.43 | 259.40 | 163.00 | 3.47 | 1.08 | 17.36 | 11.17 | 3.51 | 4.09 | 136.21 | 97.95 | 59.89 |
| 2 | 2 | 0 | 0 | 13.44 | 244.10 | 159.00 | 2.41 | 1.22 | 17.01 | 9.95 | 3.47 | 3.57 | 113.06 | 90.19 | 48.66 |
| 2 | 6 | 0 | 1 | 13.65 | 273.30 | 169.00 | 2.71 | 1.15 | 17.24 | 9.99 | 3.40 | 3.83 | 115.25 | 89.85 | 52.97 |
| 2 | 6 | 0 | 0 | 11.71 | 264.30 | 164.00 | 2.26 | 0.99 | 13.17 | 10.50 | 3.49 | 4.05 | 103.98 | 79.19 | 48.11 |
| 2 | 3 | 1 | 1 | 13.85 | 277.80 | 163.00 | 3.42 | 0.95 | 17.37 | 10.11 | 3.47 | 3.80 | 118.39 | 92.94 | 53.31 |
| 2 | 3 | 1 | 0 | 12.10 | 255.60 | 157.00 | 2.45 | 1.33 | 17.40 | 10.20 | 3.46 | 3.90 | 104.33 | 80.99 | 47.88 |
| 2 | 7 | 1 | 1 | 13.09 | 276.50 | 170.00 | 2.85 | 0.61 | 16.16 | 10.65 | 3.31 | 3.88 | 117.85 | 83.82 | 51.49 |
| 2 | 7 | 1 | 0 | 12.63 | 262.60 | 167.00 | 2.59 | 0.67 | 17.26 | 10.45 | 3.26 | 3.71 | 111.51 | 79.62 | 47.54 |
| 2 | 1 | 0 | 1 | 12.06 | 278.60 | 163.00 | 2.47 | 0.53 | 14.35 | 10.07 | 3.31 | 3.63 | 102.64 | 77.37 | 44.35 |
| 2 | 1 | 0 | 0 | 12.19 | 253.40 | 163.00 | 2.56 | 0.68 | 14.46 | 10.19 | 3.30 | 3.69 | 104.93 | 77.76 | 45.59 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|-------|--------|--------|------|------|-------|-------|------|------|--------|--------|-------|
| 2 | 5 | 1 | 1 | 16.25 | 314.60 | 179.00 | 2.66 | 0.85 | 15.38 | 11.86 | 3.28 | 3.51 | 162.95 | 103.16 | 57.88 |
| 2 | 5 | 1 | 0 | 13.85 | 233.50 | 162.00 | 2.94 | 0.85 | 15.36 | 9.09 | 3.12 | 3.72 | 106.36 | 83.69 | 52.18 |
| 3 | 6 | 0 | 1 | 15.06 | 295.10 | 179.00 | 3.78 | 0.60 | 16.74 | 11.82 | 2.88 | 3.30 | 150.40 | 83.98 | 50.34 |
| 3 | 6 | 0 | 0 | 14.94 | 312.60 | 169.00 | 2.64 | 0.59 | 16.31 | 11.88 | 3.37 | 3.54 | 149.96 | 97.52 | 53.63 |
| 3 | 2 | 0 | 1 | 12.63 | 291.80 | 177.00 | 3.26 | 0.67 | 14.65 | 10.71 | 2.91 | 3.36 | 114.34 | 71.15 | 43.05 |
| 3 | 2 | 0 | 0 | 12.59 | 272.60 | 168.00 | 3.54 | 0.49 | 15.28 | 8.86 | 2.73 | 3.22 | 94.24 | 66.46 | 41.17 |
| 3 | 1 | 0 | 1 | 12.34 | 291.60 | 173.00 | 3.17 | 0.50 | 15.22 | 11.15 | 2.56 | 2.97 | 116.28 | 61.14 | 37.20 |
| 3 | 1 | 0 | 0 | 11.93 | 261.20 | 171.00 | 2.89 | 0.46 | 13.26 | 10.71 | 2.63 | 3.13 | 108.01 | 60.76 | 37.86 |
| 3 | 8 | 0 | 1 | 12.52 | 305.90 | 170.00 | 2.98 | 0.45 | 14.33 | 10.94 | 2.74 | 3.26 | 115.70 | 66.45 | 41.43 |
| 3 | 8 | 0 | 0 | 12.21 | 260.70 | 169.00 | 3.14 | 0.43 | 13.17 | 9.33 | 2.75 | 3.24 | 96.19 | 64.86 | 40.11 |
| 3 | 3 | 1 | 1 | 14.95 | 272.60 | 164.00 | 3.26 | 0.85 | 13.42 | 9.93 | 2.85 | 3.14 | 125.43 | 82.40 | 47.58 |
| 3 | 3 | 1 | 0 | 13.61 | 272.60 | 166.00 | 4.03 | 0.61 | 12.64 | 11.09 | 2.87 | 3.38 | 127.53 | 75.57 | 46.63 |
| 3 | 5 | 1 | 1 | 15.09 | 295.00 | 176.00 | 3.07 | 0.43 | 14.37 | 11.65 | 2.45 | 2.94 | 148.63 | 71.68 | 44.96 |
| 3 | 5 | 1 | 0 | 13.99 | 283.20 | 183.00 | 4.18 | 0.52 | 15.57 | 11.23 | 2.68 | 3.28 | 132.77 | 72.47 | 46.49 |
| 3 | 4 | 0 | 1 | 13.75 | 285.30 | 171.00 | 3.37 | 0.58 | 13.68 | 11.37 | 2.40 | 3.01 | 132.12 | 63.91 | 41.99 |
| 3 | 4 | 0 | 0 | 11.93 | 263.70 | 171.00 | 3.18 | 0.48 | 15.38 | 10.94 | 2.46 | 3.09 | 110.33 | 56.89 | 37.35 |
| 3 | 7 | 1 | 1 | 13.37 | 275.80 | 164.00 | 3.55 | 0.38 | 15.36 | 11.19 | 2.45 | 3.12 | 126.46 | 63.51 | 42.26 |
| 3 | 7 | 1 | 0 | 12.95 | 272.00 | 168.00 | 3.15 | 0.42 | 15.72 | 9.28 | 2.41 | 3.26 | 101.50 | 60.40 | 42.82 |

