FLUID

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2011 Fluid Forum Proceedings

"CROPPING INTENSIFICATION ON THE FARM"

Report to the Fluid Fertilizer
Foundation Membership **Volume 28**
Scottsdale, Arizona
February 20-22, 2011

PROCEEDINGS OF 2011
FLUID FORUM

FLUID FERTILIZER FOUNDATION

SCOTTSDALE, ARIZONA

February 20-22, 2011

Volume 28

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Acknowledgement

The Fluid Fertilizer Foundation and the research project leaders wish to thank all of the cooperating laboratories that provide essential laboratory services to the research projects. Without their contributions and support, much of the efforts of the Fluid fertilizer Foundation would not be possible.

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Role of Zinc Nutrition in Crop Production and Human Nutrition

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Introduction

Zinc Deficiency: A Global Nutritional Problem in Human Populations
Zinc (Zn) has particular physiological functions in all living systems, such as i) maintenance of structural and functional integrity of biological membranes, ii) detoxification of highly toxic oxygen free radicals and iii) contribution to protein synthesis and gene expression. Among all metals, Zn is needed by the largest number of proteins. Zinc-binding proteins make up nearly 10 % of the proteomes in eukaryotic cells, indicating that at least 2800 proteins are zinc dependent. About 36% of the eukaryotic Zn-proteins are involved in gene expression (Andreini et al., 2006). Its deficiency, therefore, results in diverse impairments in biological systems.

Zinc deficiency represents a common micronutrient deficiency problem in human populations, resulting in severe impairments in human health. Major health complications caused by Zn deficiency include impairments in brain function, weakness in immune system to deadly infectious disease and alterations in physical development. Zinc deficiency is known to be responsible for deaths of nearly 450,000 children under 5 years old annually (Black et al., 2008). Analyses made by a panel of 8 top-economists (including 5 Nobel Laureates) under the Copenhagen Consensus in 2008 (www.copenhagenconsensus.com) identified Zn deficiency, together with vitamin A deficiency, as the top priority global issue. Copenhagen Consensus concluded that elimination of the Zn deficiency problem in human populations will result in immediate impacts and high returns for humanity in the developing world.

It is estimated that Zn deficiency affects, on average, one-third of the world's population, ranging from 4 to 73 % in different countries (Hotz and Brown, 2004). Low dietary intake is known to be the major reason for high incidence of Zn deficiency in human populations, particularly in the countries/regions where soils are low in available Zn, and cereal grains with low Zn concentration are the major source of calorie intake. Increasing Zn concentration of food crops is, therefore, an important challenge.

Soil Zinc Deficiency Represents an Important Constraint to Crop Production and Nutritional Quality of Grains

Nearly the half of the cultivated soils are affected from low levels of plant available Zn, especially calcareous soils of arid and semi-arid regions. Major soil factors resulting in adverse impacts on solubility of Zn in soils include high pH, low organic matter, low soil moisture and high metal oxides with large fixing capacity for Zn (Fig. 1).

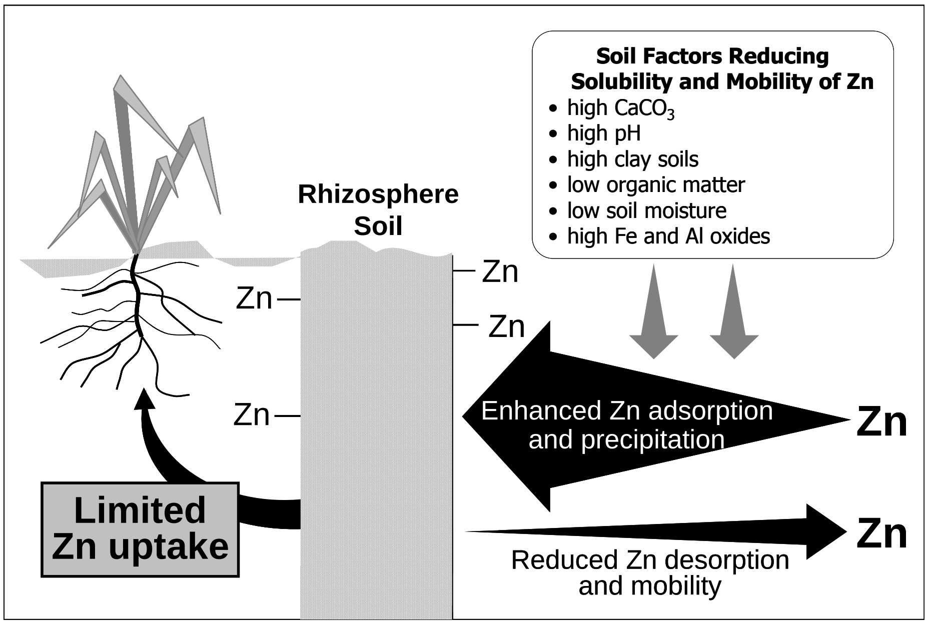

Fig. 1: Main soil factors affecting solubility and root uptake of Zn in soils (from Cakmak, 2008)

Since food crops, particularly cereal crops, are inherently low in grain Zn concentration, growing them on potentially Zn-deficient soils further reduces Zn concentration of food crops and thus dietary intake of Zn of human populations. Based on a range of reports and survey studies, the average concentration of Zn in whole grain of wheat in various countries range between 20 to 35 mg kg^{-1} (Rengel et al., 1999; Cakmak et al., 2004) which are not adequate for human nutrition with Zn. Same situation is also known for rice and maize which even contain much less Zn than wheat. In the case of Zn-deficient soils, the reported Zn concentrations for wheat are much lower and range between 5 to 15 mg kg^{-1} (Erdal et al 2002; Kalayci et al., 1999).

Soil Zn deficiency (i.e., low plant availability of Zn) has severe impacts on crop production. In certain regions with very low plant available Zn in soils (DTPA-Zn: around 0.1 mg kg^{-1}) cereal production is not economic with grain yields of 250 kg ha^{-1} and Zn fertilization is necessary to obtain a proper yield. As shown in Central Anatolia, application of Zn fertilizers in such soils enhances grain yield by a factor of 6 to 8 to around 2 000 kg ha^{-1}. In general, soils containing less than 0.5 mg DTPA-extractable Zn are considered potentially Zn deficient that may respond well to Zn fertilizers (Lindsay and Norvell, 1978). Low concentration of Zn in seeds has also negative impacts on growth of plants in Zn deficient soils. Evidence is available showing that seedlings derived from seeds with low concentrations of Zn are highly susceptible to biotic and abiotic stress conditions during seed germination and early growth stages.

These results indicate that improving Zn concentration of seeds/grains is also important for better agronomic performance of seedlings. Seeds with high nutrient density, especially with micronutrients, contribute greatly to better agronomic performance of seedlings besides its positive impacts on human nutrition. In future, a particular attention should be, therefore, paid to routine seed analyses for composition of mineral nutrients. Harvesting seeds with high nutrient density represent an important challenge.

Solutions to the Zinc Deficiency Problem

Currently, various strategies are being discussed to alleviate Zn deficiency related problems in human nutrition. Giving Zn supplements to the target populations or fortification of foods with Zn are considered as useful interventions against the problem. Although these approaches are very effective in reducing the extend of the problem, these interventions seem to be, however, not affordable long-term and not easily accessible by the target populations living in the rural parts of the developing countries. For example, 25 million USD is needed annually to eliminate micronutrient deficiencies in a nation with 50 million affected people by using food fortification program (Bouis et al., 2000).

Alternatively, agriculture offers simple and cost-effective solutions to the problem. Plant breeding and agronomy represent cost effective strategies to alleviate micronutrient malnutrition problem by increasing grain concentrations of micronutrients and their daily intake through diets (Pfeiffer and McClafferty, 2007; Cakmak et al., 2010a). It is well-documented that plant genotypes are highly different in utilization of poorly-soluble sources of micronutrients in soils and translocation of micronutrients into grain (Cakmak, 2002; White and Broadley, 2009). For example in case of Zn, genotypes of a given food crop species show impressive genetic variation for Zn accumulation in grain, especially wild and primitive forms of food crops. Such large natural variations in seed concentrations of Zn can be exploited under breeding programs to improve modern cultivars with high concentrations of Zn (e.g., genetic biofortification). The genetic biofortification strategy is a highly promising, cost-effective and long-term solution to Zn deficiency problem in human populations. Currently, impressive progress is being made under different breeding programs in improving stable food crops with high concentrations of micronutrients, especially under HarvestPlus program (www.harvestplus.org), which is established under the Consultative Group on International Agricultural Research. Harvest Plus program uses plant breeding tools to improve stable food crops with Zn, Fe and vitamin A and to contribute to human health globally. The main sponsor of this global program is Bill and Melinda Gates Foundation.

Agronomy and Plant Mineral Nutrition

Developing new Zn-dense genotypes by using plant breeding approach takes, however, a long time, and the impact and success of a breeding program depend on sufficient amount of readily available pools of Zn in soil solution (Cakmak, 2008). High Zn deficiency incidence in human populations are observed mainly in the regions where soils are very low in plant available (chemically soluble) Zn. Majority of cereal-cultivated soils globally have number of adverse soil chemical factors (i.e., high pH values, low soil moisture and low organic matter) that can potentially diminish the expression of high grain Zn trait and limit the capacity of newly developed (biofortified) cultivars to absorb adequate amount of Zn from soils and accumulate in grain. For example, among the soil chemical factors, soil pH plays a decisive role in chemical solubility and root uptake of Zn. In a pH range between 5.5 and 7.0, Zn concentration in soil solution is decreased up to 45-fold for each unit increase in soil pH. This increases risk for inducing Zn deficiency problem in plants and leading to low yield and simultaneously low Zn concentrations in grain (Marschner, 1993).

Increasing cultivation of high-yielding cultivars may further contribute to the extent of Zn deficiency in soils by progressively depleting available soil-Zn pools. This depletion of available Zn pools by large off-take in agricultural produce may occur to a greater extent in soils with low Zn solubility. Intensification of farming by introducing high-yielding cultivars contributes not only to Zn depletion in the soil but also to dilution of Zn in the harvested parts of plants such as in seeds/grains (Cakmak, 2008). Increasing evidence is available showing that selection of modern cultivars with high yield capacity over more than 100 years caused clear decline in grain concentrations of minerals, especially micronutrients (Garvin et al., 2006; Fan et al., 2008)

Zinc Fertilizer Strategy for Improving Yield and Grain Zn Concentrations

A short-term and complementary solution is, therefore, required to alleviate Zn deficiency related problems in human populations. In this regard, agronomy (e.g., fertilizer strategy) offer quick and effective practices to biofortify food crops with Zn at desirable levels. Fertilizer strategy simultaneously also contributes to better yield depending on the secerity of soil Zn deficiency.

Increasing chemical solubility of Zn in the rhizosphere by adding different organic amendments into soils, shifting from monocropping into intercropping systems, and applications of Zn fertilizers to soil and foliar are well-documented agricultural strategies which can significantly contribute to root uptake and grain density of Zn (Cakmak, 2008; Zuo and Zhang, 2009). It has been well-documented that addition of different organic materials into soils as compost or farmyard manures greatly contributes to solubility and spatial availability of Zn and also the total amount of plant-available Zn concentrations (e.g., DTPA-extractable Zn) in soils (Srivastava and Sethi, 1981; Arnesen and Singh, 1998; Asada et al., 2010). Existence of a strong positive relationship between soil organic matter and soluble Zn concentrations in rhizosphere soil was reported in a study of 18 different soils collected in Colorado (Catlett et al., 2002), indicating importance of organic matter in improving spatial availability of Zn to plant roots (Marschner, 1993). In the case of biofortification of dicots with micronutrients, intercropping dicots together with cereal species is a very useful practice as presented in Fig. 2. Iron concentration in different parts of peanut plants is significantly increased by intercropping with maize plants, possibly due to the root-induced changes in solubility of micronutrients and/or increases in biological activity in the rhizosphere (Zuo and Zhang, 2009).

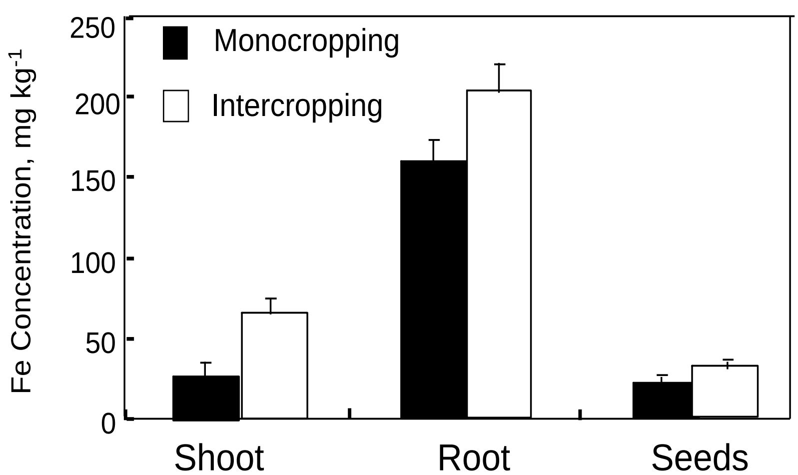

Fig. 2: Effect of intercropping peanut with maize plants on Fe concentration of shoot, roots and seeds of peanut plants grown on a calcareous soil (Zuo and Zhang, 2009).

Application of Zn fertilizers or the NPK fertilizers containing Zn represent a useful and quick approach to improving concentrations of Zn in food crops. Zinc can be directly applied to soil as both organic and inorganic compounds. Zinc sulfate ($ZnSO_4$) is the most commonly applied inorganic source of Zn due to its higher solubility and lower cost. Zinc can also be applied to soils in form of ZnO and Zn-oxysulfate (Mordvedt, 1991; Martens and Westermann, 1991). A factor affecting the selection of the source of Zn fertilizers is how uniformly they can be applied to soil. To ensure uniform application of Zn into soil, Zn can be incorporated into, or coated on, the granular N-P-K fertilizers. In India, urea is most commonly applied N fertilizer, and suggested to be good option for the enrichment with Zn. In various field tests conducted with wheat and rice in India it has been demonstrated that enrichment urea fertilizer with Zn up to 3 % improved significantly both grain yield and grain Zn concentration (Table 1). In these experiments, ZnO and ZnSO4 have been used to enrich urea with Zn, and both Zn sources were similarly effective in improving grain Zn concentrations, although ZnSO4 always tended to be better than ZnO in increasing grain Zn and improving yield (Shiway et al., 2008).

Table 1: Effect of Zn-enriched urea (ZEU) on grain yield and grain Zn concentrations of aromatic rice grown under field conditions in India (Shivay et al., 2008)

Treatments	Zn Added	Grain Yield	Grain Zn Concentration
	kg ha^{-1}	ton ha^{-1}	mg kg^{-1}
Prilled Urea	-	3.87	27
0.5% ZEU	1.3	4.23	29
1.0% ZEU	2.6	4.39	33
2.0% ZEU	5.2	4.60	39
3.0% ZEU	7.8	4.76	42

In the Central Anatolia, where Zn deficiency is a well-documented problem in Turkey, soil application of Zn fertilizers significantly increased both grain yield and grain concentrations of Zn (Fig. 3). Combined application of soil and foliar Zn fertilizers are more effective in enhancing grain Zn concentration, and causes increases in grain Zn concentration up to 3-fold (Cakmak et al., 2010a,b).

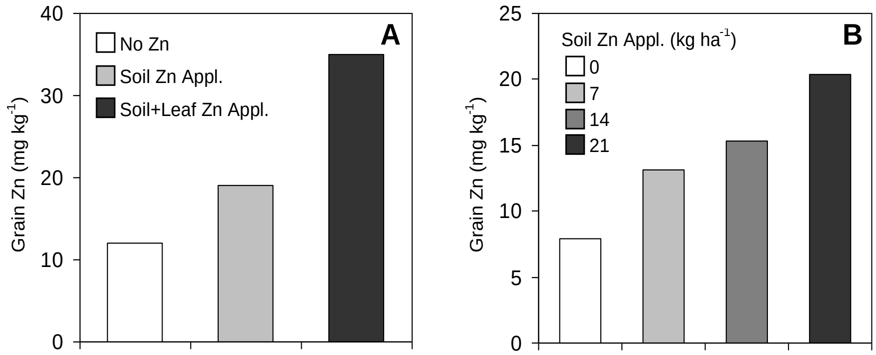

Fig. 3: Grain Zn concentrations of durum wheat treated by soil and foliar application of $ZnSO_4$ (A) and increasing amount of Zn fertilization into soil (B) grown on a highly Zn-deficient calcareous soil under field conditions in Central Anatolia (Cakmak et al., 2010a)

The effect of soil-applied Zn fertilizers on grain Zn concentration is not sufficiently high in soils with adequate amount of plant available Zn. Under such conditions, foliar application of Zn fertilizers is an essential practice in order to improve grain Zn concentration of cereal crops at adequate amounts for a better human nutrition. Martens and Westermann (1991) reported 0.5 to 1.0 kg Zn ha^{-1} as the most commonly used rates of Zn in foliar applications to correct Zn deficiency in plants. . Foliar application of Zn fertilizers can be performed by using either $ZnSO_4$ or chelated forms of Zn (e.g., Zn-EDTA). Our recent results show that ZnSO4 is a better Zn source in increasing grain Zn concentration when compared to ZnEDTA and ZnO when sprayed to foliar in wheat (unpublished results; see also Cakmak, 2008).

Timing of Zn spray on foliage plays an important role in effectiveness of the foliarly applied Zn fertilizers in increasing grain Zn concentration (Cakmak et al., 2010b). As discussed by Cakmak (2008) particular increases in Zn deposition into grain can be achieved when foliar Zn fertilizers are applied to plants at a late growth stage. Ozturk et al. (2006) monitored changes in Zn concentration in wheat grain during the grain development and found that the highest accumulation of Zn in grain takes place during the milk stage of the grain development. In a recently published study it has been shown that foliar spray of Zn late in the growing season in wheat (e.g., at milk and dough stage) resulted in much larger enhancement in grain Zn concentration when compared to the applications of Zn at earlier growth stages (Table 2).