B.2: 2010 Field Study Raw Data

| Rep | TRT | Avail | Starter | Grain Yield | Seed Wt. | Moisture | N Stover | P Stover | K Stover | N Kernel | P Kernel | K Kernel | Grain N Removal | Grain P Removal | Grain K Removal |
|-----|-----|-------|---------|---------------------|-----------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-----------------------|---|--------------------------------------|
| | | | | Mg ha ⁻¹ | mg seed ⁻¹ | g kg ⁻¹ | g kg ⁻¹ | g kg ⁻¹ | g kg ⁻¹ | g kg ⁻¹ | g kg ⁻¹ | g kg ⁻¹ | kg N ha ⁻¹ | kg P ₂ O ₅ ha ⁻¹ | kg K ₂ O ha ⁻¹ |
| 1 | 5 | 1 | 1 | 10.93 | 258.30 | 139.00 | 5.86 | 1.96 | 15.83 | 12.04 | 3.55 | 4.06 | 111.19 | 75.00 | 44.99 |
| 1 | 5 | 1 | 0 | 10.59 | 277.50 | 144.00 | 5.04 | 2.36 | 14.71 | 12.10 | 3.68 | 4.21 | 108.35 | 75.40 | 45.26 |
| 1 | 1 | 0 | 1 | 10.34 | 260.00 | 139.00 | 5.02 | 2.68 | 13.83 | 11.78 | 3.29 | 4.07 | 102.90 | 65.89 | 42.73 |
| 1 | 1 | 0 | 0 | 9.86 | 258.90 | 138.00 | 4.71 | 2.46 | 12.90 | 12.53 | 3.61 | 3.93 | 104.37 | 68.78 | 39.27 |
| 1 | 4 | 0 | 1 | 12.17 | 252.40 | 138.00 | 5.56 | 2.66 | 13.03 | 11.87 | 3.59 | 4.16 | 122.06 | 84.55 | 51.32 |
| 1 | 4 | 0 | 0 | 10.82 | 266.40 | 139.00 | 4.91 | 1.67 | 13.61 | 11.96 | 3.75 | 4.07 | 109.40 | 78.48 | 44.74 |
| 1 | 2 | 0 | 1 | 10.18 | 256.50 | 140.00 | 5.33 | 1.77 | 18.15 | 12.03 | 3.59 | 4.17 | 103.51 | 70.63 | 43.03 |
| 1 | 2 | 0 | 0 | 8.82 | 232.70 | 136.00 | 4.64 | 2.04 | 14.62 | 11.58 | 4.05 | 4.37 | 86.33 | 69.07 | 39.11 |
| 1 | 3 | 1 | 1 | 11.83 | 244.00 | 138.00 | 5.13 | 2.78 | 16.86 | 12.52 | 3.66 | 4.24 | 125.21 | 83.73 | 50.89 |
| 1 | 3 | 1 | 0 | 10.77 | 248.20 | 140.00 | 4.59 | 2.22 | 16.89 | 11.84 | 3.59 | 4.17 | 107.74 | 74.79 | 45.51 |
| 1 | 6 | 0 | 1 | 10.38 | 240.70 | 137.00 | 5.50 | 2.79 | 15.86 | 11.70 | 3.67 | 4.23 | 102.65 | 73.79 | 44.57 |
| 1 | 6 | 0 | 0 | 9.49 | 181.70 | 137.00 | 3.95 | 1.48 | 14.13 | 11.43 | 3.97 | 4.26 | 91.72 | 72.89 | 41.02 |
| 1 | 8 | 0 | 1 | 10.67 | 254.80 | 137.00 | 4.35 | 1.42 | 14.95 | 12.06 | 3.81 | 4.34 | 108.74 | 78.74 | 46.98 |
| 1 | 8 | 0 | 0 | 9.80 | 197.80 | 136.00 | 5.40 | 2.15 | 14.78 | 13.02 | 4.08 | 4.66 | 107.81 | 77.41 | 46.33 |
| 1 | 7 | 1 | 1 | 10.83 | 245.70 | 138.00 | 4.59 | 1.95 | 14.55 | 11.75 | 3.51 | 4.13 | 107.50 | 73.46 | 45.34 |
| 1 | 7 | 1 | 0 | 10.19 | 226.30 | 139.00 | 5.26 | 1.73 | 18.62 | 11.83 | 3.69 | 4.29 | 101.90 | 72.83 | 44.37 |
| 2 | 8 | 0 | 1 | 10.57 | 235.90 | 129.00 | 4.84 | 1.83 | 19.39 | 12.27 | 3.38 | 3.91 | 109.64 | 69.18 | 41.98 |
| 2 | 8 | 0 | 0 | 9.35 | 222.70 | 127.00 | 4.81 | 1.79 | 19.67 | 12.58 | 3.95 | 4.42 | 99.43 | 71.53 | 41.90 |
| 2 | 4 | 0 | 1 | 10.91 | 244.30 | 129.00 | 5.28 | 2.39 | 19.12 | 11.51 | 3.93 | 4.55 | 106.16 | 83.05 | 50.39 |
| 2 | 4 | 0 | 0 | 9.58 | 214.60 | 127.00 | 4.79 | 2.39 | 18.99 | 12.46 | 3.86 | 4.45 | 100.86 | 71.55 | 43.20 |
| 2 | 2 | 0 | 1 | 10.84 | 235.70 | 127.00 | 4.58 | 1.86 | 17.34 | 12.99 | 3.62 | 4.25 | 118.97 | 75.93 | 46.66 |
| 2 | 2 | 0 | 0 | 9.73 | 239.50 | 132.00 | 5.07 | 2.07 | 17.90 | 12.72 | 4.05 | 4.43 | 104.59 | 76.28 | 43.69 |
| 2 | 6 | 0 | 1 | 11.11 | 236.40 | 127.00 | 5.65 | 1.92 | 19.41 | 12.56 | 3.95 | 4.35 | 117.94 | 84.99 | 49.03 |
| 2 | 6 | 0 | 0 | 9.87 | 237.30 | 130.00 | 6.16 | 2.05 | 16.74 | 12.43 | 3.93 | 4.48 | 103.74 | 75.03 | 44.91 |
| 2 | 3 | 1 | 1 | 11.20 | 223.00 | 129.00 | 4.64 | 1.45 | 16.60 | 11.67 | 3.80 | 4.36 | 110.41 | 82.35 | 49.47 |
| 2 | 3 | 1 | 0 | 10.88 | 247.50 | 130.00 | 5.09 | 1.60 | 19.29 | 11.42 | 3.83 | 4.17 | 104.93 | 80.59 | 46.01 |
| 2 | 7 | 1 | 1 | 11.28 | 256.50 | 130.00 | 4.76 | 1.54 | 18.79 | 11.06 | 3.58 | 4.31 | 105.47 | 78.16 | 49.33 |
| 2 | 7 | 1 | 0 | 9.91 | 205.20 | 129.00 | 4.54 | 1.20 | 17.86 | 12.00 | 3.92 | 4.07 | 100.52 | 75.27 | 40.89 |
| 2 | 1 | 0 | 1 | 10.62 | 248.30 | 130.00 | 5.14 | 1.47 | 17.01 | 11.74 | 3.85 | 4.39 | 105.36 | 79.06 | 47.29 |
| 2 | 1 | 0 | 0 | 9.27 | 240.80 | 132.00 | 5.42 | 1.33 | 16.38 | 11.49 | 3.76 | 4.21 | 90.10 | 67.41 | 39.58 |
| 2 | 5 | 1 | 1 | 11.59 | 262.10 | 131.00 | 4.80 | 0.90 | 20.47 | 11.98 | 3.62 | 4.24 | 117.38 | 81.30 | 49.86 |
| 2 | 5 | 1 | 0 | 10.29 | 236.50 | 133.00 | 4.83 | 1.44 | 19.05 | 11.64 | 3.82 | 4.45 | 101.23 | 76.14 | 46.40 |
| 3 | 6 | 0 | 1 | 9.42 | 231.80 | 134.00 | 5.76 | 1.02 | 18.03 | 12.61 | 2.59 | 3.51 | 100.33 | 47.26 | 33.53 |
| 3 | 6 | 0 | 0 | 10.58 | 245.50 | 130.00 | 5.37 | 0.96 | 17.01 | 12.57 | 3.25 | 3.65 | 112.45 | 66.54 | 39.16 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|------|--------|--------|------|------|-------|-------|------|------|--------|-------|-------|
| 3 | 2 | 0 | 1 | 9.82 | 237.90 | 131.00 | 5.79 | 0.85 | 17.99 | 12.11 | 3.40 | 3.79 | 100.51 | 64.64 | 37.76 |
| 3 | 2 | 0 | 0 | 9.72 | 252.90 | 134.00 | 4.52 | 0.71 | 17.04 | 12.25 | 3.32 | 3.66 | 100.59 | 62.37 | 36.09 |
| 3 | 1 | 0 | 1 | 8.58 | 243.60 | 130.00 | 4.34 | 0.75 | 17.79 | 12.83 | 3.26 | 3.93 | 93.11 | 54.23 | 34.17 |
| 3 | 1 | 0 | 0 | 7.75 | 243.50 | 130.00 | 3.62 | 0.70 | 15.88 | 11.91 | 3.37 | 3.84 | 77.95 | 50.55 | 30.20 |
| 3 | 8 | 0 | 1 | 9.53 | 248.50 | 132.00 | 5.04 | 0.89 | 18.69 | 11.62 | 2.80 | 3.30 | 93.62 | 51.64 | 31.85 |
| 3 | 8 | 0 | 0 | 9.06 | 232.60 | 135.00 | 5.36 | 0.85 | 16.07 | 12.33 | 2.83 | 3.34 | 94.36 | 49.52 | 30.67 |
| 3 | 3 | 1 | 1 | 9.60 | 223.80 | 132.00 | 6.26 | 0.99 | 16.57 | 12.49 | 3.25 | 3.80 | 101.28 | 60.28 | 37.01 |
| 3 | 3 | 1 | 0 | 8.35 | 220.10 | 133.00 | 6.27 | 0.86 | 17.71 | 12.26 | 2.84 | 3.56 | 86.57 | 45.88 | 30.14 |
| 3 | 5 | 1 | 1 | 9.67 | 229.60 | 132.00 | 6.20 | 0.89 | 19.88 | 12.10 | 2.67 | 3.39 | 98.89 | 49.87 | 33.24 |
| 3 | 5 | 1 | 0 | 8.75 | 237.00 | 129.00 | 5.91 | 0.84 | 18.49 | 12.74 | 3.12 | 3.81 | 94.19 | 52.85 | 33.82 |
| 3 | 4 | 0 | 1 | 9.48 | 243.80 | 137.00 | 6.39 | 0.74 | 20.91 | 12.41 | 3.15 | 3.66 | 99.44 | 57.80 | 35.23 |
| 3 | 4 | 0 | 0 | 8.39 | 222.70 | 132.00 | 5.59 | 0.98 | 19.08 | 12.75 | 2.97 | 3.76 | 90.40 | 48.24 | 31.97 |
| 3 | 7 | 1 | 1 | 9.26 | 221.30 | 132.00 | 6.33 | 0.98 | 19.08 | 11.89 | 3.26 | 3.73 | 93.05 | 58.38 | 35.02 |
| 3 | 7 | 1 | 0 | 8.88 | 260.60 | 135.00 | 5.97 | 0.97 | 16.70 | 12.57 | 3.13 | 3.52 | 94.35 | 53.72 | 31.71 |