Table 2: Zinc concentrations of the whole grain and the bran, embryo and endosperm fractions of the wheat grown under field conditions with foliar Spray of 0.5% $ZnSO_4.7H_2O$ at different growth stages in the Konya (a Zn-deficient location) and Samsun locations in Turkey (from Cakmak et al. 2010b)

	Zn concentration (mg kg^{-1})							
	Konya				Adana			
Foliar Zn Treatment Stages	Whole Grain	Bran	Embryo	Endosperm	Whole Grain	Bran	Embryo	Endosperm
Control (No Zn appl.)	12	20	38	8	32	42	70	11
Stem + Booting	19	28	47	10	51	72	96	15
Milk + Dough	25	41	63	15	57	88	98	16

Increases in concentration of whole grain Zn associated with late foliar Zn applications were also well reflected in various grain fractions such as embryo, aleurone and endosperm. The increases found in concentration of endosperm Zn through Zn spray during the reproductive growth stage were particularly impressive (Fig. 4). These increases in endosperm Zn concentration may have important impacts on human nutrition, because the endosperm part is the most commonly eaten part of wheat in number of countries where Zn deficiency incidence in human populations is very high.

Nitrogen nutritional status of plants has also positive impacts on grain concentration of Zn. Increase in grain Zn concentration by applying soil and/or foliar Zn fertilizers is maximized when the N nutritional status of plants is improved either by soil or foliar application of N fertilizers (e.g., urea) (Kutman et al., 2010, 2011). It seems that N and Zn act synergistically in improving grain Zn concentration in wheat when Zn and N are sufficiently high in growth media or plant tissues. Most probably, improving N nutritional status of plants contribute to better root Zn uptake and/or Zn accumulation in grain by affecting at least one of the following processes: i) root exudation of compounds contributing to solubility and uptake of Zn (e.g., phytosiderophores), ii) root growth and morphology, iii) abundance and expression of transporter proteins mediating uptake and transport of Zn in root cells, iii) nitrogenous compounds contributing to mobility and transport (and retranslocation) of Fe and Zn by chelation (e.g., nicotianamine, amino acids) and iv) increasing amount of seed proteins which bind/store Zn. The positive impacts of N nutrition on grain Zn indicate that an increasing attention should be paid to N management in cultivation of food crops and in establishing breeding programs for an effective biofortification of grains with Zn.

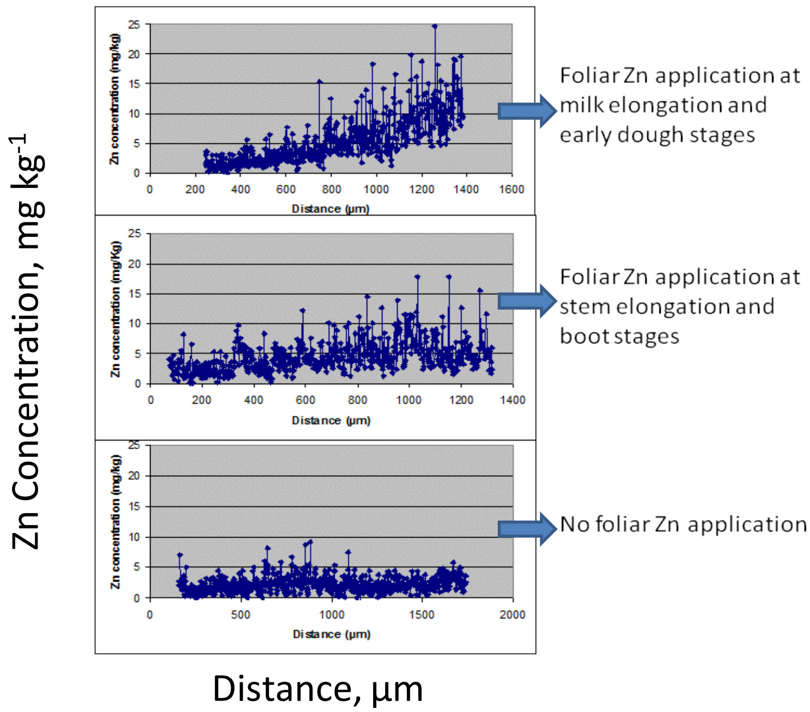

Fig. 4: Changes in Zn concentrations of endosperm part of bread wheat grains harvested at the Adana locations in Turkey. Grains subjected to laser ablaited-ICP-MS analysis were from plants which were either not treated (no foliar Zn application) or treated with foliar spray of $ZnSO_4$. $7H_2O$ at the stem elongation and booting or at the milk and dough stages. For further details see Cakmak et al. 2010b.

Agronomic Benefits Resulted from Zn Fertilization

Increasing seed concentration of micronutrients by soil and/or foliar applications of Zn also provides additional positive impacts in terms of seed vitality and seedling vigour. As reviewed by Welch (1999) when seeds with low concentration of Zn are sown, the ability of the new crop to withstand environmental stresses at the early growth stages is greatly impaired. Plants emerging from seeds with low Zn have poor seedling vigor and field establishment on Zn-deficient soils. Under rainfed conditions, wheat plants derived from seeds containing 1.5 µg Zn per seed had better seedling establishment and 2-fold higher grain yields than the wheat plants that emerged from seeds containing only 0.4 µg Zn per seed (Yilmaz et al., 1998). Similarly, Rengel and Graham (1995) showed that increasing seed-Zn contents from 0.25 µg per seed to 0.70 µg per seed significantly improved root and shoot growth of wheat plants under Zn deficiency. Priming seeds in Zn-containing solutions is an alternative way to increase seed Zn prior to sowing (Harris et al., 2007). High Zn concentrations in seeds ensure good root growth and contribute to better protection against soil-borne pathogens.

Conclusions

Improving Zn nutritional status of food crops by applying soil and/or foliar Zn fertilizers offers a practical and rapid solution to the well-documented Zn deficiency problem in human populations. In the target countries with high incidence of Zn deficiency, new fertilizer policies should be developed to promote application of Zn containing fertilizers to soil and/or foliar for a quick biofortification of food crops with Zn. The returns associated with Zn fertilization of food crops are expected to be very high with significant impacts on humanity and also crop production.

ACHIEVING 300 BUSHELS-PER-ACRE CORN SUSTAINABLY: A PROCEEDINGS OF THE 2011 FLUID FERTILIZER FOUNDATION SYMPOSIUM – CROPPING INTENSIFICATION ON THE FARM

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ABSTRACT

As the world's greatest producer of corn, U.S. agriculture is obligated to pursue both higher yields and sustainable production practices. The United Nations predicts that the global human population will increase by more than 30% to 9 billion by 2050. Agricultural researchers and policy makers estimate that grain yields must increase by 70-200% to meet demands of a growing population that is increasingly demanding a meat-based diet. While low-input, low-intensity farming systems preserve soil resources and meet most definitions of agricultural sustainability, these systems often sacrifice yield potential. For the world's three staple foodcrops (rice, wheat, and corn) we must find ways to increase, not decrease, the yield per unit of cropped land. Based on increased net primary productivity, greater nutrient use efficiency, and suitable conservation practices, high-population corn systems may be more environmentally sustainable than current production systems when managed appropriately and when restricted to the most suitable land. By assessing agricultural sustainability in terms of the energy resources embodied in long- and short-term energy/carbon plant fractions, we present a research approach to agricultural intensification that pursues higher yields, biofuel production potential, and preservation of our soil and water resources.

INTRODUCTION

Based on United Nations predictions that the human population will increase by 30% by 2050, scientists and policy makers conclude that we will need to increase 2009 grain yield levels by up to 200% to meet demands of a growing population that is increasingly demanding a meat-based diet. According to the USDA's October 2010 Grain World Market Report, the United States produced 55% of the world's corn last year. Over 40% of American-grown corn came from Iowa, Illinois, Nebraska, and Minnesota. As the world's greatest producers of corn, we are obligated to pursue both higher yields and sustainable production practices. Academic thought regarding sustainable farming of staple crops is shifting from a low-input, low-intensity philosophy to a system of intensification. The low-input low-intensity method preserves soil resources, yet sacrifices yield potential. This may be acceptable for most commodities, but for the world's three staple foodcrops (rice, wheat, and corn) we must find ways to increase, not decrease, the yield per unit of cropped land. This new philosophy of intensification pursues higher yields exclusively on the land best-suited for crop production and utilizes agricultural practices that protect the soil resource and enhances efficiency of nutrient uptake (Cassman et al. 2002). Our research approach evaluates corn grain for feed and food, stover for feed and biofuel production, and belowground roots and exudates to return soil organic matter and support a larger soil biological community (bacteria, fungi, nematodes, earthworms, etc.).

It is widely recognized among growers that losing agricultural inputs via leaching, denitrification, erosion, and runoff is wasteful economically, agronomically, and environmentally. Research shows that improved use efficiency of nitrogen and other agricultural inputs is well within our grasp. Tilman et al. (2002) point out that U.S. corn yields increased by nearly 40% from 1980-2000 without any increase in nitrogen fertilizer application and they predicted that advances in plant breeding, biotechnology, and crop and soil management will account for future increases in global crop production without negative environmental consequences. Edgerton (2009) states that the combination of marker-assisted breeding, biotechnology traits, and continued advances in agronomic practices will make it possible for the U.S. to double corn yields over the next two decades. This advancement in yield entails a 10 tonne/ha yield increase over the current U.S. corn yield average; Edgerton estimates that about 80% of the increased yield gain will be the result of introducing new biotechnology traits and marker-assisted breeding practices. New corn hybrids with genetic traits that confer greater tolerance to herbicide, insect feeding, pathogens, drought, low soil fertility, and other plant stressors create the potential for yield increase.

However, to realize the full potential of new genetics, modern hybrids must be grown at higher plant populations than their predecessors (Tollenaar 1989; Tokatlidis and Koutroubas 2004). Increasing corn plant populations has been shown to improve N and P use efficiency (Boomsma et al. 2009; Clay et al. 2009) and may also improve water-use efficiency (Kuchenbuch et al. 2009) as well as uptake of other agricultural inputs such as sulfur, fungicides, and insecticides. Additionally, evidence suggests that increasing corn plant populations using narrower corn rows may also produce more corn stover than traditional 30-inch rows (Hammer et al. 2009) and greater belowground plant biomass (Kuchenbuch et al. 2009). Additionally, corn root biomass is substantially more effective at increasing soil organic matter and sequestering carbon than corn stover (Balesdent & Balabane 1996; Hooker et al. 2005; Johnson et al. 2007). Most current models estimating sustainable levels of stover removal also fail to include the substantial mass of carbon released to the soil in the form of root exudates (Wilts et al. 2004; Amos & Walters 2006). Despite frequently-voiced concerns about removal of corn stover as an agent for reducing soil organic matter, we suggest based on previous soil physical, chemical, and biological property analysis (Hooker et al. 2005, Johnson et al. 2006, Wilhelm et al. 2007) that a percentage of corn stover is most judiciously used to promote the increasingly more efficient biofuel industry. A primary directive of the 2007 Energy Independence and Security Act is to promote ethanol production with a goal of 36 billion gallons by 2022, of which 21 billion gallons are to derive from cellulosic feedstock. When viewed from the landscape scale, we believe supporting the biofuel industry with harvested stover can be environmentally sustainable while also serving to help meet governmental directives regarding national energy independence and reducing dependence on fossil fuels.

WORK PLAN

The Crop Physiology Laboratory at UIUC has conducted experiments over the last 20 years to identify the principle factors that result in increased corn yields. The seven factors (sometimes referred to as the "Seven wonders of the corn yield world") that were found to have the greatest impact on high yielding corn production are: 1. Weather; 2. Nitrogen; 3. Hybrid; 4. Previous Crop; 5. Population; 6. Tillage; and 7. Growth Regulators. Based on this information, an omission plot experimental design was conceived to test five of the identified factors (nitrogen, other fertility, genetic traits, population, and growth regulators) for their individual and cumulative effects on yield. This highly-managed, systematic approach to yield factor identification is described in Table 1. Based on data from 2008 and 2009, it was determined that population is an integral factor for high yield; however, we also recognized the need for plant density management at high populations to avoid inter-plant competition which can decrease per-plant yield (Boomsma et al. 2009). We identified twin row planting technology as a method to manage high plant populations that also provides the opportunity to make a fertilizer application at planting near the seed.

Based on the data collected from two years of high-yield studies, we propose to expand the study design to include conservation practices and sustainability measurements. In 2011, we will add three additional factors to the omission plot experimental design: rotation, partial stover removal, and tillage. Research and anecdotal evidence show that corn following soybean produce greater yields than following corn. Research by the Crop Physiology Lab has indicated that the primary agent of yield reduction in corn-corn rotations is corn residue, although the mechanism is not fully understood. A number of studies (e.g. Fronning et al. 2008) have shown that with proper management and additional organic inputs, stover removal can be performed without degrading soil quality or reducing soil organic matter content. We propose that partial stover removal in the high-yield corn environment can not only be performed in a sustainable manner, but that the use of stover for biofuels or animal feed is a more environmentally sustainable application for corn stover than allowing it to slowly decompose at the soil surface. Another benefit of partial stover removal is that less corn residue greatly facilitates strip tillage activities from a mechanical perspective, thus promoting conservation tillage in the high-yield environment. We will assess the effects of removing corn stover for reducing soil organic matter and for reducing the continuous corn yield penalty. We will also conduct extensive plant tissue analyses of removed stover to estimate soil nutrients removed at various stover removal rates. This will result in information that can be used to create appropriate fertilizer recommendations at variable stover harvest rates.

Strip tillage is a relatively new reduced tillage system that protects soil from erosion, retains plant-available water later in the growing season, and allows banding of fertilizers for more efficient plant uptake and reduced erosional losses associated with broadcast fertilization. Although strip tillage has been used exclusively in single-row cropping systems to date, we propose that strip tillage can also be used with twin-row corn systems and that pairing strip tillage and twin row technologies will result in improved plant nutrient uptake, reduced soil erosion, and increased soil organic matter retention.

ANTICIPATED RESULTS

Yield Results

In the previously described high-yield study investigating the individual and combined use of five "high yield" factors vs. traditional practices, the combined "high-tech" treatment yielded 14-66 bushels per acre more grain than the treatment combining only "traditional" inputs and practices. Although there was variation in the dataset influenced by site and weather, in all cases the value of a given high-yield factor was more influential for increasing yield when combined with other high-yield factors rather than provided alone. These trials show that single production factors used alone do not guarantee high corn yields; rather, it is the positive interaction among multiple complementary factors that will optimize the production potential of each plant and result in highest corn yields possible. We will implement the same treatment design of Below and colleagues utilizing combinations of complementary high-yielding management practices to assess the effect of the practices both on yield and sustainability metrics.

Environmental Results

We define agricultural sustainability as:
A system of crop and animal production that, over the long term,

- Satisfies human, food, fiber, forage, and fuel needs
- Sustains the economic vitality of farm operations
- And maintains or improves soil organic matter, soil structure, and water quality.

(Modified from the 1990 Farm Bill)

Specifically, we propose to maintain or improve soil organic matter by increasing plant populations, thus creating more belowground root biomass and exudates, and reducing tillage using strip tillage. We will maintain and improve soil structure with strip tillage and addition of plant biomass to increase soil organic matter. Finally, we will maintain or improve water quality by optimizing the use of every agricultural input that is added to the crop. Specifically, we will achieve this by improving nitrogen uptake efficiency with split N application and optimizing placement of inputs by banding P and S fertilizer with the strip tiller. Finally, by creating a favorable rooting environment with strip tillage and banding nutrients and using the most advanced suitable crop hybrids, we will optimize the corn root system to optimize fertilizer recovery and increase belowground soil carbon sequestration.

We will evaluate sustainability in a number of ways, primarily focusing on nutrient uptake efficiency and the validity of removing corn stover based on additional root production in the high-yield environment. Less tangible and quantifiable sustainable outcomes (e.g. improved water availability and soil structure, reduced soil erosion and fossil fuel combustion) will be observed and recorded whenever possible.

From an environmental perspective, the outcome of this project will be highly beneficial, resulting in preservation of our soil and water resources for future generations.

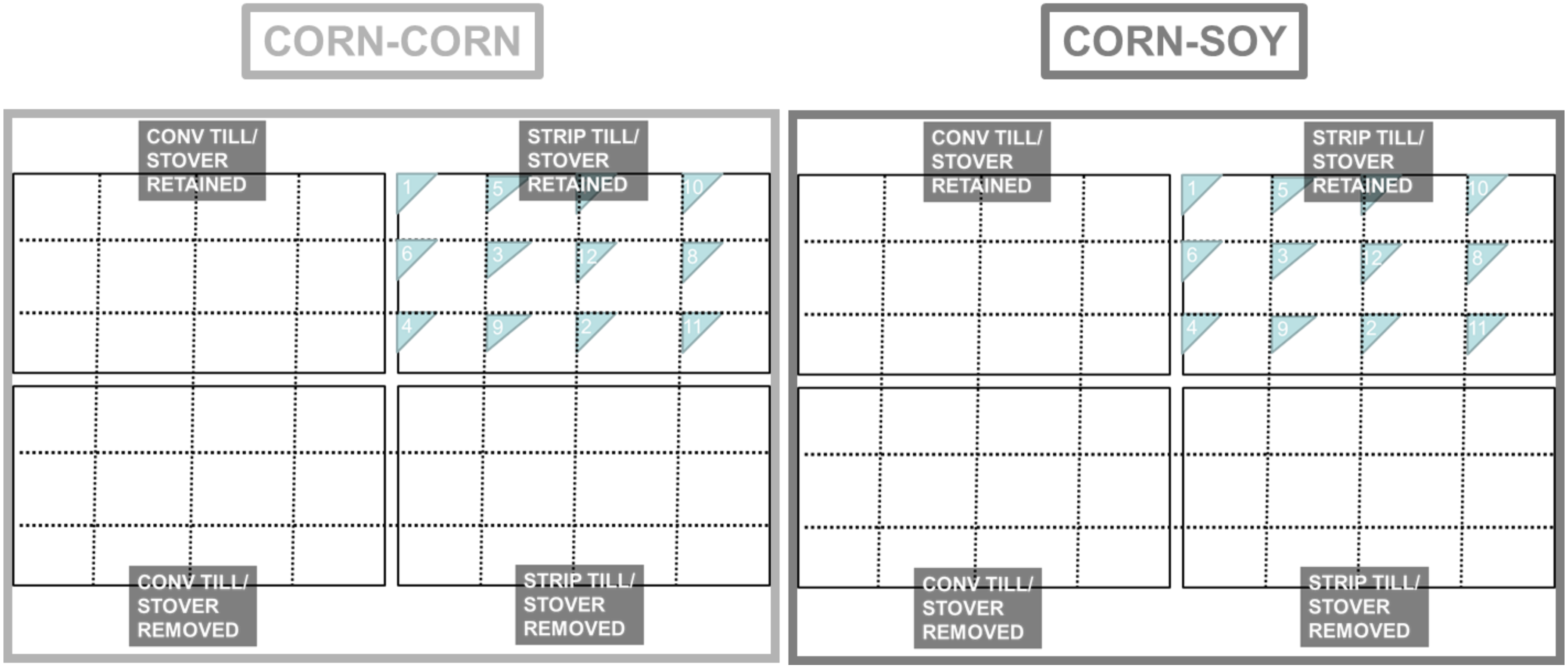

Figure 1. Experimental design of one replication of the 2011/2012 proposed project. The 12 treatments are repeated in each quadrat of each rotation (corn-corn or corn-soy) plot. The eight split plots (conventional tillage+stover, conventional tillage-stover, strip tillage+stover, strip tillage-stover) assess residue management concerns in high-yielding corn systems. The 12 split-split plot treatments are described in Table 1.