Appendix C: Precipitant Lab Study Raw Data

C.1: Fertilizer Only Raw Data

| Name | Formulation | State | Color | Rep | TRT | pH water | pH fert. | pH mix | Temp | EC | Precipitant Mass | Filtration Time | Amt Ca | Amt P | Amt Fe |
|--------------|-------------|-------|---------|-----|-----|----------|----------|--------|-------|-------------------|-----------------------|-------------------------|---------------------|---------------------|---------------------|
| | | | | | | | | | °C | S m ⁻¹ | g 500mL ⁻¹ | sec 500mL ⁻¹ | mg kg ⁻¹ | mg kg ⁻¹ | mg kg ⁻¹ |
| NF Goldstart | 6--24--6 | Fluid | Colored | 1 | 1 | 7.15 | 6.85 | 7.00 | 15.40 | 0.637 | 0.334 | 482.00 | 2.3462 | 5.0381 | 1.2560 |
| NF Goldstart | 6--24--6 | Fluid | Colored | 2 | 1 | 7.19 | 6.22 | 6.78 | 16.00 | 0.538 | 0.216 | 600.00 | | | |
| NF Goldstart | 6--24--6 | Fluid | Colored | 3 | 1 | 7.48 | 6.31 | 6.99 | 16.30 | 0.652 | 0.209 | 462.00 | | | |
| AC Start | 5--20--5 | Fluid | Clear | 1 | 2 | 7.21 | 6.59 | 7.04 | 14.90 | 0.752 | 0.140 | 92.00 | 1.4320 | 1.2779 | 0.2542 |
| AC Start | 5--20--5 | Fluid | Clear | 2 | 2 | 7.22 | 6.44 | 6.85 | 16.30 | 0.618 | 0.127 | 136.00 | | | |
| AC Start | 5--20--5 | Fluid | Clear | 3 | 2 | 7.45 | 6.52 | 7.06 | 14.40 | 0.780 | 0.111 | 85.00 | | | |
| NF Goldstart | 9--18--9 | Fluid | Colored | 1 | 3 | 7.24 | 7.23 | 7.16 | 14.90 | 0.749 | 0.244 | 1278.00 | 1.9616 | 4.1063 | 0.9115 |
| NF Goldstart | 9--18--9 | Fluid | Colored | 2 | 3 | 7.17 | 6.91 | 6.91 | 16.10 | 0.591 | 0.285 | 908.00 | | | |
| NF Goldstart | 9--18--9 | Fluid | Colored | 3 | 3 | 7.49 | 6.94 | 7.15 | 14.50 | 0.721 | 0.343 | 1174.00 | | | |
| NF Diamond | 9--18--9 | Fluid | Clear | 1 | 4 | 7.28 | 7.54 | 7.35 | 14.90 | 0.876 | 0.109 | 86.00 | 0.8756 | 0.7700 | 0.1808 |
| NF Diamond | 9--18--9 | Fluid | Clear | 2 | 4 | 7.23 | 6.85 | 6.89 | 16.60 | 0.649 | 0.110 | 124.00 | | | |
| NF Diamond | 9--18--9 | Fluid | Clear | 3 | 4 | 7.54 | 6.79 | 7.10 | 14.60 | 0.782 | 0.149 | 86.00 | | | |
| NF Diamond | 10--10--10 | Fluid | Clear | 1 | 5 | 7.30 | 7.54 | 7.25 | 15.50 | 0.812 | 0.150 | 73.00 | 1.6927 | 1.4810 | 0.2638 |
| NF Diamond | 10--10--10 | Fluid | Clear | 2 | 5 | 7.21 | 7.19 | 6.97 | 16.50 | 0.632 | 0.157 | 60.00 | | | |
| NF Diamond | 10--10--10 | Fluid | Clear | 3 | 5 | 7.58 | 7.24 | 7.20 | 15.00 | 0.847 | 0.141 | 62.00 | | | |
| NF Goldstart | 10--10--10 | Fluid | Colored | 1 | 6 | 7.30 | 7.53 | 7.20 | 15.30 | 0.805 | 0.267 | 421.00 | 2.9635 | 4.9689 | 0.7871 |
| NF Goldstart | 10--10--10 | Fluid | Colored | 2 | 6 | 7.20 | 7.37 | 7.00 | 16.90 | 0.596 | 0.188 | 346.00 | | | |
| NF Goldstart | 10--10--10 | Fluid | Colored | 3 | 6 | 7.55 | 7.39 | 7.26 | 15.00 | 0.701 | 0.249 | 608.00 | | | |
| Na-Churs | 3--18--18 | Fluid | Clear | 1 | 7 | 7.33 | 7.58 | 7.18 | 15.30 | 0.817 | 0.131 | 49.00 | 1.4383 | 1.1679 | 0.2316 |
| Na-Churs | 3--18--18 | Fluid | Clear | 2 | 7 | 7.20 | 7.37 | 7.01 | 17.10 | 0.667 | 0.134 | 54.00 | | | |
| Na-Churs | 3--18--18 | Fluid | Clear | 3 | 7 | 7.60 | 7.47 | 7.25 | 14.80 | 0.833 | 0.150 | 66.00 | | | |
| Na-Churs | 9--18--9 | Fluid | Clear | 1 | 8 | 7.39 | 7.72 | 7.60 | 15.70 | 0.824 | 0.132 | 62.00 | 1.2900 | 1.1178 | 0.2790 |
| Na-Churs | 9--18--9 | Fluid | Clear | 2 | 8 | 7.20 | 7.26 | 7.11 | 17.00 | 0.696 | 0.148 | 75.00 | | | |
| Na-Churs | 9--18--9 | Fluid | Clear | 3 | 8 | 7.61 | 7.41 | 7.38 | 15.60 | 0.831 | 0.142 | 58.00 | | | |
| Na-Churs | 6--24--6 | Fluid | Colored | 1 | 9 | 7.35 | 6.78 | 7.25 | 15.20 | 0.766 | 0.433 | 802.00 | 3.9934 | 10.7270 | 1.6801 |
| Na-Churs | 6--24--6 | Fluid | Colored | 2 | 9 | 7.24 | 6.35 | 6.80 | 17.00 | 0.624 | 0.326 | 578.00 | | | |
| Na-Churs | 6--24--6 | Fluid | Colored | 3 | 9 | 7.35 | 6.26 | 6.81 | 15.70 | 0.690 | 0.398 | 778.00 | | | |
| Geary APP | 10--34--0 | Fluid | Colored | 1 | 10 | 7.40 | 6.12 | 7.02 | 14.40 | 0.830 | 0.182 | 301.00 | 1.3714 | 2.1762 | 0.4923 |
| Geary APP | 10--34--0 | Fluid | Colored | 2 | 10 | 7.28 | 5.70 | 6.59 | 17.00 | 0.565 | 0.142 | 240.00 | | | |
| Geary APP | 10--34--0 | Fluid | Colored | 3 | 10 | 7.64 | 5.82 | 6.86 | 15.70 | 0.593 | 0.159 | 289.00 | | | |

| | | | | | | | | | | | | | | | |
|---------------|---------------|----------|---------|---|----|------|------|------|-------|-------|-------|--------|--------|--------|--------|
| Geary Mix | 17--17--0 | Fluid | Colored | 1 | 11 | 7.14 | 5.74 | 6.62 | 15.00 | 0.958 | 0.144 | 168.00 | 0.8727 | 1.4048 | 0.3094 |
| Geary Mix | 17--17--0 | Fluid | Colored | 2 | 11 | 7.26 | 5.74 | 6.57 | 17.00 | 0.862 | 0.157 | 200.00 | | | |
| Geary Mix | 17--17--0 | Fluid | Colored | 3 | 11 | 7.27 | 5.64 | 6.59 | 15.40 | 0.974 | 0.129 | 47.00 | | | |
| Rotem PeKAcid | 0--60--20 | Granular | None | 1 | 12 | 7.23 | 1.97 | 2.46 | 14.50 | 0.447 | 0.018 | 37.00 | 0.0016 | 0.0141 | 0.0200 |
| Rotem PeKAcid | 0--60--20 | Granular | None | 2 | 12 | 7.23 | 1.88 | 2.59 | 16.00 | 0.431 | 0.009 | 36.00 | | | |
| Rotem PeKAcid | 0--60--20 | Granular | None | 3 | 12 | 7.24 | 1.83 | 2.41 | 15.00 | 0.421 | 0.004 | 31.00 | | | |
| Rotem MAP | 12--61--0 | Granular | None | 1 | 13 | 7.23 | 4.28 | 5.70 | 14.70 | 0.477 | 0.027 | 50.00 | 0.0100 | 0.0250 | 0.0647 |
| Rotem MAP | 12--61--0 | Granular | None | 2 | 13 | 7.25 | 4.14 | 5.80 | 15.70 | 0.497 | 0.025 | 45.00 | | | |
| Rotem MAP | 12--61--0 | Granular | None | 3 | 13 | 7.34 | 4.10 | 5.56 | 16.60 | 0.433 | 0.023 | 64.00 | | | |
| Rotem MKP | 0--52--34 | Granular | None | 1 | 14 | 7.27 | 4.02 | 5.69 | 14.20 | 0.531 | 0.026 | 42.00 | 0.0069 | 0.0227 | 0.0591 |
| Rotem MKP | 0--52--34 | Granular | None | 2 | 14 | 7.32 | 3.86 | 5.84 | 16.00 | 0.524 | 0.017 | 38.00 | | | |
| Rotem MKP | 0--52--34 | Granular | None | 3 | 14 | 7.40 | 3.84 | 5.59 | 16.90 | 0.454 | 0.012 | 38.00 | | | |
| Haifa MAP | 12--61--0 | Granular | None | 1 | 15 | 7.30 | 4.08 | 5.71 | 14.00 | 0.479 | 0.025 | 62.00 | 0.0073 | 0.0195 | 0.0574 |
| Haifa MAP | 12--61--0 | Granular | None | 2 | 15 | 7.30 | 3.95 | 5.88 | 16.00 | 0.457 | 0.015 | 68.00 | | | |
| Haifa MAP | 12--61--0 | Granular | None | 3 | 15 | 7.30 | 3.92 | 5.57 | 16.70 | 0.475 | 0.019 | 38.00 | | | |
| Haifa PN | 13.5--0--46.2 | Granular | None | 1 | 16 | 7.27 | 4.48 | 7.00 | 14.30 | 0.698 | 0.023 | 24.00 | 0.0068 | 0.0035 | 0.0513 |
| Haifa PN | 13.5--0--46.2 | Granular | None | 2 | 16 | 7.30 | 4.30 | 7.08 | 16.00 | 0.672 | 0.016 | 37.00 | | | |
| Haifa PN | 13.5--0--46.2 | Granular | None | 3 | 16 | 7.35 | 4.58 | 6.82 | 16.80 | 0.654 | 0.019 | 19.00 | | | |

C.2: P-enhancing polymer addition raw data

| Name | Formulation | Avail | Rep | TRT | pH water | pH fert. | pH mix | Temp | EC | Precipitant Mass | Filtration Time | Amt Ca | Amt P | Amt Fe |
|--------------|-------------|-------|-----|-----|----------|----------|--------|-------|-------------------|-----------------------|-------------------------|---------------------|---------------------|---------------------|
| | | | | | | | | °C | S m ⁻¹ | g 500mL ⁻¹ | sec 500mL ⁻¹ | mg kg ⁻¹ | mg kg ⁻¹ | mg kg ⁻¹ |
| NF Goldstart | 6--24--6 | 0 | 1 | 1 | 7.15 | 6.85 | 7.00 | 15.40 | 0.637 | 0.334 | 482.00 | 2.3462 | 5.0381 | 1.2560 |
| NF Goldstart | 6--24--6 | 0 | 2 | 1 | 7.19 | 6.22 | 6.78 | 16.00 | 0.538 | 0.216 | 600.00 | | | |
| NF Goldstart | 6--24--6 | 0 | 3 | 1 | 7.48 | 6.31 | 6.99 | 16.30 | 0.652 | 0.209 | 462.00 | | | |
| NF Goldstart | 6--24--6 | 1 | 1 | 2 | 7.17 | 6.93 | 7.00 | 16.40 | 0.672 | 0.244 | 315.00 | 1.7867 | 4.0968 | 1.0155 |
| NF Goldstart | 6--24--6 | 1 | 2 | 2 | 7.21 | 6.22 | 6.72 | 16.10 | 0.584 | 0.185 | 450.00 | | | |
| NF Goldstart | 6--24--6 | 1 | 3 | 2 | 7.49 | 6.33 | 7.00 | 14.90 | 0.702 | 0.178 | 306.00 | | | |
| AC Start | 5--20--5 | 0 | 1 | 3 | 7.21 | 6.59 | 7.04 | 14.90 | 0.752 | 0.140 | 92.00 | 1.4320 | 1.2779 | 0.2542 |
| AC Start | 5--20--5 | 0 | 2 | 3 | 7.22 | 6.44 | 6.85 | 16.30 | 0.618 | 0.127 | 136.00 | | | |
| AC Start | 5--20--5 | 0 | 3 | 3 | 7.45 | 6.52 | 7.06 | 14.40 | 0.780 | 0.111 | 85.00 | | | |
| AC Start | 5--20--5 | 1 | 1 | 4 | 7.25 | 6.63 | 7.00 | 14.70 | 0.761 | 0.031 | 127.00 | 0.0761 | 0.0679 | 0.0526 |
| AC Start | 5--20--5 | 1 | 2 | 4 | 7.24 | 6.45 | 6.85 | 15.90 | 0.600 | 0.018 | 130.00 | | | |
| AC Start | 5--20--5 | 1 | 3 | 4 | 7.47 | 6.49 | 7.08 | 14.30 | 0.773 | 0.031 | 212.00 | | | |
| NF Goldstart | 9--18--9 | 0 | 1 | 5 | 7.24 | 7.23 | 7.16 | 14.90 | 0.749 | 0.244 | 1278.00 | 1.9616 | 4.1063 | 0.9115 |
| NF Goldstart | 9--18--9 | 0 | 2 | 5 | 7.17 | 6.91 | 6.91 | 16.10 | 0.591 | 0.285 | 908.00 | | | |
| NF Goldstart | 9--18--9 | 0 | 3 | 5 | 7.49 | 6.94 | 7.15 | 14.50 | 0.721 | 0.343 | 1174.00 | | | |
| NF Goldstart | 9--18--9 | 1 | 1 | 6 | 7.25 | 7.25 | 7.08 | 15.30 | 0.749 | 0.207 | 1147.00 | 1.7251 | 3.7272 | 0.8449 |
| NF Goldstart | 9--18--9 | 1 | 2 | 6 | 7.22 | 6.91 | 6.83 | 16.30 | 0.559 | 0.280 | 952.00 | | | |
| NF Goldstart | 9--18--9 | 1 | 3 | 6 | 7.50 | 6.96 | 7.07 | 14.20 | 0.703 | 0.305 | 1060.00 | | | |
| Geary APP | 10--34--0 | 0 | 1 | 7 | 7.40 | 6.12 | 7.02 | 14.40 | 0.830 | 0.182 | 301.00 | 1.3714 | 2.1762 | 0.4923 |
| Geary APP | 10--34--0 | 0 | 2 | 7 | 7.28 | 5.70 | 6.59 | 17.00 | 0.565 | 0.142 | 240.00 | | | |
| Geary APP | 10--34--0 | 0 | 3 | 7 | 7.64 | 5.82 | 6.86 | 15.70 | 0.593 | 0.159 | 289.00 | | | |
| Geary APP | 10--34--0 | 1 | 1 | 8 | 7.35 | 6.11 | 6.97 | 14.40 | 0.701 | 0.139 | 305.00 | 1.0442 | 1.5254 | 0.3448 |
| Geary APP | 10--34--0 | 1 | 2 | 8 | 7.27 | 5.71 | 6.55 | 17.00 | 0.540 | 0.101 | 285.00 | | | |
| Geary APP | 10--34--0 | 1 | 3 | 8 | 7.67 | 5.82 | 6.74 | 15.90 | 0.642 | 0.138 | 318.00 | | | |
| Rotem MAP | 12--61--0 | 0 | 1 | 9 | 7.23 | 4.28 | 5.70 | 14.70 | 0.477 | 0.027 | 50.00 | 0.0100 | 0.0250 | 0.0647 |
| Rotem MAP | 12--61--0 | 0 | 2 | 9 | 7.25 | 4.14 | 5.80 | 15.70 | 0.497 | 0.025 | 45.00 | | | |
| Rotem MAP | 12--61--0 | 0 | 3 | 9 | 7.34 | 4.10 | 5.56 | 16.60 | 0.433 | 0.023 | 64.00 | | | |
| Rotem MAP | 12--61--0 | 1 | 1 | 10 | 7.22 | 4.32 | 5.65 | 14.40 | 0.459 | 0.024 | 43.00 | 0.0082 | 0.0215 | 0.0539 |
| Rotem MAP | 12--61--0 | 1 | 2 | 10 | 7.30 | 4.13 | 5.73 | 15.20 | 0.467 | 0.020 | 43.00 | | | |
| Rotem MAP | 12--61--0 | 1 | 3 | 10 | 7.38 | 4.10 | 5.41 | 16.70 | 0.452 | 0.016 | 26.00 | | | |