Table 1. Subplot treatments evaluated in the 2011/2012 Sustainability Omissions Plot Design. The six subplot treatments are plant population, hybrid traits, N rate, other nutrients, and crop protection inputs (fungicide).

Trt. No.	Trt.	Pop	Hybrid	N	Fert.	Fungicide
1	HIGH YIELD	45K	MULTI-TRAIT	BASE+SLOW REL	MESZ	STROBILURIN
2	-POPULATION	32K	MULTI-TRAIT	BASE+SLOW REL	MESZ	STROBILURIN
3	-HYBRID TRAIT	45K	REFUGE	BASE+SLOW REL	MESZ	STROBILURIN
4	-NITROGEN	45K	MULTI-TRAIT	BASE	MESZ	STROBILURIN
5	-FERTILITY	45K	MULTI-TRAIT	BASE +SLOW REL	NONE	STROBILURIN
6	-FUNGICIDE	45K	MULTI-TRAIT	BASE +SLOW REL	MESZ	NONE
7	TRADITIONAL	32K	REFUGE	BASE	NONE	NONE
8	+POPULATION	45K	REFUGE	BASE	NONE	NONE
9	+HYBRID TRAIT	32K	MULTI-TRAIT	BASE	NONE	NONE
10	+NITROGEN	32K	REFUGE	BASE+SLOW REL	NONE	NONE
11	+FERTILITY	32K	REFUGE	BASE	MESZ	NONE
12	+FUNGICIDE	32K	REFUGE	BASE	NONE	STROBILURIN

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Setting the stage for higher yields at the grower level
A long-winded, kitchen sink approach to enhance grain yields and profits!

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Brief summary of presentation from 2011 Fluid Forum

Far too often in life we have a natural tendency to focus on one item as the answer to a problem. However, reality teaches us that multiple factors usually contribute to the solution. In modern agriculture we face a similar dilemma. We may promote product A or product B as the yield enhancing miracle cure. Sometimes that is indeed true, but more often it is only part of the cure, modern agriculture demonstrates that reality.

Twenty-four planters, Class 9 combines, and 600 horsepower tractors all point to the future or re-invention of grain farming. Three hundred bushel corn needs to be the norm not the exception! We have entered an age of amazing precision in agriculture. Not only does size matter, but with size comes performance and improved accuracy. We need to accept the reality of this fundamental shift in agriculture, and respond with research driven by understanding every aspect of producing grain.

Factors of genetics, information, profitability, equipment, inputs/outputs and the soil as well as honing our skills all must be part of this re-invention.

Genetics are the fundamental foundation of yield. Marketers often fixate that it is the GMO trait produces yield. Actually, it is the agronomic and DNA traits that determine potential yield. The GMO traits assist in protecting that yield potential. Additionally, seed selection based on yield, test weight, and grain dry down are important, but we must also look at percent germination, seed size, relative maturity, root size, stalk strength, stay-green, disease package, early season vigor, and population density. These additional factors must be identified to unlock the hidden yield potential in every hybrid/variety.

Building upon our genetic selection includes our need to access information. Our sources of information may originate from seed and/or pesticide suppliers, custom applicators, farm service agencies, university extension, friends, neighbors, even the internet! Accurate and timely information will be needed to assist producers in their pursuit of higher yields.
We often use yield as the sole source of success in what we do, but we would be remiss if we did not also factor in profitability. Cost of inputs versus expected outputs, cost per acre, cost per bushel, profit per bushel and profit per acre all must be calculated to help producers to market

their products. Knowing your costs signifies knowing the cost of everything, land costs (rents, leases, mortgages, needed improvements such as tiling), cost of added fertilizers, cost of pesticides, costs of seed and seed additives, fuel, equipment cost and maintenance, and labor must all be known to maintain profitability. Throughout the growing season any additional applications must be calculated as to what impact it would have on yield and profitability.

We know equipment is easy to access. Simply put: choose a color, find a dealer, pay the money and you get equipment. It is the challenge of choosing the correct type of equipment, how to utilize that equipment and how to properly drive and maintain that equipment that creates more anxiety. Our equipment needs ranges from tractors and tillage pieces, to planters, to sprayers, to applicators, and finally to our combines. We have made great improvements in our planters, much with respect to their increased size and improvement in efficiency. Planters do, however, require maintenance and attention to detail to maintain optimum performance. Losses in potential grain yield can be significant due to skips, doubles and poor stands. Follow strict guidelines to wear tolerances on coulters, seed openers, tubes, seed meter brushes as well as proper tire inflations. Other yield factor enhancements involve slower planter speeds (4-4.5 mph) proper seeding depths (2-2.5 inches). Remember stand uniformity is the key to producing high yielding corn. Maintain your equipment to have success in this area. Everything we do to a crop later in the season reflects on starting right! Equipment also relates to tractors and relating tractor power to wheel slip, to soil compaction, to fuel economy and so forth.

What about the combine? Sadly, the combine often gets forgotten as a machine that can be made more efficient. Many are able to drive a combine, however, few understand combines well enough to operate without higher than necessary grain losses. A productive combine requires adjustments throughout the harvest season.

Inputs are much more involved than just seed and pesticides. Inputs include seeding rates and row spacings, as well as adding herbicide and insecticide traits to them. Fertilizers include not just the formulation, but also the type and timing. Considerations of fertilizer loss due to volatilization and denitrification as well as through surface run-off may encourage producers to apply their fertilizer in different forms and at different timings to more effectively match crop needs. Matching crop yields to fertilizer needs and application timing may also encourage the use of starters, in-season sidedress application, as well as adding micronutrients to, soil or via foliar sprays.

What about our herbicides? We know that glyphosate is the standard, but with the threat of weed specie shifts and/or potential resistance issues, we may need to revisit the need to utilize a variety of modes of action to maintain weed-free fields. Likewise, it is important to understand the activity of a herbicide class and any additives in the mix to understand how the crop will respond, hidden yield losses are always possible.

Use of foliar fungicides and/or insecticides are a hot topic, are they necessary? Do we spray in the absence of visual symptoms and spray for plant health? Accurate answers include use of crop scouting and understanding the impact on your crop.

Do not forget the soil. All crops require 16 essential nutrients, however, at different levels. Yet, even in a soil with good fertility levels, a soil with low or high pH may not provide a proper level of available nutrients.

Finally, our skills reflect on our ability to pull it all together. Are we innovators, adopters or followers? The category we find ourselves within can determine our level of success. A skilled operator knows how to produce profitable grain!

So, it may be a gross exaggeration to say farming is simple, it is not. Modern grain production is an expensive business that requires high-tech inputs in the hands of knowledgeable people. If all that was required would be to grow 100 bushel corn, most could do that with their eyes closed. In the future, the level of expectation may be to produce 300 or even 400 bushel corn. To produce corn at that level will involve close scrutiny of every aspect of a producers operation not just those on the surface.

NITROUS OXIDE EMISSIONS FROM SEVERAL NITROGEN SOURCES APPLIED TO A STRIP-TILLED CORN FIELD[1]

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ABSTRACT

We evaluated the effects of nitrogen (N) source on nitrous oxide (N_2O) emissions from a clay loam soil that was in strip-tilled (ST), irrigated continuous corn production in 2010 near Fort Collins, CO. Emissions were monitored from six different inorganic N fertilizer sources (urea, ESN[1], SuperU, UAN, UAN+AgrotainPlus, UAN+Nfusion). Each N source was applied at a rate of 202 kg N/ha, surface band applied near the corn row and watered into the soil the day after application including a subsurface band application of ESN (ESNssb). A check treatment (no N applied since 2000) located in separate plots and a blank treatment (no N applied) located within the N source plots were included. All treatments except the check were located in plots ST in 2009 that had received 202 kg N/ha of ESN. Nitrous oxide fluxes were measured during the growing season using static, vented chambers for gas sample collection, one to three times per week, and analyzed with a gas chromatograph. With the exception of ESNssb, all N sources had significantly lower growing season N_2O emissions than dry granular urea. Cumulative increases in daily N_2O fluxes were more rapid for urea and UAN than the other N sources following N fertilizer application. The enhanced efficiency fertilizers (polymer-coated, stabilized, and slow release) sources showed potential for reducing N_2O emissions during the 2010 growing season. Corn grain yields in 2010 were not significantly different among N sources, but greater than the blank or check treatments with no N applied. These results indicate that N source selection can be of value in reducing N_2O emissions in irrigated cropping systems under strip-till in the Central Great Plains.

INTRODUCTION

Nitrous oxide is produced in soils through nitrification and denitrification processes (Follett, 2001) with agriculture contributing approximately 67% of the total U.S. N_2O emissions (USEPA, 2010). Nitrous oxide has a global warming potential (GWP) approximately 298 times greater than that of CO_2 (Solomon et al., 2007), thus it is important to develop methods that reduce N_2O emissions in agricultural systems. Nitrogen fertilizer application generally increases N_2O production from irrigated Central Great Plains cropping systems (Mosier et al., 2006, Halvorson et al., 2008).

[1]Published in Proceedings of 2011 Fluid Form, Fluid Fertilizer Foundation, February 20-22, 2011, Scottsdale, AZ. Trade names and company names are included for the benefit of the reader and do not imply any endorsement or preferential treatment of the product by the authors or the USDA, Agricultural Research Service.

Available data for analyzing N_2O emissions impact on GWP in irrigated crop production systems is limited (Mosier et al., 2006; Snyder et al., 2009; Archer and Halvorson, 2010). Research reported by Mosier et al. (2006) and Halvorson et al., (2008, 2010b,c) from irrigated cropping systems exhibited a sharp rise in N_2O emissions within days following N fertilization with urea-ammonium nitrate (UAN) or urea fertilizers in conventional-till continuous corn (CT-CC), no-till continuous corn (NT-CC), and no-till corn-soybean cropping systems. The N_2O emissions stabilized to near background levels in about 40-45 days following N fertilization and were minimal for the rest of the growing season and non-crop period.

Venterea et al. (2005, 2010) found N source influenced N_2O emissions from corn production systems in Minnesota with greatest N_2O emissions from anhydrous ammonia application, with significantly lower emissions from UAN, and lowest emissions from broadcast urea. Halvorson et al. (2010b) reported reduced N_2O emissions from application of a polymer-coated urea and stabilized N sources when compared to urea in irrigated NT cropping systems. Halvorson et al. (2010c) measured reductions in N_2O emissions as great as 50% using enhanced-efficiency fertilizers compared with dry granular ureas. Hyatt et al. (2010) reported equal potato yields with a single application of polymer-coated urea products compared to 5-6 smaller applications of urea during the growing season, with slightly lower N_2O emissions with the polymer-coated urea products.

Our objective was to determine the effects of N fertilizer source on growing season N_2O emissions from a strip-tilled, irrigated continuous corn production system in 2010.

MATERIALS and METHODS

The study was conducted in a strip-tilled continuous corn field located on a Fort Collins clay loam soil at the Agricultural Research, Development, and Education Center (ARDEC) north of Fort Collins, CO. The plot area had been in a ST-CC production system in 2009. Plots receiving 202 kg N/ha in 2007, 2008, and 2009 were used for this N source study. Fertilizer N sources evaluated were urea (46% N), urea-ammonium nitrate (UAN, 32% N), a polymer-coated urea (ESN, 44% N), a stabilized granular urea (SuperU, 46% N), a stabilized UAN (UAN plus AgrotainPlus), and a slow release N source (UAN + 20% Nfusion, 22% N). All N sources were surface band applied next to the corn row at emergence and watered into the soil with about 19 mm of water with a linear-move sprinkler irrigation system the day after application. An additional ESN treatment was included as a subsurface band application (ESNssb) near the corn row at emergence. A blank treatment (no N applied) was included within the same plot area with the N sources. In addition, a check plot that had not received N for nine years was included in the GHG measurements. The polymer-coated urea, ESN, is produced by Agrium Advanced Technologies, Inc. SuperU is a finished urea product produced by Agrotain International that is a homogenous blend with urease (NBPT) and nitrification (DCD) inhibitors included at the time of production. AgrotainPlus includes these same inhibitors as SuperU and is produced by Agrotain International. The Nfusion added to UAN was a slow release liquid N made up of slowly available urea polymers in the form of methylene urea plus triazone and is produced by Georgia Pacific Chemicals, LLC.

The N treatments were arranged in a randomized complete block design with three replications. Each N source plot was 3 m long x 4.6 m wide. The ST operations were strip-till in March, plant in early May, spray after crop emergence for weed control (twice), and harvest.

Grain yield was estimated by harvesting 24 corn plants at maturity, removing the ears, and shelling them to determine grain weight at 15.5% water content. Yields were calculated using established plant stands. Soil samples were collected before spring planting from the 0- to 30.4-cm depth and analyzed for NH_4-N and NO_3-N content.

Greenhouse gas fluxes were generally monitored two to three days per week during the 2010 growing season in each N treatment. Gas samples were collected from two sampling sites within each N treatment replicate for a total of six gas samples for each treatment on each sampling day. A vented chamber technique was used to collect the gases in the field and a gas chromatograph used to analyze gas concentration as described by Mosier et al. (2006). A randomized complete block ANOVA was used to determine differences in N_2O emissions and grain yield among N source treatments.

RESULTS

Greenhouse Gas Emissions. Cumulative N_2O emissions for the growing season are shown in Fig. 1. The N was applied on May 25th (DOY 145) followed by an immediate (within a few days after application) rise in N_2O emissions from urea and UAN. The enhanced efficiency fertilizers (ESN, SuperU, and UAN+AgrotainPlus) had lower N_2O emissions immediately following N application than urea or UAN. This demonstrates the delayed release of NH_4-N from these N sources until later in the growing season. As was the case in 2009 (Halvorson and Del Grosso, 2010a), there was little difference between the check plot that had not received an inorganic N application since 2000 and the blank treatment that had received 202 kg N/ha from 2007-2009.

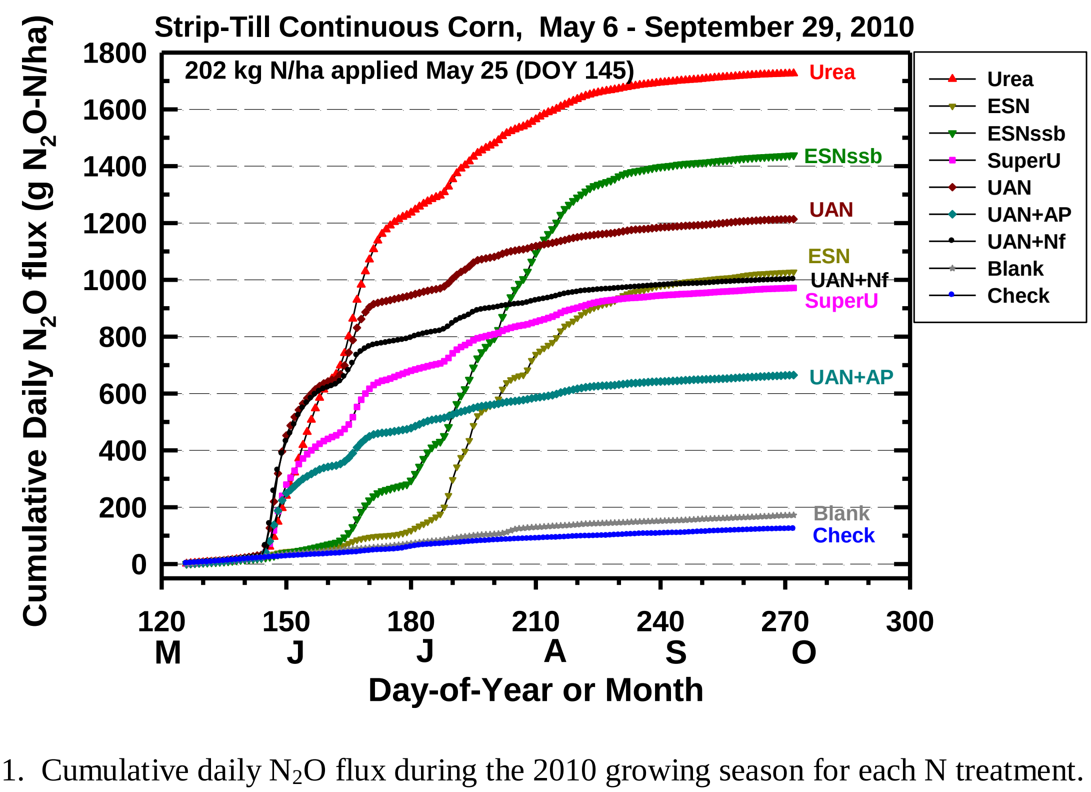

Fig. 1. Cumulative daily N_2O flux during the 2010 growing season for each N treatment.