C.3: Rate of Avail raw data

| Name | Formulation | Avail | Rep | TRT | pH water | pH fert. | pH mix | Temp | EC | Precipitant Mass | Filtration Time | Amt Ca | Amt P | Amt Fe |
|--------------|-------------|-------|-----|-----|----------|----------|--------|-------|-------------------|-----------------------|-------------------------|---------------------|---------------------|---------------------|
| | | | | | | | | °C | S m ⁻¹ | g 500mL ⁻¹ | sec 500mL ⁻¹ | mg kg ⁻¹ | mg kg ⁻¹ | mg kg ⁻¹ |
| NF Goldstart | 6--24--6 | 0.0 | 1 | 1 | 7.15 | 6.85 | 7.00 | 15.40 | 0.637 | 0.334 | 482.00 | 2.3462 | 5.0381 | 1.2560 |
| NF Goldstart | 6--24--6 | 0.0 | 2 | 1 | 7.19 | 6.22 | 6.78 | 16.00 | 0.538 | 0.216 | 600.00 | | | |
| NF Goldstart | 6--24--6 | 0.0 | 3 | 1 | 7.48 | 6.31 | 6.99 | 16.30 | 0.652 | 0.209 | 462.00 | | | |
| NF Goldstart | 6--24--6 | 0.5 | 1 | 2 | 7.23 | 6.94 | 7.03 | 15.40 | 0.667 | 0.230 | 220.00 | 1.8270 | 3.9470 | 0.9795 |
| NF Goldstart | 6--24--6 | 0.5 | 2 | 2 | 7.25 | 6.22 | 6.78 | 16.50 | 0.555 | 0.164 | 136.00 | | | |
| NF Goldstart | 6--24--6 | 0.5 | 3 | 2 | 7.48 | 6.30 | 6.98 | 14.20 | 0.696 | 0.172 | 496.00 | | | |
| NF Goldstart | 6--24--6 | 1.0 | 1 | 3 | 7.17 | 6.93 | 7.00 | 16.40 | 0.672 | 0.244 | 315.00 | 1.7867 | 4.0968 | 1.0155 |
| NF Goldstart | 6--24--6 | 1.0 | 2 | 3 | 7.21 | 6.22 | 6.72 | 16.10 | 0.584 | 0.185 | 450.00 | | | |
| NF Goldstart | 6--24--6 | 1.0 | 3 | 3 | 7.49 | 6.33 | 7.00 | 14.90 | 0.702 | 0.178 | 306.00 | | | |
| NF Goldstart | 6--24--6 | 2.0 | 1 | 4 | 7.23 | 6.90 | 6.90 | 16.40 | 0.618 | 0.237 | 374.00 | 2.4288 | 5.4188 | 1.2561 |
| NF Goldstart | 6--24--6 | 2.0 | 2 | 4 | 7.24 | 6.21 | 6.69 | 16.20 | 0.564 | 0.182 | 342.00 | | | |
| NF Goldstart | 6--24--6 | 2.0 | 3 | 4 | 7.45 | 6.31 | 6.90 | 14.60 | 0.679 | 0.179 | 434.00 | | | |
| Geary APP | 10--34--0 | 0.0 | 1 | 5 | 7.40 | 6.12 | 7.02 | 14.40 | 0.830 | 0.182 | 301.00 | 1.3714 | 2.1762 | 0.4923 |
| Geary APP | 10--34--0 | 0.0 | 2 | 5 | 7.28 | 5.70 | 6.59 | 17.00 | 0.565 | 0.142 | 240.00 | | | |
| Geary APP | 10--34--0 | 0.0 | 3 | 5 | 7.64 | 5.82 | 6.86 | 15.70 | 0.593 | 0.159 | 289.00 | | | |
| Geary APP | 10--34--0 | 0.5 | 1 | 6 | 7.32 | 6.10 | 7.00 | 14.70 | 0.708 | 0.117 | 247.00 | 0.6911 | 1.0014 | 0.2371 |
| Geary APP | 10--34--0 | 0.5 | 2 | 6 | 7.27 | 5.68 | 6.55 | 17.00 | 0.554 | 0.085 | 140.00 | | | |
| Geary APP | 10--34--0 | 0.5 | 3 | 6 | 7.69 | 5.81 | 6.78 | 15.60 | 0.620 | 0.132 | 305.00 | | | |
| Geary APP | 10--34--0 | 1.0 | 1 | 7 | 7.35 | 6.11 | 6.97 | 14.40 | 0.701 | 0.139 | 305.00 | 1.0442 | 1.5254 | 0.3448 |
| Geary APP | 10--34--0 | 1.0 | 2 | 7 | 7.27 | 5.71 | 6.55 | 17.00 | 0.540 | 0.101 | 285.00 | | | |
| Geary APP | 10--34--0 | 1.0 | 3 | 7 | 7.67 | 5.82 | 6.74 | 15.90 | 0.642 | 0.138 | 318.00 | | | |
| Geary APP | 10--34--0 | 2.0 | 1 | 8 | 7.40 | 6.13 | 6.92 | 14.20 | 0.692 | 0.140 | 321.00 | 0.9480 | 1.4128 | 0.3404 |
| Geary APP | 10--34--0 | 2.0 | 2 | 8 | 7.28 | 5.70 | 6.45 | 16.70 | 0.539 | 0.101 | 227.00 | | | |
| Geary APP | 10--34--0 | 2.0 | 3 | 8 | 7.70 | 5.84 | 6.70 | 16.00 | 0.641 | 0.130 | 173.00 | | | |
| Rotem MAP | 12--61--0 | 0.0 | 1 | 9 | 7.23 | 4.28 | 5.70 | 14.70 | 0.477 | 0.027 | 50.00 | 0.0100 | 0.0250 | 0.0647 |
| Rotem MAP | 12--61--0 | 0.0 | 2 | 9 | 7.25 | 4.14 | 5.80 | 15.70 | 0.497 | 0.025 | 45.00 | | | |
| Rotem MAP | 12--61--0 | 0.0 | 3 | 9 | 7.34 | 4.10 | 5.56 | 16.60 | 0.433 | 0.023 | 64.00 | | | |
| Rotem MAP | 12--61--0 | 0.5 | 1 | 10 | 7.18 | 4.33 | 5.67 | 14.20 | 0.475 | 0.025 | 45.00 | 0.0076 | 0.0197 | 0.0547 |
| Rotem MAP | 12--61--0 | 0.5 | 2 | 10 | 7.25 | 4.12 | 5.77 | 15.30 | 0.470 | 0.020 | 43.00 | | | |
| Rotem MAP | 12--61--0 | 0.5 | 3 | 10 | 7.32 | 4.12 | 5.50 | 16.90 | 0.452 | 0.020 | 33.00 | | | |
| Rotem MAP | 12--61--0 | 1.0 | 1 | 11 | 7.22 | 4.32 | 5.65 | 14.40 | 0.459 | 0.024 | 43.00 | 0.0082 | 0.0215 | 0.0539 |
| Rotem MAP | 12--61--0 | 1.0 | 2 | 11 | 7.30 | 4.13 | 5.73 | 15.20 | 0.467 | 0.020 | 43.00 | | | |
| Rotem MAP | 12--61--0 | 1.0 | 3 | 11 | 7.38 | 4.10 | 5.41 | 16.70 | 0.452 | 0.016 | 26.00 | | | |
| Rotem MAP | 12--61--0 | 2.0 | 1 | 12 | 7.27 | 4.32 | 5.49 | 14.10 | 0.477 | 0.021 | 47.00 | 0.0056 | 0.0170 | 0.0452 |