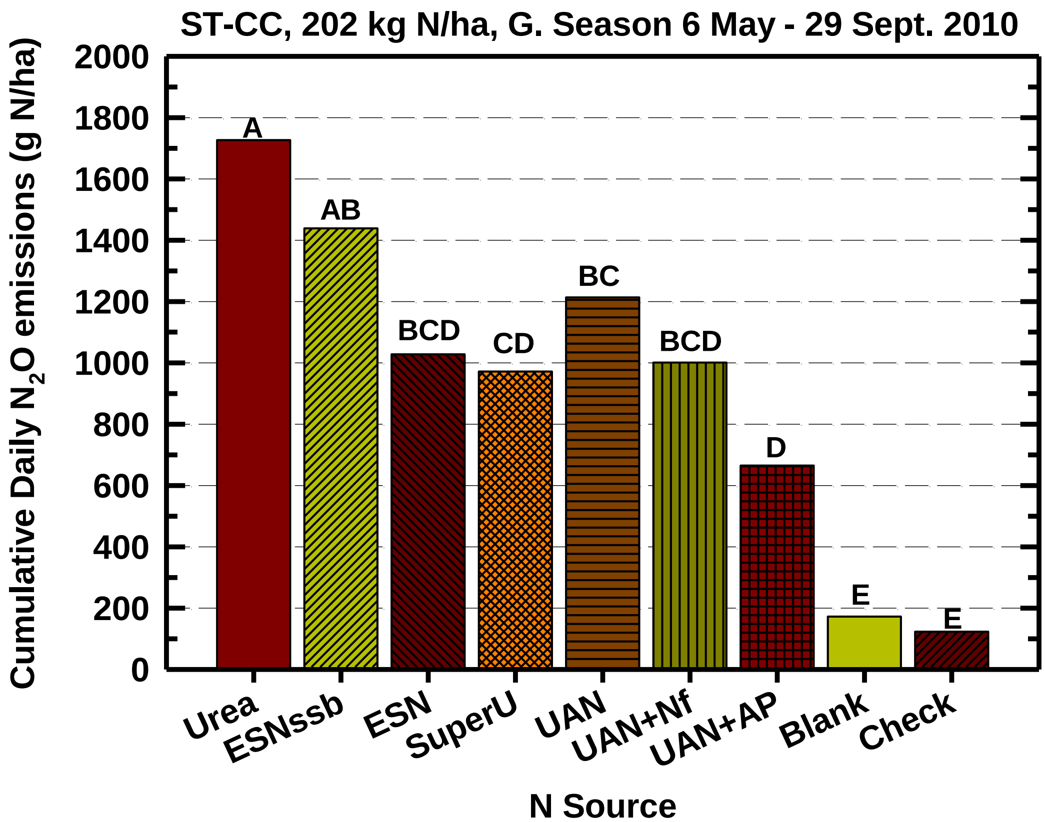

Fig. 2. Cumulative daily N_2O emissions for each N source at end of 2010 growing season. Bars with the same letter on top are not significantly different at $P = 0.05$.

Differences between N treatments at the end of the growing season are shown in Fig. 2. Dry granular urea had the highest level of N_2O emissions for the growing season and was significantly greater than all other sources except ESNssb (Fig. 2). The higher level of N_2O emission from ESN subsurface banded than ESN surface banded possibly resulted from the soil disturbance during subsurface banding the ESN and a more rapid break down and release of urea from the ESNssb granule which was surrounded by wet soil. Thus a potentially higher concentration of NH_4 in the soil for nitrification with ESNssb than the ESN surface banded. The ESNssb, UAN, ESN, SuperU, and UAN+Nf had similar levels of N_2O emissions for the growing season. Adding AgrotainPlus to UAN resulted in significantly lower N_2O emissions than from UAN. The blank and check treatments were not significantly different. This may indicate increased N_2O emissions occurred only when a new supply of N fertilizer was added. Average spring soil NH_4-N and NO_3-N levels in the 0- to 30.4 cm soil depth were 13 and 26 kg N/ha, respectively, within with the N source plot area. Average spring soil NH_4-N and NO_3-N levels in the 0- to 30.4-cm soil depth were 17and 13 kg N/ha, respectively, in the check plots. Thus, even though there was a slightly higher residual soil N level in the upper 30 cm of soil in the plots previously receiving fertilizer N than in the check plot, N_2O emissions of the blank treatment were not greater than in the check treatment. The 2010 data confirm the 2009 observation (Halvorson and Del Grosso, 2010a) that there was no difference between the blank and check treatments in N_2O emissions. Grain yields for each of the N treatments are shown in Fig. 3. There was no significant difference in grain yields among the N sources applied, but yields with N application were significantly greater than those of the blank and check treatments. The check treatment receiving no fertilizer N for nine years had significantly lower yields than all other N treatments.

SUMMARY

Growing season N_2O emissions were reduced by all N sources when compared to dry granular urea in this ST continuous corn production system in 2010. Adding AgrotainPlus to UAN significantly reduced growing season N_2O emissions when compared to UAN alone. The 2010 data confirm the 2009 results (Halvorson and Del Grosso, 2010a) that enhanced-efficiency N sources can reduce N_2O emissions from irrigated cropping systems in the semi-arid Central Great Plains.

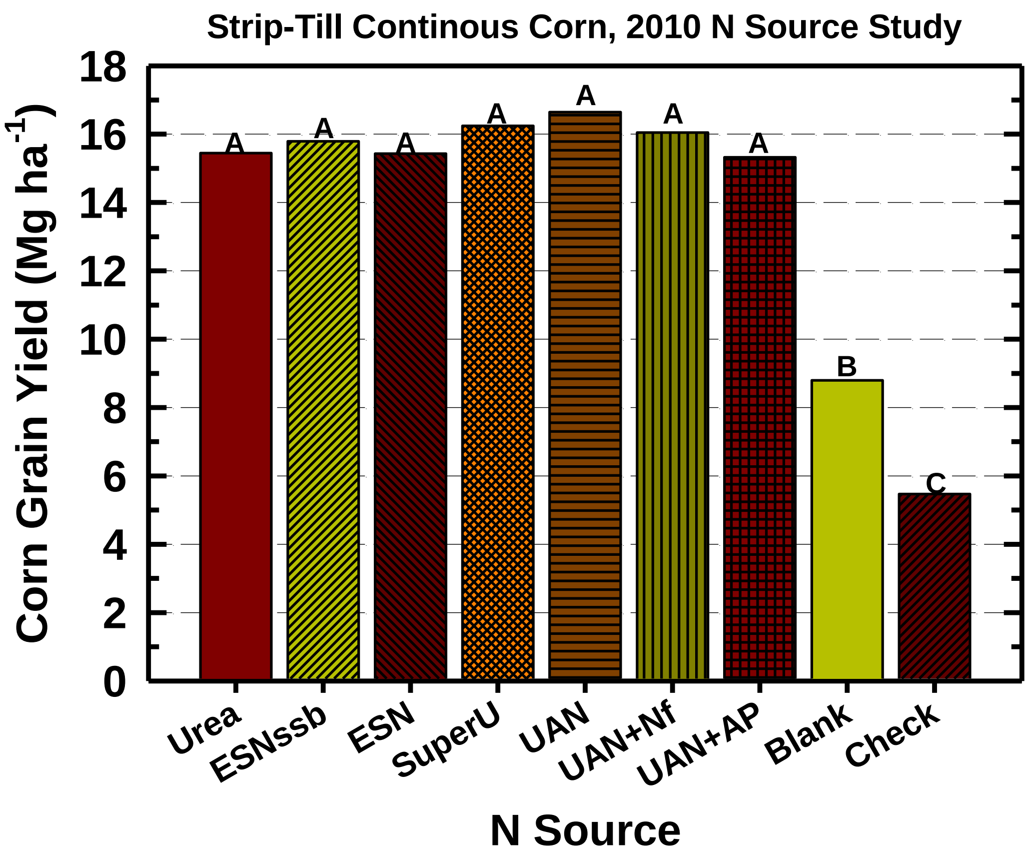

Fig. 3. Grain yields (15.5% water content) for each of the N source treatments in 2010. Bars with the same letter on top are not significantly different at $P = 0.05$.

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ACKNOWLEDGEMENT

The authors thank B. Floyd, R. D'Adamo, P. Norris, M. Smith, K. Nichols, M. Carey, and M. Reyes-Fox for their technical assistance and the IPNI Foundation for Agronomic Research (with funding from Agrium Inc. and Agrotain International); Georgia Pacific Chemicals LLC; Fluid Fertilizer Foundation; and USDA-ARS GRACEnet project for supporting this study.

Enhancing Continuous Corn Production in Conservation Tillage with Nitrogen, Phosphorus, and Sulfur Starter Fluid Combinations and Placements
2010

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ABSTRACT

Continuous corn production using conservation tillage often results in less uniform and smaller early season growth along with lower grain yields and profitability. This is especially true on fine-textured and poorly drained soils in the northern part of the Corn Belt where decomposition of surface residues is slower and soil temps are colder. The primary objective of this study was to determine the effects of fluid starter fertilizer combinations and placement of 10-34-0 (APP), 28-0-0 (UAN), and 12-0-0-26 (ATS) on second-year corn production in reduced tillage/high-residue conditions. Two field experiments, one on a Webster clay loam soil at Waseca and another on a Mt Carroll silt loam near Rochester, were established in April of 2010. Twelve of the 14 total treatments were comprised of a factorial combination of rates of three fluid starter fertilizers: 0 or 4 gal/ac of APP, 0 or 8 gal/ac of UAN, and 0, 2, and 4 gal/ac of ATS. The APP was applied in-furrow with the seed while UAN and ATS were applied as a dribble band on the soil surface within 2” of the seed row. Corn was planted at 35,000 seeds/ac on May 3 at Waseca and April 27 at Rochester. At V2-3 UAN was injected 3” deep midway between the rows to give a total (at planting + V2-3) N rate of 180 lb/ac on all plots. At V7-8 stage corn plants were harvested from each plot to determine dry matter yield, and the plant tissue was analyzed for N, P, K and S concentration. Grain yield and moisture content were determined by combine harvesting. Grain samples were analyzed for N, P, K and S concentration. A record wet June and July at Waseca stressed corn and may have reduced yield potential. Crop response to treatments varied markedly between locations. Early plant growth (plant heights and dry matter yields) were enhanced when N, P and S starter fertilizers as APP, UAN and ATS were applied at the Waseca site. Whereas only APP application affected early plant growth at Rochester. Grain moisture was reduced about 1.0 percentage points when APP or UAN were applied at Waseca, while moisture was reduced 1.5 and 2.5 percentage points with the 2 and 4 gal/ac rate of ATS, respectively, compared with 0 gal/ac. At Rochester, grain moisture was reduced about 1 percentage point with APP, slightly with UAN, and was not affected by ATS application. Corn grain yields were 6 to 9 bu/A greater with ATS (sulfur fertilization) at Waseca, when averaged across APP and UAN treatments. A significant UAN×ATS interaction for grain yield showed when UAN was not applied at planting, grain yields increased about 18 bu/ac with ATS fertilization. When UAN was applied, no yield response to ATS was observed. At Waseca adding 1 gal/ac of ATS to 4 gal/ac of APP applied in-furrow increased grain yields 12 bu/ac compared with APP alone and final plant populations were not reduced significantly. No grain yield responses to N, P, and S starter fertilizer treatments were found at Rochester.

INTRODUCTION

Crop rotations in the Midwest have changed from the traditional corn-soybean rotation to more corn-intensive rotations. Due to the expanding demand for corn to supply the ethanol industry and the increasing insect and disease challenges facing soybean producers, some farmers are switching to a corn-corn-soybean rotation or for some, continuous corn. These rotations produce large amounts of biomass (corn stover) that often remain on the soil surface with present day tillage systems. This is good in terms of erosion control, but can be a significant problem from the standpoint of seedbed preparation, early corn growth, and yield.

The switch back to corn dominated rotations presents a huge tillage challenge to corn producers on many poorly drained, colder soils of the northern Corn Belt because corn yields following corn are generally reduced significantly when conservation tillage practices are used. Research by Randall and Vetsch (2010) has shown many of the early growth and yield problems associated with corn after corn could be eliminated by using conventional tillage (i.e. moldboard plow) in combination with fluid starter fertilizers. Generally, for most northern Corn Belt farmers the moldboard plow is not an option, because of increased potential for erosion, equipment, or labor (time). This research also showed fluid starter fertilizers [APP (10-34-0) applied in furrow or APP and UAN (28-0-0) dribbled on the soil surface] significantly increased early growth of corn by 13 to 43% and corn yield by 5 to 7 bu/ac. This study did not address a commonly asked question, would dual placement (APP in furrow and UAN dribbled on the soil surface) further enhance corn production.

Continuous corn generally shows slow early growth, pale spindly plants, and reduced yields with reduced tillage systems. Sulfur deficiency in corn has contributed to some of these pale looking plants. Corn yield responses to sulfur have been reported on medium and fine-textured soils in Minnesota and Iowa. In Minnesota we have very little data on the optimum rate and placement of sulfur containing fluid starter fertilizers for corn. With increased costs and price volatility of fertilizers, farmers have questions about what products, placements, and rates give them the most “bang for their buck”.

The objectives of this study were to: 1) determine the effects of fluid starter fertilizer combinations and placement of 10-34-0 (APP), 28-0-0 (UAN), and 12-0-0-26 (ATS) on second-year corn production in reduced tillage/high-residue conditions and 2) provide management guidelines on placement and rates of UAN, APP, and ATS combined as a starter for crop consultants, local advisors, and the fertilizer industry as they serve corn producers trying to meet the growing needs for corn grain by the ethanol industry and livestock producers.

EXPERIMENTAL PROCEDURES

Two field experiments were established in April. One on a Webster clay loam soil at the Southern Research and Outreach Center, Waseca, MN and another on a Mt Carroll silt loam five miles east of Rochester (southeast) MN. Both sites were planted to corn in 2009 and were fall chisel plowed after harvest. Fourteen total treatments were arranged in a randomized, complete-block design with four replications. Twelve of the 14 treatments comprised a factorial combination of sources and rates of three fluid starter fertilizers: 0 or 4 gal/ac of APP (5+16+0, lb/ac of N, P_2O_5, and S, respectively); 0 of 8 gal/ac or UAN (24+0+0); and 0, 2, and 4 gal/ac of ATS (2 gal = 3+0+5.8 and 4 gal = 5+0+11.5). The APP fluid starter was applied in-furrow with the seed while UAN and ATS were applied as a dribble band on the soil surface within 2” of the seed row. Two additional treatments were included to measure crop response when adding 1 gal/ac of ATS in-furrow with 4 gal/ac of APP with and without 8 gal/ac of UAN dribbled on the soil surface. Each plot was 10’ wide (4 30-inch rows) by 50’ long. Soil samples (0-6” depth) were taken from each rep to characterize the research plot areas. Soil tests averaged: pH = 5.5, organic matter = 6.1%, Bray P_1 = 42 ppm (VH) and exchangeable K = 191 ppm (VH) at Waseca and pH = 7.3, organic matter = 4.8%, Bray P_1 = 22 ppm (VH) and exchangeable K = 170 ppm (VH) at Rochester.

Corn (DeKalb 52-43 at Waseca and 48-37 at Rochester) was planted at 35,000 seeds/ac on May 3 (Waseca) and April 27 (Rochester). Weeds were controlled with a combination of pre [Harness (1.5 pt/ac) and Callisto (5 oz/ac)] and post [glyphosate (32 oz/ac)] emergence herbicide applications. Surface residue accumulation after planting averaged about 40-45%. In early June stand counts were taken on the center two rows of each plot and plots were thinned to a uniform plant population. At V2-3 on June 3 at Waseca and June 7 at Rochester, UAN was injected 3” deep midway between the rows to give a total (at planting + at V2-3) N rate of 180 lb/ac on all plots. On June 21 at Waseca and June 24 at Rochester (V7-8 stage) 8 random plants from each plot were cut at ground level, dried, weighed to determine dry matter yield, ground, and analyzed for N, P, K and S concentration in plant tissue. On the same dates extended leaf plant heights from 10 random plants per plot were also measured. At R1 (July 20 at Waseca and July 16 at Rochester) SPAD meter readings were taken from the ear leaf of 30 plants in each plot. Relative leaf chlorophyll content was calculated from these measurements. At physiological maturity (black layer) corn stover yield was obtained by machine harvesting 15’ of one row after removing the ear (Waseca site only). A subsample of the stover was dried, ground, and analyzed for N, P, K and S concentration. Grain yield and moisture content were determined on October 4 (Waseca) and 12 (Rochester) by harvesting the center two rows of each plot with a research plot combine equipped with a weigh cell and moisture sensor. Grain yields were calculated at 15.5% moisture. Grain samples were saved, dried, ground, and analyzed for N, P, K and S.

RESULTS AND DISCUSSION

The 2010 growing season was warm and wet. Two months [June (9.64”, 5.42” greater-than-normal) and September (12.66”, 9.47” greater-than-normal)] set 96-year records for precipitation at Waseca (Table 1). The June + July total precipitation (16.25”) and the growing season total (34.61”) were also records. Growing season precipitation at the Rochester location was about 50% greater-than-normal. With much of the excess falling during the months of June, August, and September. At Waseca growing degree units (GDU) for the entire growing season May 1 through October 3 (first frost) totaled 2,606 which was 8% greater-than-normal.

The extremely wet conditions in June and July at Waseca were conducive to N loss via denitrification and leaching. These research sites and many farmer fields in Southern Minnesota would have benefited from supplemental N applications. Unfortunately, these research sites and many farmer fields did not receive supplemental N because: many fields had standing water or were too wet for equipment traffic; by the time fields dried out corn was too large for conventional sidedress equipment; and some corn was already in reproductive stages and the benefit of N applied this late was questioned.

Waseca site

Plant heights and whole plant dry matter yields were affected by all three of the treatment main effects in the factorial analysis of treatments 1-12 (Table 2). Heights and yields were increased when APP was applied in-furrow and when UAN and ATS were applied as a surface band. The 4 gal/ac rate of ATS did not increase heights or yields above the 2 gal/ac rate, when averaged across APP and UAN treatment main effects. A significant APP×UAN interaction for plant height was explained by the magnitude of the response in plant height when fertilized with one vs both of these nutrients. Plant heights increased about 4” when fertilized with either UAN or APP, compared with plots without UAN and APP. Whereas plant heights increased only 2” when fertilized with both UAN and APP, compared with either UAN or APP. The 1 gal/ac of ATS plus 4 gal/ac or APP applied in-furrow treatment increased V7 plant heights and yields compared with 4 gal/ac of APP alone. The application of fluid fertilizers at planting resulted in dramatic visual (early growth, vigor, and color) differences as shown in Figure 1.