| | | | | | | | | | | | |
|-----------|-----------|-----|---|----|------|------|------|-------|-------|-------|-------|
| Rotem MAP | 12--61--0 | 2.0 | 2 | 12 | 7.28 | 4.14 | 5.63 | 15.50 | 0.458 | 0.017 | 41.00 |
| Rotem MAP | 12--61--0 | 2.0 | 3 | 12 | 7.36 | 4.11 | 5.34 | 16.80 | 0.453 | 0.016 | 55.00 |

Appendix D: Soil Sampling Near Emitter Raw Data

D.1: 2009 Raw Data

| Year | Grid # | Sub-sample | Fertilized | mehlich 3 P mg kg ⁻¹ | Year | Grid # | Sub-Sample | Fertilized | mehlich 3 P mg kg ⁻¹ |
|------|--------|------------|------------|------------------------------------|------|--------|------------|------------|------------------------------------|
| 2009 | A1 | 1 | 0 | 7.40 | 2009 | A1 | 1 | 1 | 8.40 |
| 2009 | A2 | 1 | 0 | 7.00 | 2009 | A2 | 1 | 1 | 13.80 |
| 2009 | A3 | 1 | 0 | 7.60 | 2009 | A3 | 1 | 1 | 7.10 |
| 2009 | A4 | 1 | 0 | 6.50 | 2009 | A4 | 1 | 1 | 7.10 |
| 2009 | B1 | 1 | 0 | 7.00 | 2009 | B1 | 1 | 1 | 21.80 |
| 2009 | B2 | 1 | 0 | 6.60 | 2009 | B2 | 1 | 1 | 40.70 |
| 2009 | B3 | 1 | 0 | 6.90 | 2009 | B3 | 1 | 1 | 24.10 |
| 2009 | B4 | 1 | 0 | 7.20 | 2009 | B4 | 1 | 1 | 73.00 |
| 2009 | C1 | 1 | 0 | 8.10 | 2009 | C1 | 1 | 1 | 5.70 |
| 2009 | C2 | 1 | 0 | 7.90 | 2009 | C2 | 1 | 1 | 11.70 |
| 2009 | C3 | 1 | 0 | 7.70 | 2009 | C3 | 1 | 1 | 14.10 |
| 2009 | C4 | 1 | 0 | 7.30 | 2009 | C4 | 1 | 1 | 10.20 |
| 2009 | D1 | 1 | 0 | 6.30 | 2009 | D1 | 1 | 1 | 6.60 |
| 2009 | D2 | 1 | 0 | 5.60 | 2009 | D2 | 1 | 1 | 8.30 |
| 2009 | D3 | 1 | 0 | 6.10 | 2009 | D3 | 1 | 1 | 9.70 |
| 2009 | D4 | 1 | 0 | 5.50 | 2009 | D4 | 1 | 1 | 8.90 |
| 2009 | A1 | 2 | 0 | 6.70 | 2009 | A1 | 2 | 1 | 10.00 |
| 2009 | A2 | 2 | 0 | 7.30 | 2009 | A2 | 2 | 1 | 9.10 |
| 2009 | A3 | 2 | 0 | 5.30 | 2009 | A3 | 2 | 1 | 8.30 |
| 2009 | A4 | 2 | 0 | 4.10 | 2009 | A4 | 2 | 1 | 8.90 |
| 2009 | B1 | 2 | 0 | 6.80 | 2009 | B1 | 2 | 1 | 15.60 |
| 2009 | B2 | 2 | 0 | 7.20 | 2009 | B2 | 2 | 1 | 53.60 |
| 2009 | B3 | 2 | 0 | 6.70 | 2009 | B3 | 2 | 1 | 33.80 |
| 2009 | B4 | 2 | 0 | 6.80 | 2009 | B4 | 2 | 1 | 45.00 |
| 2009 | C1 | 2 | 0 | 7.16 | 2009 | C1 | 2 | 1 | 7.28 |
| 2009 | C2 | 2 | 0 | 7.72 | 2009 | C2 | 2 | 1 | 12.36 |
| 2009 | C3 | 2 | 0 | 6.93 | 2009 | C3 | 2 | 1 | 12.66 |
| 2009 | C4 | 2 | 0 | 9.08 | 2009 | C4 | 2 | 1 | 8.30 |
| 2009 | D1 | 2 | 0 | 8.96 | 2009 | D1 | 2 | 1 | 7.66 |

| | | | | |
|------|----|---|---|-------|
| 2009 | D2 | 2 | 0 | 8.04 |
| 2009 | D3 | 2 | 0 | 7.15 |
| 2009 | D4 | 2 | 0 | 7.51 |
| 2009 | A1 | 3 | 0 | 10.90 |
| 2009 | A2 | 3 | 0 | 7.30 |
| 2009 | A3 | 3 | 0 | 15.40 |
| 2009 | A4 | 3 | 0 | 7.67 |
| 2009 | B1 | 3 | 0 | 9.82 |
| 2009 | B2 | 3 | 0 | 10.50 |
| 2009 | B3 | 3 | 0 | 9.49 |
| 2009 | B4 | 3 | 0 | 9.37 |
| 2009 | C1 | 3 | 0 | 12.50 |
| 2009 | C2 | 3 | 0 | 14.00 |
| 2009 | C3 | 3 | 0 | 10.00 |
| 2009 | C4 | 3 | 0 | 12.00 |
| 2009 | D1 | 3 | 0 | 12.30 |
| 2009 | D2 | 3 | 0 | 10.90 |
| 2009 | D3 | 3 | 0 | 9.42 |
| 2009 | D4 | 3 | 0 | 9.72 |

| | | | | |
|------|----|---|---|-------|
| 2009 | D2 | 2 | 1 | 7.08 |
| 2009 | D3 | 2 | 1 | 6.18 |
| 2009 | D4 | 2 | 1 | 6.85 |
| 2009 | A1 | 3 | 1 | 12.70 |
| 2009 | A2 | 3 | 1 | 34.60 |
| 2009 | A3 | 3 | 1 | 13.50 |
| 2009 | A4 | 3 | 1 | 13.30 |
| 2009 | B1 | 3 | 1 | 24.00 |
| 2009 | B2 | 3 | 1 | 39.80 |
| 2009 | B3 | 3 | 1 | 36.03 |
| 2009 | B4 | 3 | 1 | 41.20 |
| 2009 | C1 | 3 | 1 | 12.80 |
| 2009 | C2 | 3 | 1 | 11.95 |
| 2009 | C3 | 3 | 1 | 10.89 |
| 2009 | C4 | 3 | 1 | 10.26 |
| 2009 | D1 | 3 | 1 | 14.00 |
| 2009 | D2 | 3 | 1 | 10.30 |
| 2009 | D3 | 3 | 1 | 10.80 |
| 2009 | D4 | 3 | 1 | 9.63 |