A few nutrient concentrations and nearly all nutrient uptakes in V7 corn plants were affected by the treatment main effects in this study (Table 2). Nitrogen and S concentrations were reduced when 4 gal/ac of APP was applied in-furrow compared with 0 gal/ac of APP (likely due to dilution), when averaged across UAN and ATS treatments. Sulfur concentration increased as the rate of S fertilizer (ATS) increased, when averaged across UAN and APP treatments. However, adding 1 gal/ac of ATS to 4 gal/ac of APP applied in-furrow, did not affect S concentration in V7 corn plants, compared with 4 gal/ac of APP alone. Applying 4 gal/ac of APP in-furrow increased N, P, and K uptake, when averaged across UAN and ATS treatments. Nitrogen, P, K and S uptake in corn plants were increased when UAN and ATS were applied at planting. Generally, the nutrient uptake responses to treatment main effects found in this study were a result of small plant DM yield responses to treatments and not to increased nutrient concentrations. Several significant APP×UAN interactions for nutrient concentration and uptake were found. The APP×UAN interaction for P concentration showed when APP or UAN were applied at planting, P concentration in whole plants increased compared with the control (when neither were applied). However when APP and UAN were applied together, P concentration declined slightly (data not shown). An APP×UAN interaction for S concentration showed S concentration was reduced slightly when both APP and UAN were applied, whereas when APP or UAN were applied S concentrations were similar to the control (data not shown). Significant APP×UAN interactions for N, P and S uptake in V7 corn plants were a result of increased growth and have the same explanation as the APP×UAN interaction for plant height in the previous paragraph (data not shown).

Treatment effects on grain moisture and grain, stover, and silage yields are presented in Table 3. Grain moisture was reduced 0.9 percentage points with APP (4 gal/ac vs 0 gal) and UAN (8 gal/ac vs 0 gal) application. Grain moisture was reduced 1.5 and 2.5 percentage points with the 2 and 4 gal/ac rate of ATS, respectively, compared with 0 gal of ATS and averaged across APP and UAN treatments. The driest grain (16.5%) was obtained when N, P, and S were applied at planting (treatment # 12). The wettest grain (20.7%) was found in the control plot (treatment # 1). Corn grain, stover, and silage yields were not affected by the application of APP or UAN at planting, although APP and UAN application enhanced early growth and reduced grain moisture. Grain yields were 9 bu/ac greater than the control with 2 gal/ac of ATS, when averaged across APP and UAN treatments. Yields were not different between the 2 and 4 gal/ac rates of ATS. Applying 1 gal/ac of ATS and 4 gal/ac of APP in-furrow increased yields 12 bu/ac compared with APP alone (treatments 13 vs 7). A significant UAN×ATS interaction for grain yield showed a 19 bu/ac response to ATS when UAN was not applied, but no response to ATS when 8 gal/ac of UAN was applied at planting (Figure 2). Sulfur fertilization (ATS) increased stover and silage yields, when averaged across UAN and APP treatments. Stover yields were greatest with the 4 gal/ac rate of ATS, whereas silage yields were not significantly different between the 2 and 4 gal/ac rate.

Treatment effects on plant stand, final population and reIative leaf chlorophyll content (RLC) are presented in Table 3. Initial plant stand was reduced slightly (500 plants/ac) with APP fertilization, when averaged across UAN and ATS treatments. Initial stand and final plant population were affected by ATS application in this study, but the differences were generally very small and would not have affected corn production. When 1 gal/ac of ATS and 4 gal/ac of APP were applied in-furrow (treatment # 13), initial plant stand and final plant population trended lower, but they were not significantly less than 4 gal/ac of APP alone (treatment # 7). Significant interactions for final plant population were found, but the differences were small about 300 plants/ac and would not have influenced corn production. Relative leaf chlorophyll content at VT-R1 increased slightly with 8 gal/ac of UAN applied at planting compared with 0 gal of UAN, when averaged across APP and ATS treatments. The 2 and 4 gal/ac rates of ATS increased RLC 5.0 and 7.7 percentage points, respectively, compared with the control (0 gal/ac), when averaged across APP and UAN treatments. One gal/ac of ATS and 4 gal/ac of APP applied in-furrow increased RLC significantly compared with 4 gal/ac of APP alone. No difference in RLC was found when the 1 gal/ac of ATS plus 4 gal/ac of APP applied in-furrow treatment (# 13) was compared to the 4 gal/ac of APP applied in-furrow plus 2 gal/ac of ATS applied as a surface dribble band treatment (# 8). The significant APP×ATS interaction for RLC showed without ATS, APP increased RLC slightly (1-2 percentage points). Whereas with ATS at 2 or 4 gal/ac, APP application had no affect on RLC (data not shown). The significant UAN×ATS interaction for RLC was similar to the APP×ATS interaction. It showed at the 0 and 2 gal/ac rates of ATS, UAN application increased RLC slightly, whereas at the 4 gal/ac rate of ATS, UAN application had no affect on RLC (data not shown). These data show a small amount of N at planting, either from APP applied in-furrow or UAN applied as a surface dribble band, increased VT-R1 RLC values slightly in the absence of ATS. However when ATS was applied, the response in RLC was significantly large and masked any effect of APP or UAN. Interestingly, the 1 and 2 gal/ac rates of ATS resulted in corn plants that were pale (significantly less RLC) when compared to the 4 gal/ac rate, but these treatments produced similar grain yields as the 4 gal/ac treatments. This suggests at this site only a small amount of S (1 gal/ac of ATS = 2.9 lb S/ac) applied in the seed furrow at planting was needed to get a yield response on this high organic matter soil.

Treatment effects on the concentration of N, P, K and S in corn stover, harvested at physiological maturity (black layer), and corn grain are presented in Table 4. Generally APP did not affect nutrient concentrations in corn stover or grain on this very high P testing site. Stover N and K concentration declined slightly when 8 gal/ac of UAN was applied at planting compared with 0 gal/ac, when averaged across APP and ATS treatments. This response could be a result of greater N loss during the wet period in June and July when 24 lb N/ac was applied at planting, which limited N supply later during grain fill, thus requiring the plant to utilize more of the N in the stalk to fill grain in August and early September. Averaged across APP and UAN treatments, 2 gal/ac of ATS increased stover N compared with the control; however, stover N concentration was not different between the 0 (control) and 4 gal/ac rate of ATS. Stover P concentration declined slightly when 2 gal/ac or ATS was applied compared with 0 gal/ac. Sulfur concentration in corn grain increased with increasing ATS rate. No plausible explanation exists for the significant three-way interaction for stover K concentration and no other significant interactions were found. The 1 gal/ac of ATS and 4 gal/ac of APP treatment applied in-furrow increased grain S concentration compared with 4 gal/ac of APP alone.

The treatment effects on stover, grain, and total nutrient uptake are presented in Table 5. Total K uptake increased slightly with APP application, when averaged across UAN and ATS treatment main effects. However APP did not affect any other nutrient uptakes on this very high P testing site. Application of 8 gal/ac of UAN at planting decreased stover and total N and K uptake, when averaged across APP and ATS treatments. Averaged across APP and UAN treatments, stover, grain and total N uptake increased with ATS application, however no differences were found between the 2 and 4 gal/ac rates. Total N uptake was greatest (176 lb/ac) with treatments that contained very little N at planting and 2 gal/ac of ATS (treatment #'s 2 and 8). Total N uptake was 10-12 lb/ac less with treatments 11 and 12, even though they had greater early growth (V7 dry matter yield) and greater RLC. Treatments 11 and 12 contained the greatest amount of N (31 and 34 lb N/A, respectively) at planting in combination with P and S. These data show less total N was taken up by corn when more N was applied at planting and less N was applied at V2. This suggests greater N loss occurred during the wet period in June and July on treatments that received more N at planting. A reduction in N uptake probably reduced yield potential in these treatments in 2010 a high N stress growing season. Stover and total uptake of K was greatest with the 4 gal/ac rate of ATS compared with 0 or 2 gal/ac rates, when averaged across APP and UAN treatments. Generally, stover, grain, and total S uptake increased with increasing rate of ATS. Total S uptake in the corn plant increased only 2.1 lb/ac for the 4 gal/ac rate of ATS (11.5 lb S/ac) compared with the control, when averaged across APP and UAN treatments.

Several significant ($P <= 0.10$) interactions were found for stover, grain and total nutrient uptake (Table 5). An APP×UAN interaction for stover K showed K uptake was reduced about 11 lb/ac when UAN was applied without APP, while other combinations of APP and UAN (with UAN and with APP, no UAN and no APP, and no UAN with APP) had similar K uptake (data not shown). The significant UAN×ATS interactions for grain N, P and S uptake and total P uptake were similar to and a result of the same interaction for yield (Figure 2). Moreover greatest nutrient uptake values were obtained with 2 or 4 gal/ac of ATS without UAN, when UAN was applied uptake values across all rates of ATS were similar (data not shown). The APP×UAN interactions for grain P and K uptake were similar and showed P and K uptake was greatest when either APP or UAN were applied, while uptake was reduced when both were applied (data not shown). An APP×ATS interaction for total P uptake showed when APP was not applied P uptake was 37, 39. and 41 lb/ac for the 0, 2, and 4 gal/ac rates of ATS, respectively. However, when APP was applied P uptake was 40, 39, and 38 for the 0, 2, and 4 gal/ac rates, respectively (data not shown). Generally these small differences in nutrient uptake from one-site year of data would not raise much concern. However, these data suggest a potential for negative consequences when combinations of fluid fertilizers are applied at planting. Whether that potential is realized will depend on the interactions expressed in years 2 and 3 of this study. Consistent and repeated responses would lead to more definitive conclusions. The significant three-way interaction for K uptake in grain has no plausible explanation.

Rochester site

Treatment effects on early growth of small corn plants harvested on June 24 (V7-8 stage) are presented in Table 6. Plant heights and dry matter yields were increased with 4 gal/ac of APP applied in-furrow compared with 0 gal/ac, when averaged across UAN and ATS treatments. Plant heights and dry matter yields were not affected by the main effects of UAN and ATS application, and there were no significant interactions. This suggests the early growth response at this site was primarily due to P in the APP starter. Adding 1 gal/ac of ATS to 4 gal/ac of APP in-furrow had no effect on plant height and dry matter yield compared with APP alone. Nitrogen and S concentrations in V7-8 corn plants were reduced with APP application, averaged across UAN and ATS treatments. This response is likely a result of the "dilution effect". The dilution effect occurs when early growth increases dramatically, thus causing concentrations of some nutrients to decline. The large increase in dry matter yield with APP fertilization observed in this study, resulted in increased N, P, K, and S uptake compared with plots that did not get APP. When UAN was applied at planting, P concentration in small plants decreased slightly, while S concentration and uptake increased. Four gal/ac of ATS increased N concentration in small plants compared to the 0 and 2 gal/ac treatments, when averaged across APP and UAN treatments. Sulfur concentration increased as ATS rate increased, but no differences in S uptake were found. Adding 1 gal/ac of ATS to 4 gal/ac of APP in-furrow, generally did not affect nutrient concentrations or uptakes in small corn plants compared with APP alone. The highly significant APP×ATS interactions for K concentration and uptake in V7-8 corn plants showed without APP, K concentration and uptake declined when ATS was applied. Whereas with APP, K concentration and uptake increased as the rate of ATS increased (data not shown). Lowest K concentrations and uptakes were found when APP was not applied and 4 gal/ac of ATS was applied (data not shown). These results were not found at the S-responding Waseca site. Three other interactions had P values slightly less than alpha = 0.10 level of significance. However, the author feels they are of little consequence and do not warrant further discussion.

Treatment effects on grain moisture, grain yield, initial plant stand, final plant population, and relative leaf chlorophyll content are presented in Table 7. Grain moisture was reduced 0.9 percentage points with 4 gal/ac of APP compared with 0 gal/ac, when averaged across UAN and ATS treatments. Application of UAN reduced grain moisture slightly (0.3 percentage points), when averaged across APP and ATS treatments. Three significant interactions (APP×ATS, UAN×ATS and APP×UAN×ATS) were found for corn grain moisture. Generally these interactions showed when APP was not applied, grain moisture was reduced with ATS with or without UAN. However when APP was applied, the grain moisture response to

ATS with or without UAN was erratic. Corn yields only ranged from 207 to 213 bu/ac across all 14 treatments in this study. No significant differences were found among treatments, and there were no interactions. No differences in final plant population were found among treatment main effects. At VT-R1 RLC ranged from 94.6 to 99.1% and was not affected by the main effects of APP and UAN application. The 2 and 4 gal/ac rates of ATS increased RLC about 1 percentage point compared with the 0 gal/ac rate of ATS, when averaged across APP and UAN main effects. The author has no plausible explanation for the significant three-way interaction for RLC.

Treatment effects on corn grain nutrient concentration and uptake are presented in Table 8. Significant differences among the 14 treatment means were not found for any of the nutrient concentrations or uptakes in corn grain. The very small differences in S concentration and uptake found in main effects were insignificant.

SUMMARY

An early and warmer-than-normal spring in 2010 appeared ideal for growing corn. Extreme wet conditions in June and July at Waseca, when soil temperatures were warm, were conducive to N loss via denitrification and leaching and probably reduced yield potential. Crop response to the treatments varied markedly between locations. The Waseca site responded more to S (ATS application), whereas the Rochester site had few responses and those were usually due to P (APP application). The primary observations from the first year of this 3-year study were:

1) Early plant growth (plant heights and dry matter yields) were enhanced when N, P and S starter fertilizers as APP, UAN and ATS were applied at the Waseca site, but only APP application affected early plant growth at Rochester.
2) Grain moisture was reduced about 1.0 percentage points when APP or UAN were applied at Waseca. The grain moisture response was similar for APP, but less for UAN at Rochester. Grain moisture was reduced 1.5 and 2.5 percentage points with the 2 and 4 gal/ac rate of ATS, respectively, compared with 0 gal/ac of ATS at Waseca. Grain moisture was not affected by ATS application at Rochester.
3) Corn grain yields were 6 to 9 bu/A greater with ATS (sulfur fertilization) at Waseca, when averaged across APP and UAN treatments. A significant UAN×ATS interaction for grain yield showed when UAN was not applied at planting, grain yields increased about 18 bu/ac with ATS fertilization. When UAN was applied, no yield response to ATS was observed. This interaction data along with N uptake data suggest N loss was greater during the very wet June and July period and N supply was less when UAN was applied at planting, which probably reduced yields on those treatments.
4) At Waseca in-furrow application of 1 gal/ac of ATS and 4 gal/ac of APP increased grain yields 12 bu/ac compared with 4 gal/ac of APP alone.
5) No yield responses to N, P and S starter fertilizers were found at Rochester. This site has a recent (2 years ago) history of fertilization with beef manure. It’s likely mineralization from past manure applications provided adequate nutrients for corn in 2010 at the Rochester location.

ACKNOWLEDGEMENT

Grateful appreciation is extended to the Minnesota Agricultural Fertilizer Research and Education Council and the Fluid Fertilizer Foundation for funding this research, and to Ward Laboratories, Inc. for conducting the plant analyses as part of in-kind support given to the Fluid Fertilizer Foundation.

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Table 1. Precipitation at Waseca and Rochester and growing degree units (GDUs) at Waseca.

		Precipitation					
		Waseca		Rochester		Waseca GDUs	
Month	Year	2010	Normal[1/]	2010	Normal[1/]	2010	Normal[1/]
		- - - - - inches - - - - -		- - - - - inches - - - - -			
May	2010	3.27	3.96	3.72	3.5	363	337
June	2010	9.64	4.22	6.55	4.0	509	532
July	2010	6.61	4.47	3.81	4.6	691	644
Aug.	2010	2.43	4.58	6.49	4.3	698	584
Sept.	2010	12.66	3.19	9.62	3.1	320	322
May-Sept.	Total	34.61	20.42	30.19	19.6	2581[2/]	2419

[1/] 30-Yr normal, 1971-2000.
[2/] May – September total.

Table 2. Growth, nutrient concentration and uptake of V7 corn plants at Waseca.

	Fertilizer rate			V7 Plant	Whole Plant Samples at V7 (June 21)								
						Concentration				Uptake			
Trt	APP	UAN	ATS	height	Yield	N	P	K	S	N	P	K	S
#	------	gal/ac	-------	inch	lb/ac	-------------	%	-------------		----------	lb/ac	-----------	
1	0	0	0	28.4	438	3.85	0.423	4.60	0.200	17.0	1.89	20.3	0.88
2	0	0	2	31.4	593	3.85	0.420	4.77	0.195	22.9	2.50	28.5	1.16
3	0	0	4	31.9	636	3.70	0.445	4.76	0.218	23.6	2.84	30.4	1.39
4	0	8	0	33.9	767	3.88	0.463	4.50	0.195	29.7	3.50	34.6	1.50
5	0	8	2	34.9	815	3.97	0.440	4.59	0.208	32.3	3.58	37.4	1.69
6	0	8	4	35.6	852	3.87	0.463	4.66	0.218	33.1	3.95	40.1	1.86
7	4	0	0	32.9	584	3.62	0.433	4.60	0.193	21.2	2.52	26.8	1.12
8	4	0	2	35.0	730	3.84	0.463	4.74	0.200	28.0	3.37	34.5	1.46
9	4	0	4	35.0	720	3.76	0.433	4.50	0.213	27.3	3.10	32.3	1.53
10	4	8	0	34.9	810	3.65	0.435	4.90	0.175	29.5	3.53	39.6	1.42
11	4	8	2	37.1	913	3.71	0.438	4.72	0.193	33.9	4.00	43.1	1.76
12	4	8	4	36.6	847	3.70	0.430	4.54	0.213	31.2	3.64	37.9	1.80
13	4	0	1*	34.7	749	3.79	0.443	4.68	0.193	28.3	3.31	35.0	1.44
14	4	8	1*	35.0	786	3.69	0.440	4.87	0.185	29.1	3.46	38.6	1.46
Stats for a Factorial Design (Treatments 1-12)													
APP (10-34-0) applied in-furrow													
None				32.7	683	3.85	0.442	4.65	0.205	26.4	3.04	31.9	1.41
4 gal/ac				35.3	767	3.71	0.438	4.67	0.198	28.5	3.36	35.7	1.51
P > F:				0.001	0.005	0.030	0.674	0.844	0.013	0.080	0.026	0.006	0.112
UAN (28-0-0) applied as a surface dribble band													
None				32.4	617	3.77	0.436	4.66	0.203	23.3	2.70	28.8	1.26
8 gal/ac				35.5	834	3.79	0.445	4.65	0.200	31.6	3.70	38.8	1.67
P > F:				0.001	0.001	0.681	0.330	0.916	0.315	0.001	0.001	0.001	0.001
ATS (12-0-0-26) applied as a surface dribble band													
None				32.5	650	3.75	0.438	4.65	0.191	24.3	2.86	30.3	1.23
2 gal/ac				34.6	763	3.84	0.440	4.71	0.199	29.3	3.36	35.9	1.52
4 gal/ac				34.8	764	3.76	0.443	4.61	0.215	28.8	3.38	35.1	1.64
P > F:				0.001	0.003	0.391	0.921	0.742	0.001	0.002	0.005	0.003	0.001
Average LSD (0.10):				0.7	59	NS	NS	NS	0.006	2.41	0.28	2.7	0.13
Interactions (P > F)													
APP×UAN				0.001	0.187	0.189	0.062	0.243	0.072	0.062	0.056	0.452	0.052
APP×ATS				0.593	0.529	0.492	0.151	0.280	0.378	0.680	0.148	0.116	0.637
UAN×ATS				0.353	0.306	0.929	0.552	0.708	0.155	0.395	0.274	0.155	0.825
APP×UAN×ATS				0.383	0.886	0.657	0.840	0.851	0.422	0.922	0.973	0.840	0.916
Stats for RCB design (all 14 treatments)													
P > F:				0.001	0.001	0.655	0.609	0.930	0.001	0.001	0.001	0.001	0.001
Average LSD(0.10):				1.4	91	NS	NS	NS	0.013	3.7	0.44	4.3	0.20

* One gal/ac rate of ATS applied in-furrow with seed and 10-34-0.

Table 3. Grain moisture, grain, stover and silage yields, plant stand, final plant population, and relative leaf chlorophyll at Waseca.

Trt	Fertilizer rate APP	Fertilizer rate UAN	Fertilizer rate ATS	Grain H_2O	Grain Yield	Stover Yield	Silage Yield	Initial Plant Stand	Final Plant Pop.	VT-R1 Leaf Chloro
#	------	gal/ac	-------	%	bu/ac	- ton dm/ac -		plants×10^3/ac		%
1	0	0	0	20.7	202	2.90	7.69	34.6	33.7	89.7
2	0	0	2	19.0	220	3.02	8.21	35.0	33.8	94.8
3	0	0	4	17.5	220	3.23	8.42	33.7	33.2	99.2
4	0	8	0	19.5	213	2.63	7.66	34.6	33.8	90.6
5	0	8	2	18.0	220	2.91	8.11	34.7	33.8	97.1
6	0	8	4	16.9	210	3.24	8.20	34.4	33.8	99.1
7	4	0	0	19.0	207	3.06	7.95	34.4	33.7	91.8
8	4	0	2	18.2	223	3.09	8.36	34.1	33.6	94.9
9	4	0	4	17.2	222	3.19	8.45	34.2	33.6	98.8
10	4	8	0	18.8	212	3.06	8.08	33.5	33.5	92.2
11	4	8	2	16.8	210	2.95	7.92	34.6	33.8	97.5
12	4	8	4	16.5	209	3.39	8.34	33.3	33.2	98.2
13	4	0	1*	18.6	219	3.13	8.31	33.6	33.4	94.2
14	4	8	1*	17.9	209	3.01	7.95	33.4	33.2	92.7
Stats for a Factorial Design (Treatments 1-12)										
APP (10-34-0) applied in-furrow										
None				18.6	214	2.99	8.05	34.5	33.7	95.1
4 gal/ac				17.7	214	3.12	8.19	34.0	33.5	95.6
P > F:				0.001	0.998	0.155	0.230	0.059	0.252	0.223
UAN (28-0-0) applied as a surface dribble band										
None				18.6	216	3.08	8.18	34.3	33.6	94.9
8 gal/ac				17.7	212	3.03	8.05	34.2	33.6	95.8
P > F:				0.002	0.193	0.594	0.261	0.566	0.963	0.022
ATS (12-0-0-26) applied as a surface dribble band										
None				19.5	209	2.91	7.84	34.3	33.7	91.1
2 gal/ac				18.0	218	2.99	8.15	34.6	33.7	96.1
4 gal/ac				17.0	215	3.26	8.36	33.9	33.4	98.8
P > F:				0.001	0.012	0.011	0.003	0.081	0.037	0.001
Average LSD (0.10):				0.5	5.1	0.19	0.23	0.5	0.2	0.8
Interactions (P > F)										
APP×UAN				0.675	0.194	0.452	0.947	0.248	0.035	0.736
APP×ATS				0.341	0.680	0.490	0.414	0.802	0.854	0.032
UAN×ATS				0.649	0.009	0.493	0.492	0.645	0.705	0.018
APP×UAN×ATS				0.488	0.719	0.783	0.622	0.109	0.026	0.872
Stats for RCB design (all 14 treatments)										
P > F:				0.001	0.021	0.195	0.063	0.057	0.022	0.001
Average LSD (0.10):				1.1	10	NS	0.45	0.9	0.4	1.6

* One gal/ac rate of ATS applied in-furrow with seed and 10-34-0.

Table 4. Nutrient concentrations in the corn stover and grain at Waseca.

	Fertilizer rate			Stover concentration				Grain concentration			
Trt	APP	UAN	ATS	N	P	K	S	N	P	K	S
#	------	gal/ac	-------	---------------------------------			%	------------------------------------			
1	0	0	0	0.61	0.115	1.51	0.063	1.26	0.31	0.39	0.085
2	0	0	2	0.73	0.110	1.41	0.065	1.27	0.32	0.40	0.088
3	0	0	4	0.63	0.118	1.41	0.068	1.27	0.33	0.42	0.100
4	0	8	0	0.58	0.113	1.26	0.068	1.26	0.32	0.42	0.088
5	0	8	2	0.66	0.083	1.30	0.063	1.25	0.32	0.42	0.090
6	0	8	4	0.62	0.110	1.33	0.065	1.27	0.33	0.42	0.098
7	4	0	0	0.63	0.115	1.38	0.063	1.27	0.33	0.45	0.080
8	4	0	2	0.67	0.108	1.37	0.073	1.27	0.33	0.41	0.085
9	4	0	4	0.62	0.088	1.43	0.065	1.25	0.32	0.41	0.093
10	4	8	0	0.57	0.123	1.43	0.063	1.25	0.33	0.42	0.085
11	4	8	2	0.62	0.093	1.45	0.068	1.28	0.31	0.40	0.090
12	4	8	4	0.60	0.105	1.27	0.070	1.27	0.30	0.44	0.095
13	4	0	1*	0.63	0.105	1.55	0.058	1.25	0.32	0.40	0.088
14	4	8	1*	0.61	0.128	1.43	0.068	1.28	0.31	0.38	0.083
Stats for a Factorial Design (Treatments 1-12)											
APP (10-34-0) applied in-furrow											
None				0.64	0.108	1.37	0.065	1.26	0.32	0.41	0.091
4 gal/ac				0.62	0.105	1.39	0.067	1.26	0.32	0.42	0.088
P > F:				0.331	0.643	0.565	0.432	0.889	0.414	0.233	0.092
UAN (28-0-0) applied as a surface dribble band											
None				0.65	0.109	1.42	0.066	1.26	0.32	0.41	0.088
8 gal/ac				0.61	0.104	1.34	0.066	1.26	0.32	0.42	0.091
P > F:				0.033	0.468	0.020	1.000	0.780	0.702	0.272	0.202
ATS (12-0-0-26) applied as a surface dribble band											
None				0.60	0.116	1.39	0.064	1.26	0.32	0.42	0.084
2 gal/ac				0.67	0.098	1.38	0.067	1.27	0.32	0.41	0.088
4 gal/ac				0.61	0.105	1.36	0.067	1.26	0.32	0.42	0.096
P > F:				0.007	0.071	0.720	0.383	0.825	0.988	0.376	0.001
Average LSD (0.10):				0.04	0.013	NS	NS	NS	NS	NS	0.004
Interactions (P > F)											
APP×UAN				0.873	0.214	0.049	1.000	0.676	0.303	0.199	0.391
APP×ATS				0.419	0.269	0.644	0.246	0.680	0.224	0.381	0.721
UAN×ATS				0.502	0.182	0.363	0.445	0.810	0.689	0.683	0.658
APP×UAN×ATS				0.783	0.872	0.073	0.445	0.756	0.988	0.114	0.954
Stats for RCB design (all 14 treatments)											
P > F:				0.096	0.270	0.042	0.412	0.993	0.891	0.100	0.004
Average LSD (0.10):				0.07	NS	0.14	0.009	0.05	0.03	0.03	0.008

* One gal/ac rate of ATS applied in-furrow with seed and 10-34-0.

Table 5. Nutrient uptake in the corn stover, grain and total dry matter at Waseca.

	Fertilizer rate			Nutrient uptake in stover				Nutrient uptake in grain				Total nutrient uptake			
Trt	APP	UAN	ATS	N	P	K	S	N	P	K	S	N	P	K	S
#	------- gal/ac --------			--- lb/acre --											
1	0	0	0	34.8	6.66	86.7	3.60	120	29.7	36.9	8.2	155	36.4	124	11.8
2	0	0	2	44.1	6.51	84.5	3.91	132	33.3	41.1	9.1	176	39.8	126	13.0
3	0	0	4	40.5	7.68	91.4	4.40	132	34.4	43.0	10.4	172	42.1	134	14.8
4	0	8	0	30.4	5.93	66.3	3.58	126	32.5	42.3	8.8	157	38.4	109	12.4
5	0	8	2	38.0	4.87	75.0	3.65	130	33.5	43.1	9.3	168	38.3	118	13.0
6	0	8	4	40.0	7.09	85.5	4.17	125	32.8	41.8	9.6	165	39.9	127	13.8
7	4	0	0	38.8	6.93	84.4	3.81	124	31.8	43.5	7.8	163	38.7	128	11.6
8	4	0	2	41.6	6.56	84.6	4.47	134	34.2	43.2	9.0	176	40.8	128	13.4
9	4	0	4	39.2	5.50	91.0	4.14	131	33.4	42.6	9.7	170	38.9	134	13.9
10	4	8	0	35.1	7.66	86.7	3.83	126	32.6	41.7	8.5	161	40.3	128	12.4
11	4	8	2	36.4	5.46	85.4	3.99	127	30.8	40.0	9.0	164	36.3	125	12.9
12	4	8	4	40.6	7.23	86.2	4.75	125	29.7	43.1	9.4	166	36.9	129	14.1
13	4	0	1*	39.5	6.56	97.1	3.60	130	32.7	40.9	9.1	169	39.2	138	12.7
14	4	8	1*	36.9	7.67	85.6	4.06	127	30.6	37.6	8.2	164	38.3	123	12.2
Stats for a Factorial Design (Treatments 1-12)															
APP (10-34-0) applied in-furrow															
None				38.0	6.46	81.6	3.89	128	32.7	41.4	9.2	166	39.1	123	13.1
4 gal/ac				38.6	6.56	86.4	4.16	128	32.1	42.4	8.9	167	38.6	129	13.1
P > F:				0.668	0.821	0.104	0.115	0.947	0.402	0.210	0.122	0.775	0.581	0.046	0.839
UAN (28-0-0) applied as a surface dribble band															
None				39.8	6.64	87.1	4.06	129	32.8	41.7	9.0	169	39.4	129	13.1
8 gal/ac				36.8	6.38	80.9	3.99	127	32.0	42.0	9.1	163	38.4	123	13.1
P > F:				0.046	0.547	0.037	0.721	0.224	0.250	0.718	0.685	0.052	0.232	0.041	0.938
ATS (12-0-0-26) applied as a surface dribble band															
None				34.8	6.80	81.0	3.71	124	31.7	41.1	8.3	159	38.4	122	12.0
2 gal/ac				40.0	5.85	82.4	4.00	131	32.9	41.8	9.1	171	38.8	124	13.1
4 gal/ac				40.1	6.88	88.5	4.36	128	32.6	42.7	9.8	168	39.5	131	14.1
P > F:				0.008	0.115	0.091	0.014	0.019	0.295	0.258	0.001	0.003	0.646	0.032	0.001
Average LSD (0.10)				3.1	NS	6.0	0.36	4	NS	NS	0.4	6	NS	6	0.5
Interactions (P > F)															
APP×UAN				0.692	0.104	0.058	0.520	0.386	0.080	0.025	0.887	0.752	0.544	0.174	0.628
APP×ATS				0.212	0.179	0.453	0.777	0.892	0.191	0.172	0.938	0.423	0.073	0.260	0.775
UAN×ATS				0.244	0.214	0.781	0.415	0.088	0.037	0.392	0.087	0.369	0.090	0.941	0.256
APP×UAN×ATS				0.986	0.720	0.318	0.432	0.772	0.876	0.059	0.820	0.861	0.742	0.610	0.413
Stats for RCB design (all 14 treatments)															
P > F:				0.076	0.278	0.022	0.194	0.262	0.133	0.008	0.002	0.089	0.345	0.021	0.001
Average LSD (0.10)				6.0	1.87	11.4	0.71	8	2.9	3.0	0.9	11	3.7	11	1.1

* One gal/ac rate of ATS applied in-furrow with seed and 10-34-0.

Table 6. Early growth, yield, nutrient concentration and uptake of V7 corn plants at Rochester.

	Fertilizer rate			V7 Plant	Whole Plant Samples at V7 (June 24)								
						Concentration				Uptake			
Trt	APP	UAN	ATS	height	Yield	N	P	K	S	N	P	K	S
#	---- gal/ac -----			inch	lb/ac	-------------- % --------------				---------- lb/ac -----------			
1	0	0	0	37.2	1464	3.57	0.433	4.35	0.200	52.2	6.33	63.2	2.93
2	0	0	2	35.7	1337	3.59	0.413	3.20	0.205	47.9	5.50	42.3	2.74
3	0	0	4	36.1	1361	3.58	0.415	3.16	0.218	48.8	5.66	43.1	2.96
4	0	8	0	37.3	1629	3.48	0.403	3.89	0.205	56.8	6.55	63.1	3.34
5	0	8	2	37.0	1577	3.50	0.393	3.07	0.213	55.2	6.19	49.8	3.32
6	0	8	4	37.4	1464	3.61	0.403	3.05	0.233	52.9	5.90	44.8	3.40
7	4	0	0	38.9	1897	3.39	0.393	3.48	0.195	64.1	7.45	67.3	3.69
8	4	0	2	40.6	1949	3.28	0.418	4.31	0.198	63.8	8.12	84.8	3.83
9	4	0	4	40.6	1888	3.48	0.405	3.47	0.203	65.8	7.71	66.2	3.85
10	4	8	0	39.3	1756	3.31	0.398	3.45	0.195	58.2	6.99	61.6	3.42
11	4	8	2	39.9	1992	3.45	0.395	3.19	0.210	68.8	7.86	63.5	4.16
12	4	8	4	40.8	2057	3.46	0.408	4.50	0.210	71.0	8.42	94.5	4.30
13	4	0	1*	40.4	1907	3.39	0.400	3.73	0.188	64.1	7.67	74.9	3.55
14	4	8	1*	40.4	1987	3.32	0.398	3.62	0.198	65.5	7.96	76.8	3.90
Stats for a Factorial Design (Treatments 1-12)													
APP (10-34-0) applied in-furrow													
None				36.8	1472	3.55	0.410	3.45	0.212	52.3	6.02	51.0	3.12
4 gal/ac				40.0	1923	3.39	0.403	3.73	0.202	65.3	7.76	73.0	3.88
P > F:				0.001	0.001	0.001	0.165	0.151	0.002	0.001	0.001	0.001	0.001
UAN (28-0-0) applied as a surface dribble band													
None				38.2	1649	3.48	0.413	3.66	0.203	57.1	6.80	61.2	3.33
8 gal/ac				38.6	1746	3.47	0.400	3.53	0.211	60.5	6.98	62.8	3.66
P > F:				0.389	0.213	0.728	0.014	0.483	0.017	0.210	0.572	0.750	0.035
ATS (12-0-0-26) applied as a surface dribble band													
None				38.2	1687	3.44	0.406	3.79	0.199	57.8	6.83	63.8	3.35
2 gal/ac				38.3	1714	3.45	0.404	3.44	0.206	58.9	6.92	60.1	3.51
4 gal/ac				38.7	1693	3.53	0.408	3.55	0.216	59.6	6.92	62.1	3.63
P > F:				0.652	0.954	0.032	0.876	0.324	0.001	0.853	0.964	0.844	0.310
Average LSD (0.10)				NS	NS	0.06	NS	NS	0.007	NS	NS	NS	NS
Interactions (P > F)													
APP×UAN				0.363	0.345	0.220	0.122	0.619	0.693	0.462	0.561	0.804	0.316
APP×ATS				0.174	0.287	0.752	0.096	0.005	0.179	0.226	0.136	0.024	0.290
UAN×ATS				0.914	0.734	0.225	0.422	0.078	0.477	0.546	0.762	0.201	0.489
APP×UAN×ATS				0.660	0.596	0.102	0.320	0.086	0.694	0.652	0.651	0.108	0.637
Stats for RCB design (all 14 treatments)													
P > F:				0.001	0.016	0.001	0.101	0.049	0.000	0.048	0.049	0.049	0.024
Average LSD(0.10):				2.0	389	0.12	NS	0.83	0.012	12.6	1.67	26.3	0.73

* One gal/ac rate of ATS applied in-furrow with seed and 10-34-0.

Table 7. Grain moisture and yield, plant stand, final plant population, and relative leaf chlorophyll at Rochester.