D.2: 2010 Raw Data

| Year | Grid # | Sub-sample | Fertilized | mehlich 3 P mg kg ⁻¹ | Year | Grid # | Sub-Sample | Fertilized | mehlich 3 P mg kg ⁻¹ |
|------|--------|------------|------------|------------------------------------|------|--------|------------|------------|------------------------------------|
| 2010 | A1 | 1 | 0 | 14.50 | 2010 | A1 | 1 | 1 | 40.30 |
| 2010 | A2 | 1 | 0 | 30.50 | 2010 | A2 | 1 | 1 | 51.80 |
| 2010 | A3 | 1 | 0 | 38.30 | 2010 | A3 | 1 | 1 | 65.70 |
| 2010 | A4 | 1 | 0 | 40.20 | 2010 | A4 | 1 | 1 | 59.30 |
| 2010 | B1 | 1 | 0 | 9.98 | 2010 | B1 | 1 | 1 | 74.00 |
| 2010 | B2 | 1 | 0 | 8.95 | 2010 | B2 | 1 | 1 | 48.80 |
| 2010 | B3 | 1 | 0 | 17.70 | 2010 | B3 | 1 | 1 | 57.60 |
| 2010 | B4 | 1 | 0 | 11.00 | 2010 | B4 | 1 | 1 | 84.70 |
| 2010 | C1 | 1 | 0 | 12.90 | 2010 | C1 | 1 | 1 | 9.01 |
| 2010 | C2 | 1 | 0 | 13.10 | 2010 | C2 | 1 | 1 | 9.27 |
| 2010 | C3 | 1 | 0 | 11.90 | 2010 | C3 | 1 | 1 | 9.09 |
| 2010 | C4 | 1 | 0 | 12.40 | 2010 | C4 | 1 | 1 | 8.66 |
| 2010 | D1 | 1 | 0 | 12.80 | 2010 | D1 | 1 | 1 | 9.66 |
| 2010 | D2 | 1 | 0 | 13.10 | 2010 | D2 | 1 | 1 | 10.70 |
| 2010 | D3 | 1 | 0 | 12.90 | 2010 | D3 | 1 | 1 | 11.40 |
| 2010 | D4 | 1 | 0 | 12.80 | 2010 | D4 | 1 | 1 | 11.40 |
| 2010 | A1 | 2 | 0 | 41.70 | 2010 | A1 | 2 | 1 | 26.10 |
| 2010 | A2 | 2 | 0 | 53.30 | 2010 | A2 | 2 | 1 | 60.80 |
| 2010 | A3 | 2 | 0 | 48.80 | 2010 | A3 | 2 | 1 | 46.60 |
| 2010 | A4 | 2 | 0 | 39.10 | 2010 | A4 | 2 | 1 | 31.10 |
| 2010 | B1 | 2 | 0 | 14.50 | 2010 | B1 | 2 | 1 | 87.00 |
| 2010 | B2 | 2 | 0 | 10.10 | 2010 | B2 | 2 | 1 | 52.40 |
| 2010 | B3 | 2 | 0 | 12.40 | 2010 | B3 | 2 | 1 | 61.00 |
| 2010 | B4 | 2 | 0 | 19.40 | 2010 | B4 | 2 | 1 | 31.10 |
| 2010 | C1 | 2 | 0 | 9.80 | 2010 | C1 | 2 | 1 | 11.60 |
| 2010 | C2 | 2 | 0 | 9.47 | 2010 | C2 | 2 | 1 | 11.20 |
| 2010 | C3 | 2 | 0 | 9.69 | 2010 | C3 | 2 | 1 | 13.90 |
| 2010 | C4 | 2 | 0 | 9.53 | 2010 | C4 | 2 | 1 | 9.58 |
| 2010 | D1 | 2 | 0 | 10.20 | 2010 | D1 | 2 | 1 | 12.30 |
| 2010 | D2 | 2 | 0 | 10.00 | 2010 | D2 | 2 | 1 | 11.50 |
| 2010 | D3 | 2 | 0 | 10.20 | 2010 | D3 | 2 | 1 | 11.30 |
| 2010 | D4 | 2 | 0 | 10.90 | 2010 | D4 | 2 | 1 | 13.20 |

| | | | | |
|------|----|---|---|-------|
| 2010 | A1 | 3 | 0 | 26.20 |
| 2010 | A2 | 3 | 0 | 32.40 |
| 2010 | A3 | 3 | 0 | 33.80 |
| 2010 | A4 | 3 | 0 | 19.80 |
| 2010 | B1 | 3 | 0 | 10.20 |
| 2010 | B2 | 3 | 0 | 10.30 |
| 2010 | B3 | 3 | 0 | 12.00 |
| 2010 | B4 | 3 | 0 | 9.85 |
| 2010 | C1 | 3 | 0 | 11.60 |
| 2010 | C2 | 3 | 0 | 12.20 |
| 2010 | C3 | 3 | 0 | 12.50 |
| 2010 | C4 | 3 | 0 | 13.00 |
| 2010 | D1 | 3 | 0 | 16.60 |
| 2010 | D2 | 3 | 0 | 13.80 |
| 2010 | D3 | 3 | 0 | 13.70 |
| 2010 | D4 | 3 | 0 | 14.00 |

| | | | | |
|------|----|---|---|-------|
| 2010 | A1 | 3 | 1 | 28.70 |
| 2010 | A2 | 3 | 1 | 71.20 |
| 2010 | A3 | 3 | 1 | 84.00 |
| 2010 | A4 | 3 | 1 | 23.50 |
| 2010 | B1 | 3 | 1 | 34.20 |
| 2010 | B2 | 3 | 1 | 28.80 |
| 2010 | B3 | 3 | 1 | 59.50 |
| 2010 | B4 | 3 | 1 | 54.30 |
| 2010 | C1 | 3 | 1 | 9.43 |
| 2010 | C2 | 3 | 1 | 9.62 |
| 2010 | C3 | 3 | 1 | 10.10 |
| 2010 | C4 | 3 | 1 | 9.20 |
| 2010 | D1 | 3 | 1 | 9.31 |
| 2010 | D2 | 3 | 1 | 10.70 |
| 2010 | D3 | 3 | 1 | 9.83 |
| 2010 | D4 | 3 | 1 | 11.70 |