	Fertilizer rate			Grain	Grain	Initial Plant	Final Plant	VT-R1 Leaf
Trt	APP	UAN	ATS	H_2O	Yield	Stand	Pop.	Chloro
#	------	gal/ac	-------	%	bu/ac	plants×10^3/A		%
1	0	0	0	17.9	207	34.4	34.2	96.9
2	0	0	2	17.6	207	35.2	34.4	98.4
3	0	0	4	17.3	211	35.0	34.4	96.8
4	0	8	0	17.6	208	34.4	33.9	94.6
5	0	8	2	17.0	209	34.7	34.3	97.8
6	0	8	4	16.7	207	34.3	33.9	99.1
7	4	0	0	16.3	209	33.9	33.7	97.1
8	4	0	2	17.3	210	34.2	33.9	96.8
9	4	0	4	16.1	210	35.1	34.5	97.9
10	4	8	0	16.5	210	34.2	34.1	98.1
11	4	8	2	16.0	211	35.2	34.5	98.3
12	4	8	4	17.0	211	34.3	34.0	96.9
13	4	0	1*	16.8	209	34.3	34.0	97.7
14	4	8	1*	16.4	213	33.4	33.4	96.2
Stats for a Factorial Design (Treatments 1-12)								
APP (10-34-0) applied in-furrow								
None				17.4	208	34.7	34.2	97.3
4 gal/ac				16.5	210	34.5	34.1	97.5
P > F:				0.001	0.211	0.431	0.550	0.581
UAN (28-0-0) applied as a surface dribble band								
None				17.1	209	34.6	34.2	97.3
8 gal/ac				16.8	209	34.5	34.1	97.5
P > F:				0.081	0.952	0.531	0.595	0.735
ATS (12-0-0-26) applied as a surface dribble band								
None				17.1	209	34.2	34.0	96.7
2 gal/ac				17.0	209	34.8	34.3	97.8
4 gal/ac				16.8	210	34.7	34.2	97.7
P > F:				0.332	0.881	0.058	0.147	0.067
Average LSD (0.10)				NS	NS	0.4	NS	0.9
Interactions (P > F)								
APP×UAN				0.191	0.625	0.134	0.103	0.401
APP×ATS				0.071	0.953	0.824	0.596	0.041
UAN×ATS				0.015	0.767	0.100	0.098	0.414
APP×UAN×ATS				0.031	0.699	0.286	0.419	0.008
Stats for RCB design (all 14 treatments)								
P > F:				0.001	0.938	0.020	0.038	0.031
Average LSD (0.10)				0.7	NS	0.8	0.5	1.8

* One gal/ac rate of ATS applied in-furrow with seed.

Table 8. Nutrient concentration and uptake in the corn grain at Rochester.

Trt	APP	UAN	ATS	N	P	K	S	N	P	K	S
	Fertilizer rate			Grain concentration				Nutrient uptake in grain			
#	------	gal/ac	-------	--------------	%	--------------		-------------	lb/ac	-------------	
1	0	0	0	1.26	0.28	0.36	0.090	123	27.7	34.9	8.8
2	0	0	2	1.23	0.28	0.34	0.090	120	27.5	33.4	8.8
3	0	0	4	1.25	0.28	0.33	0.090	124	27.7	33.1	9.0
4	0	8	0	1.24	0.30	0.37	0.095	122	29.5	35.9	9.3
5	0	8	2	1.25	0.27	0.34	0.093	124	26.4	33.3	9.1
6	0	8	4	1.22	0.28	0.34	0.095	119	27.6	33.5	9.3
7	4	0	0	1.21	0.28	0.36	0.095	119	27.9	35.4	9.4
8	4	0	2	1.25	0.28	0.35	0.090	124	28.2	34.4	9.0
9	4	0	4	1.24	0.28	0.35	0.095	123	28.0	34.7	9.4
10	4	8	0	1.21	0.30	0.37	0.093	120	29.9	36.9	9.2
11	4	8	2	1.23	0.29	0.36	0.095	123	28.9	35.7	9.5
12	4	8	4	1.24	0.28	0.34	0.095	124	27.4	33.9	9.5
13	4	0	1*	1.23	0.31	0.37	0.090	122	30.4	36.9	8.9
14	4	8	1*	1.22	0.31	0.37	0.093	123	31.2	37.5	9.3
<u>Stats for a Factorial Design (Treatments 1-12)</u>											
APP (10-34-0) applied in-furrow											
None				1.24	0.28	0.35	0.092	122	27.7	34.0	9.1
4 gal/ac				1.23	0.29	0.35	0.094	122	28.4	35.1	9.3
P > F:				0.222	0.647	0.343	0.205	0.992	0.438	0.195	0.069
UAN (28-0-0) applied as a surface dribble band											
None				1.24	0.28	0.35	0.092	122	27.8	34.3	9.1
8 gal/ac				1.23	0.29	0.35	0.094	122	28.3	34.9	9.3
P > F:				0.616	0.576	0.515	0.061	0.738	0.573	0.536	0.078
ATS (12-0-0-26) applied as a surface dribble band											
None				1.23	0.29	0.36	0.093	121	28.8	35.8	9.2
2 gal/ac				1.24	0.28	0.35	0.092	123	27.8	34.2	9.1
4 gal/ac				1.24	0.28	0.34	0.094	123	27.7	33.8	9.3
P > F:				0.559	0.414	0.109	0.489	0.506	0.479	0.163	0.539
Average LSD (0.10)				NS	NS	NS	NS	NS	NS	NS	NS
Interactions (P > F)											
APP×UAN				0.819	0.878	0.960	0.205	0.586	0.764	0.904	0.360
APP×ATS				0.091	0.748	0.910	0.901	0.257	0.727	0.908	0.943
UAN×ATS				0.825	0.535	0.856	0.733	0.635	0.476	0.767	0.686
APP×UAN×ATS				0.231	0.714	0.682	0.271	0.182	0.825	0.832	0.402
<u>Stats for RCB design (all 14 treatments)</u>											
P > F:				0.403	0.671	0.682	0.358	0.701	0.556	0.617	0.378
Average LSD (0.10)				NS	NS	NS	NS	NS	NS	NS	NS

* One gal/ac rate of ATS applied in-furrow with seed and 10-34-0.

Figure 1. The beneficial effects (greater early growth and vigor and a darker green color) of fluid starter fertilizers at Waseca. On the left no starter on the right 4 gal/ac of APP applied in-furrow plus 8 gal/ac of UAN and 4 gal/ac of ATS applied as a surface dribble band 2" to the side of the row (picture taken on June 21, 2010).

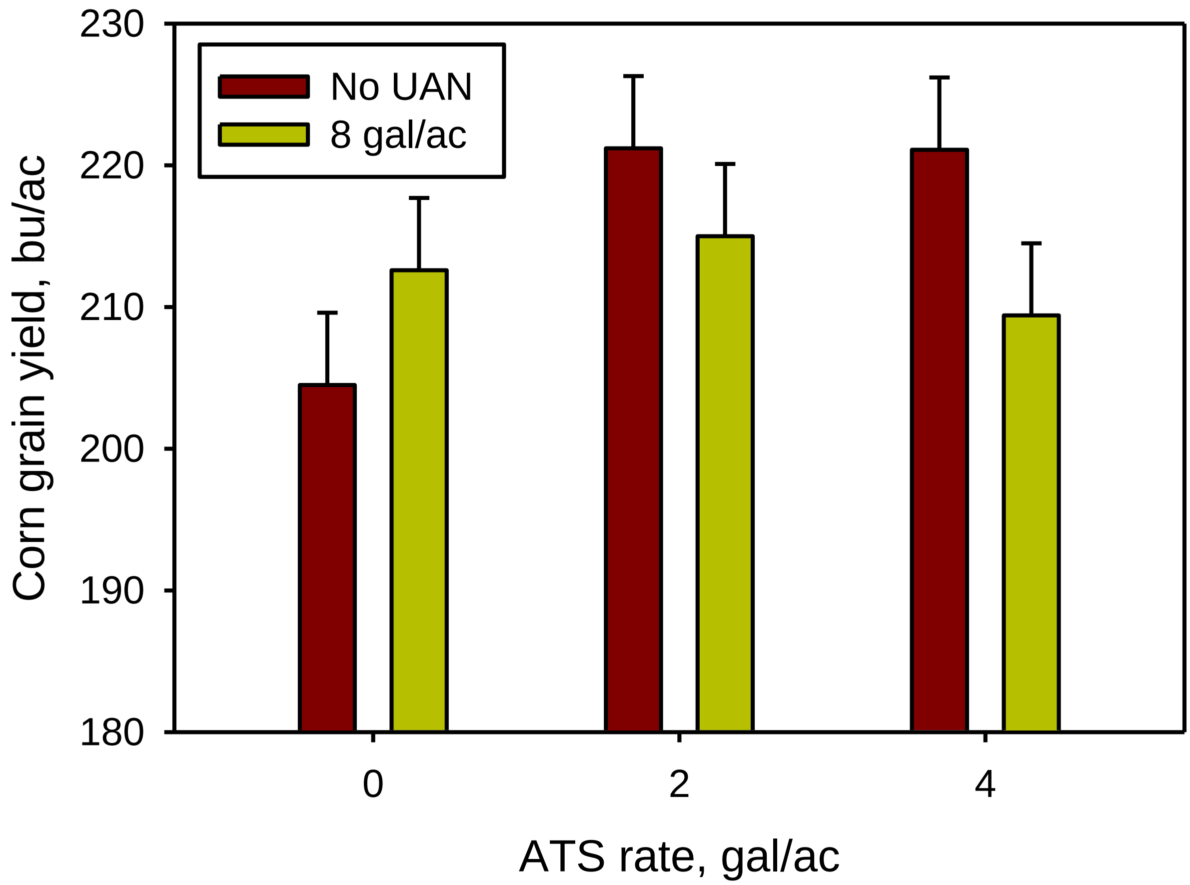

Figure 2. Corn yield as affected by ATS rate with or without 8 gal/ac of UAN applied at planting at Waseca.

INCREASING ROOT MASS AND YIELD IN CORN THROUGH THE USE OF FERTILIZER ADDITIVES

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INTRODUCTION

Two new fertilizer additives recently released by Specialty Fertilizer Products, Inc. (Lenexa, KS) have the potential to increase N and P concentrations in the root zone, reduce leaching of these nutrients, reduce volatilization losses of N, and decrease P fixation in the soil resulting in a better match between the availability of N and P and crop nutrient demand when compared with conventional fertilizers . Avail™ and Nutrisphere™ are both long chain branched polymers with large negative charge (1800 meq 100 g^{-1}). This charge makes the molecule stable at high ionic concentrations allowing it to hold other molecules in suspension. When Avail™ is added to either a liquid or solid phosphate fertilizer and applied to the soil the negative charged polymer interacts with positive cations like Ca^{++} and Mg^{++} preventing them from interacting with and fixing the phosphate molecule. Likewise, when added to a fertilizer like UAN the Nutrisphere™ coating binds to positively charged cations such as nickel with the result that these cations are no longer be available to form urease which is the catalyst for converting N into NO_3-N.

While comparative research on corn done at Kansas State University (Gordon, unpublished data), University of Illinois (Ebelhar, unpublished data) and other institutions (Randall, unpublished data) indicates that Avail™ and/or Nutrisphere™ improved crop yield on a wide variety of soil types other studies have not found improvements in yield or nutrient use efficiency (Mississippi and Arkansas, unpublished data; Cahill et al., 2010) Clearly, more information is needed to determine if either Avail™ or Nutrisphere™ are effective in increasing plant growth, yield and fertilizer use efficiency in highly productive cropping systems.

The objectives of this research are to 1) examine the impact of the fertilize additives Avail™ and Nutrisphere™ on yield in high population corn systems, 2) determine if Avail™ improves root growth in corn, and 3) determine if Nutrisphere™ influences tissue N concentration, plant biomass, or N uptake

MATERIALS AND METHODS

Planting dates and hybrids for each test are shown in Table 1. A common row spacing of 0.76 m and standard seed rate of 81 510 seeds ha^{-1} were used. At all locations and across years the plots consisted of four rows of corn that were 3.08 m wide and 12.3 m long. The center two rows of each four row plot were harvested in September using a Gleaner K2 combine with a Harvestmaster™ system (Juniper Systems, Inc., UT) that recorded plot weight, moisture, and test weight. All data were analyzed using PROC Mixed (SAS Institute, 2002-05) with replicated blocks considered as random factors. Mean separations of interest were done using contrast statements.

Table 1. Soil and crop management information for starter materials research trials conducted from 2007 through 2010.

Location	Soil Series	Planting Date	Hybrid	Seed Rate	Row Width
Pamlico 07	Wasda L. muck	Mar 28, 2007	DKC69-71	35 000	30”
Currituck 07	Pasquo. Silt L.	Apr. 3, 2007	Pioneer 31G98	33 000	30”
Perquimans 07	Roanoke F. Sand	Apr. 22, 2007	Terral TV21BR40	32 700	36”
Guilford 07	Dragston S. Loam	Apr. 20, 2007	Pioneer 31G98	33 000	30”
Davidson 07	Kirksey C Loam	May 1, 2007	Pioneer 31G98	33 000	30”
Pasquotank 08	Bladen S. Loam	Apr. 17, 2008	Pioneer 33M53/57	33 000	30”
Beaufort 08	Cape Fear S. Loam	Apr. 25, 2008	Pioneer 33M53/57	33 000	30”
Davidson 08	Kirksey C. Loam	May 2, 2008	Syngenta NK68-B8	33 000	30”
Forsythe 08	Hiwassie C. Loam	May 2, 2008	DKC61-69	33 000	30”
Guilford 08	Dragston S. Loam	May 3, 2008	DKC61-69	33 000	30”
Bertie 08	Goldsboro Sandy L.	Apr. 15, 2008	DKC61-69	33 000	36”
Pamlico 08	Yonges L. Fine Sand	Apr. 11, 2008	Pioneer 31G96	33 000	30”
Pamlico 09	Yonges L. Fine Sand	Apr. 8, 2009	Pioneer 31P44	33 000	30”
Hyde 09	Ponzer muck	Apr. 9, 2009	Pioneer 33M57	33 000	30”
Beaufort 09	Roanoke F. Sandy L.	Apr. 21, 2009	Pioneer 31P42	33 000	30”
Columbus 10	Norfolk L. Sand	Apr. 8, 2010	DeKalb DKC69-40	33 000	30”
Robeson 10	Goldsboro Sandy L.	Apr. 8, 2010	DeKalb DKC69-40	33 000	30”

Avail™ Research:

Plant and yield responses to Avail™ were tested at eight locations in North Carolina across three years: Pamlico07, Currituck07, Davidson07, Perquimens07, Guilford07, Beaufort08, Pasquotank08, and Hyde09 (Table 1). At all of these sites a split plot experimental design was used with main treatments consisting of a no-starter check, a blended liquid fertilizer (depending on the site either 10-27-0, 17-17-0, or 12-12-4), and the same liquid fertilizer with Avail™ added at 0.005 L L^{-1}. Subplots consisted of different rates of application applied in a 2 X 2 band. At Pamlico07, Currituck07, and Guilford07 rates of 46.8, 93.5, 187.0, and 374 L ha^{-1} were applied. At Davidson07 the main treatments were applied at 93.5 and 187.0 L ha^{-1}, while at Perquimans07, Pasquotank08, Beaufort08, and Hyde09 the main plot treatments were applied at only one rate of 187.0 L ha^{-1}. At all locations 30% UAN was applied at layby at rates adjusted within each treatment to provide a total of 202 kg of N ha^{-1}.

Root and stalk measurements were taken at five locations, Pamlico07, Currituck07, Beaufort08, Pasquotank08, and Hyde09 prior to R1. Five consecutive plants from the outside row of each plot were excavated by digging a 30 cm deep trench on each side of the plant and carefully removing the root ball from the soil. At the same time stalk diameter was measured at the internode below the ear leaf. The root ball was then separated from the plant by clipping above the highest brace root. Roots were washed to remove soil and the depth and the width at the widest point was measured. The root ball was then dried and weighed.

Nutrisphere™ or Combined Research:

Plant and yield responses to Nutrisphere™ were tested at eight locations: Pamlico07, Curricutck07, Guilford08, Forsythe08, Pamlico08, Bertie08, Pamlico09 and Beaufor09. At all sites with the exception of Guilford08 and Forsythe08 the experimental design was a split plot with four replications. The two main plot treatments were 30% UAN and 30% UAN with Nutrisphere™ added at the recommended rate of 0.005 L L^{-1}. Subplots consisted of four rates of application that differed slightly across years. In 2007 the N fertilizer materials were applied in a broadcast application shortly following planting. In 2008 the N fertilizer materials were applied at layby and in 2009 N materials were applied both at planting (21 April) and at layby (27 May). From the at planting application of N on all but the highest N rate treatment whole plant tissue samples were collected at growth stages V5 (27 May at Beaufort09 and 21 May at Pamlico09) and whole plant tissue samples, above ground biomass and N uptake were measured at R1 (27 June at Beaufort09 and 26 June at Pamlico09). In addition, stalk samples were collected at harvest by clipping a 15 cm portion of stalk from just above the soil surface. Tissue and stalk samples consisted of five consecutive plants collected from a random sampling of the outside rows of each plot. Samples were chopped and dried and at R1 biomass was measured before they were sent to the North Carolina Department of Agriculture and Consumer Services (NCDA&CS) laboratory in Raleigh, NC where they were analyzed using standard procedures for testing total % Kjehdal N. At each site with the exceptions of Pamlico09 and Beaufort09, starter fertilizer was applied to all the plots at planting in a 2 x 2 band at a rate of 90.4 L ha^{-1}.

At Guilford08, Forsythe08, Columbus10, and Robeson10 the Nutrisphere™ polymer test was combined with a test of starter fertilizer with and without Avail™ using a randomized complete block design with four replications. At Guilford08 and Forsythe08 ten treatments were applied: A) 12-12-4 applied as a starter in a 2 x 2 band with 30% UAN broadcast applied at 143 kg N ha^{-1}, B) 12-12-4 in a 2 x 2 band with 30% UAN broadcast applied at 179 kg N ha^{-1}, C) 12-12-4 in a 2 x 2 band with 30% UAN plus Nutrisphere broadcast applied at 143 kg N ha^{-1}, D) 12-12-4 in a 2 x 2 band with 30% UAN plus Nutrisphere broadcast at 179 kg N ha^{-1}, E) 12-12-4 in a 2 x 2 band with Avail plus 30% UAN broadcast applied at 143 kg N ha^{-1} , F) 12-12-4 in a 2 x 2 band with Avail with 30% UAN broadcast applied at 179 kg N ha^{-1}, G) 12-12-4 with Avail in a 2 x 2 band with 30% UAN plus Nutrisphere broadcast applied at 143 kg N ha^{-1}, H) 12-12-4 with Avail in a 2 x 2 band with 30% UAN plus Nutrisphere broadcast applied at 179 kg N ha^{-1}, I) no starter fertilizer with 30% UAN broadcast applied at 179 kg N ha^{-1}, and J) no fertilizer applied. The starter fertilizer with or without Avail™ was applied a rate of 187 L ha^{-1}. At Columbus10 and Robeson10 five treatments were used: A) 11-37-0 applied as a starter in a 2 x 2 band with 30% UAN broadcast applied at 179 kg N ha^{-1}, B) 11-37-0 in a 2 x 2 band with Avail with 30% UAN broadcast applied at 179 kg N ha^{-1}, C) 11-37-0 in a 2 x 2 band with 30% UAN plus Nutrisphere broadcast at 179 kg N ha^{-1}, D) 11-37-0 with Avail in a 2 x 2 band with 30% UAN plus Nutrisphere broadcast applied at 179 kg N ha^{-1}, E) no starter fertilizer with 30% UAN broadcast applied at 179 kg N ha^{-1}.

RESULTS AND DISCUSSION

IMPACT OF AVAIL™ ON PLANT GROWTH

When the data were combined across locations there were significant location by starter interactions for root ball mass, root ball depth, and stalk diameter. In most cases these significant differences were between one or more of the starter materials and the no-starter treatment (data not shown). Comparisons between the same starter material with and without Avail™ found significant differences in root mass at both locations in 2007 and differences in stalk diameter at Pamlico07, Beaufort08 and Pasquotank08 (Table 2). There were no significant differences in root ball depth or width between the same starter material with and without Avail™. In 2009, no differences were found between the 10-27-0 with or without Avail in any of the plant or root properties measured.

Table 2. Measured root and stalk properties from starter treatments with (Yes) and without (No) Avail. Letters in the same row within each root or stalk property indicate significant differences at p = 0.05.

Location - Year	Root Properties						Stalk Properties	
	Depth (in)		Width (in)		Mass (oz)		Diameter (in)	
	No	Yes	No	Yes	No	Yes	No	Yes
Pamlico – 07	5.3	6.0	5.8	6.1	7.5a	8.7b	0.95a	1.0b
Currituck – 07	3.6	3.7	5.0	5.0	9.0a	11.2b	0.93	0.95
Beaufort – 08	2.6	2.6	4.0	4.3	2.6	2.8	0.74a	0.78b
Pasquotank - 08	3.7	3.8	5.8	5.6	4.7	3.8	0.79a	0.83b
Hyde – 09	6.9	7.1	5.2	5.4	3.1	3.2	0.95	0.95

IMPACT OF AVAIL™ ON YIELD

When the data were combined across locations there were significant location and fertilizer source main effects on yield. In four of eight site years starter fertilizer significantly increased grain yield when compared to the untreated check resulting in a significant yield advantage to the use of starter fertilizer with or without Avail™. Table 3 shows the impact of starter materials with or without Avail™ on corn yield across the eight site-years tested. In six of the eight years the use of Avail™ resulted in numerically higher yield. However, only at Guilford07 was this increase significant. When these results were combined across site years Avail™ significantly increased yield when compared to the use of the blended fertilizer alone.

Table 3. Yield results from eight locations across two years comparing treatments with no starter, starter (10-27-0, 12-12-4, or 17-17-0) without Avail, and the same starter treatment with Avail. Different letters within each row indicate locations or overall average where the use of Avail resulted in a significant yield increase compared to the use of the same starter material without Avail at p=0.05.

			Corn Yield (t ha^{-1})		
Location - Year	Blended Fertilizer	Soil P Level	No Starter	Starter only	Same Starter with Avail
Pamilico 07	10-27-0	Med	11.6a	12.1ab	12.8b
Currituck 07	10-27-0	Med	12.0a	12.6a	12.6a
Davidson07	17-17-0	Med	7.8a	9.1b	8.2ab
Guilford07	12-12-4	Low	9.0a	8.9a	10.4b
Perquimans07	12-12-4	Low	8.2a	9.1ab	10.1b
Pasquotank08	10-27-0	High	10.4a	9.6a	10.1a
Beaufort08	10-27-0	High	8.1a	7.7a	8.0a
Hyde09	10-27-0	High	14.0a	14.2a	14.0a
Average			9.9a	10.5b	11.0c

IMPACT OF NUTRISPHERE™ ON YIELD

Because of differences in N rate and application timing results were combined within years with the exception of the locations Guilford08 and Forsythe08 which were analyzed as a unit due to the fact that they included starter fertilizer treatments with and without Avail™. In both 2007 and 2008 the combined analysis found a location by rate interaction ($p = 0.0022$ and 0.0059 in 2007 and 2008, respectively) and a significant rate effect ($p < 0.0001$ and 0.0055, respectively). In 2008 when N was applied at layby there was a significant source effect ($p = 0.0067$). The addition of Nutrisphere™ resulted in a significant yield increase of 0.74 t ha^{-1} compared with 30% UAN alone (Table 4). While the source by rate interaction was not significant in either 2007 or 2008 contrast statements indicated that there were differences in corn yield between 30% UAN and 30% UAN plus Nutrisphere™ at one or more N rates. In 2009 there were strong location by rate ($p < 0.0001$) and application timing by source ($p = 0.0124$) interactions. When Nutrisphere™ was added to 30% UAN and applied at planting there was a significant yield increase of 0.37 t ha^{-1} and contrast statements found a significant yield increase when Nutrisphere™ was applied with 30% UAN at a rate of 101 kg N ha^{-1} (Table 4). In 2009 no significant yield differences between 30% UAN and 30% UAN plus Nutrisphere™ were found when the applications were made at layby.

When Forsythe08 and Guilford08 were combined statistical analysis found a strong treatment effect ($p = 0.0011$). Contrast statements were used to examine differences between 30% UAN and 30% UAN with Nutrisphere™. There was a significant yield increase ($p = 0.0152$) of 0.93 t ha^{-1} resulting from the use of Nutrisphere™ whenever starter fertilizer (either 12-12-4 or 12-12-4 with Avail™) was applied (Figure 1). However, when Columbus10 and Robeson10 were combined there were no significant yield differences between the use of Avail™ or starter without Avail™ nor the use of Nutrisphere™ and 30% UAN without Nutrisphere™.

Table 4. Corn yield response to different rates of 30% UAN applied with and without Nutrisphere™ at either planting or layby.

		Nitrogen Rate Code†					
Timing/Year	Nitrogen Treatment	0	1	2	3	4	Average
		------------------------------ t ha^{-1} ------------------------------					
Plant 07	30% UAN	8.65	11.02a‡	11.06a	11.88a	12.06a	10.93A§
	UAN + Nutrisphere™	8.65	10.58a	11.86b	12.55a	12.86b	11.30A
	N Rate Averages	8.65a¶	10.80b	11.46c	12.21d	12.46d	
Layby 08	30% UAN	5.54a	6.28a	6.12a	6.89a	7.19a	6.40A
	UAN + Nutrisphere™	6.40a	6.79a	7.22b	8.08b	7.23a	7.14B
	N Rate Averages	5.97a	6.54ab	6.67bd	7.48c	7.21cd	
Plant 09	30% UAN	7.41	11.02a	11.68a	13.24a	13.18a	11.30A
	UAN + Nutrisphere™	7.41	11.71b	12.15a	13.61a	13.50a	11.67B
	N Rate Averages	7.41a	11.37b	11.91c	13.42d	13.34d	
Layby 09	30% UAN	7.11	11.37a	12.51a	13.39a	13.44a	11.09A
	UAN + Nutrisphere™	7.11	11.51a	12.32a	13.62a	13.87a	11.14A
	N Rate Averages	7.11a	11.44b	12.42c	13.50d	13.65d	

†Nitrogen rates for each year were: 2007 0 = 0, 1 = 56, 2 = 91, 3 = 161, and 4= 303 kg N ha^{-1}; 2008 – 0 = 34, 1 = 90, 2 = 202, 3 = 258, and 4 =314 kg N ha^{-1}; 2009 – 0 = 0, 1 = 101, 2 = 146, 3 = 202, and 4 = 258 kg N ha^{-1}.
‡ Different letters within each year and rate code column indicate significant differences at $p < 0.10$.
§ Different letters within each year under the Average column indicate significant differences between 30% UAN and 30% UAN plus Nutrisphere™ at $p < 0.10$.
¶ Different letters within each row showing the N rate averages indicate significant differences at $p < 0.10$.

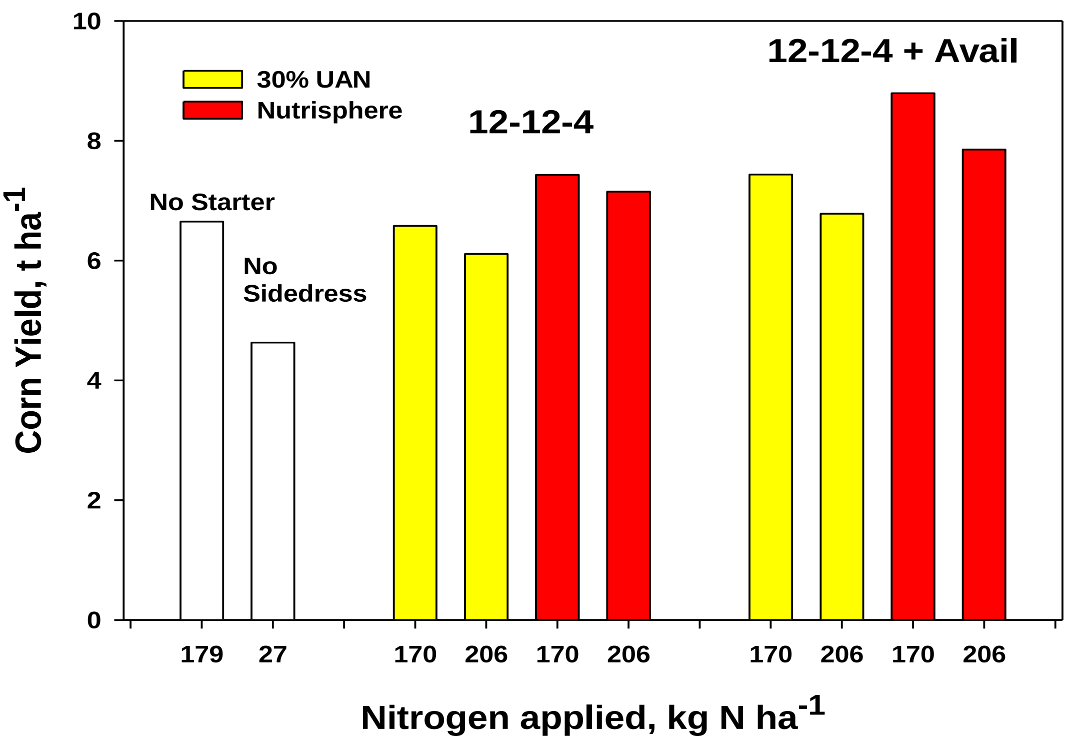

Figure 1. Grain yield measured with various treatments including either no starter, 12-12-4, or 12-12-4 plus Avail™ applied in a 2 x 2 band at planting and a layby application of either 30% UAN or 30% UAN with Nutrisphere™ added. Contrast statements found that when either 12-12-4 or 12-12-4 with Avail™ was used Nutrisphere™ added to 30% UAN significantly increased corn yield compared to the use of 30% UAN alone at p = 0.0152.

Nitrogen Management For Hybrid Bermudagrass Sod Production – Preliminary Report

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Introduction

As nitrogen prices continue to climb sod producers are searching for alternative N sources to the commonly applied granular sources ammonium nitrate (AN), urea (U) and ammonium sulfate (AS). In sod production, the application of N fertilizers is a balancing act between adding sufficient N to push the crop towards timely harvest, and then sustaining regrowth until the next harvest. Unlike a grain crop, which is harvested in a certain time window, with the grain then stored off-site, sod is 'stored' in the field until the market creates a need to harvest. Thus, N fertilizer is often applied for both agronomic and market needs.

Hybrid bermudagrass is a warm season grass that is widely used in the south, west and some areas of the Midwest as a lawn, sports and golf course turf. Because most of the bermudagrass cultivars are interspecific hybrids (*Cynodon dactylon x C. transvaalensis*) they are sterile, and can only be propagated via sprigs or sod. Hybrid bermudagrass represents a significant portion of the southern sod market, and is grown on the greatest number of sod-production acres in the southeast. The only exception is Florida, which has more acres of Saint Augustinegrass. Hybrid bermudagrass is also prized as a sod crop because it grows quickly, and sod can be harvested more frequently than comparable fields of zoysiagrass.

A typical N fertilization schedule for bermudagrass re-establishment is to apply from 4 to 6 lbs N/1,000 sq. ft (175 - 260 lb N/A) during the months when the grass is actively growing. Consultation with local sod producers revealed the following typical N fertilization plan for their 2008 sod crops: 1 lb N/1,000 sq. ft (44 lb N/A) in April and May, with a late May/early June harvest to follow, 1 lb N in June, after harvest, and 1 lb N in August. That is a total of 4 lb N/1,000 sq. feet for the growing year, with a harvest in the following spring, after winter dormancy. Others plan to push the sod with additional summer N, allowing the crop to be harvested in the fall.

Thus, fertilization issues in sod production include both N rate and N source questions, but the question of N timing also needs to be answered. This is especially true in warm-season grass production, as fall dormancy and spring greenup affect harvest time and N fertilization. The objective of this research proposal was to examine various N fertilizer programs (N source, rate and timing) to determine the best program for production and maintenance of hybrid bermudagrass destined for harvest as a sod crop.

Experiment Design:

The experiment consisted of 4 total N rates and 3 N sources, with all N applied at the rate of 1 lb N/1,000 sq. ft per monthly application. Nitrogen rates were 3, 4, 5, or 6 lb N total/1,000 sq. ft per year (130, 175, 218, or 260 lb N/acre/year), with the N applied as either granular ammonium sulfate, fluid urea-ammonium nitrate (UAN) or fluid slow-release urea-trizone. Specifically, the N Sources were: 1) UAN (32-0-0), 2) ammonium sulfate (21-0-0), 3) 29-2-3 (20.88% urea-triazone and 8.12% urea). The selected N rates bracketed those used by most southern sod growers for bemudagrass production. N applied was 4 split applications of 0.75, 1.0, 1.25 or 1.5 lb N 1,000 ft^{-2} $month^{-1}$. For 2009 the fertilizers were applied in June, July, August, Sept, and in 2010 the fertilizers were applied in April, May, June and July.

The study consisted of 48 plots (4 N rates x 3 N sources x 4 replications, plus a zero N control), each measuring 6 x 8 feet. Ammonium sulfate was applied using a Gandy fertilizer spreader, while UAN and urea-trizone were sprayed applied using a backpack CO_2 sprayer as liquids in a total carrier volume of 4 gal 1,000 ft^{-2}.

The experiment was conducted on an existing stand of Tifway hybrid bermudagrass located at the Auburn University Turfgrass Research Unit (TGRU). In both years the turf was first harvested for sod, simulating typical harvesting procedures. The fertilizer treatments and all data collection were then collected from this tilled area, as the sod was allowed to regrow for the next harvest.

Each week the following data was collected from each plot: 1) phytoxicity using a 1-9 relative scale (1 = none, 9 = complete damage), 24 hr after spraying, with repeated ratings until damage was gone, and, 2) percent establishment as determined via a line-transect method (a string with 50 marks was stretched across each plot in 2 places, and the number of times plant tissue hits a mark was counted towards a measurement of percent establishment). Additional data collection included determinations of shoot density and fall soil analysis (0-3 inch sampling depth) for 2M KCl extractable soil nitrate and ammonium.

One-half of each plot area was used for destructive data collection as the plots matured. Three sections of sod (18 x 24 inches) were randomly collected from the destructive half of each plot, cut using the sod cutter. These sections were used to determine sod strength, using a sod strength machine, which determined the tensile strength (measured as a resistance against a measured pull) of harvested sod.

Results

In both years of the study (2009 and 2010) there was never any evidence of phytotoxicity (turf burn) due to the application of any N sources. Additionally, the interaction of N rate and N source was rarely significant for any of the measured variables. Thus, results discussed in this report will focus on the separate main effects of N rate and N source.

N Source

In 2009 sod which had received 29-2-3 (fluid trizone) as the N source had greater sod strength than that which had been fertilized with UAN or ammonium sulfate. Any fertilized sod was stronger than that which was not fertilized. In 2010 there was no difference in sod strength due to N source, and all fertilized sod was stronger than unfertilized (Table 1, below).
Shoot density (2009 data only at this point, 2010 data to be collected this spring) was also unaffected by N source.

N Rate

In both years establishment was maximized at an N rate of between 5.6 and 6.0 lb N/1,000 square feet/year, indicating that the highest N rate of 6 lbs N was often needed to effectively and quickly grow a sod crop. In both 2009 and 2010 sod strength was maximized at an N rate of 4.6 lb N/M/season.

Conclusion – To Date

Use of liquid N sources such as UAN did not negatively affect sod establishment or strength. These sources offer an alternative N source for sod growers, and may be especially useful in fertigation.

Table 1. Sod strength of harvested hybrid bermudgrass sod as measured by tensile pull, 2009 and 2010, Auburn, AL.

N Source	Harvest Month/Year		
	Foot pounds of force at which the sod tears		
	Oct 19 2009	19 April 2010	
Control	25.3 b	41.9 c	
UAN	49.6 a	73.0 b	
29-2-3	65.4 a	87.5 a	
NH4SO4	47.1 a	74.4 b	
	14 July 2010	17 Aug 2010	18 Nov 2010
Control	0 b	17.6 b	29.6 b
UAN	21.7 a	37.5 a	49.5 a
29-2-3	22.9 a	37.8 a	51.9 a
NH4SO4	23.2 a	36.6 a	51.7 a

EFFECT OF SOIL WATER ON PHOSPHORUS USE IN AGRICULTURAL SOILS

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ABSTRACT

An accurate knowledge of phosphorus (P) fertilizer efficiency as affected by season and soil type is an important component of nutrient budgeting. Radioisotopes were used to directly measure fertilizer efficiency at seven agricultural sites in Southern Australia. We compared the effect of below average with above average in-season rainfall on fertilizer efficiency in the year applied and on the use of subsoil vs. topsoil P. The amount of P fertilizer added that was used by the crop plant increased with increasing rainfall but was not directly related to whether the soil was deficient or sufficient in P. The use of subsoil P increased with the addition of P fertilizer, suggesting that the P fertilizer stimulated root growth into the subsoil.

INTRODUCTION

Phosphorus fertilizer efficiency varies across sites and seasons. Soil fertility and seasonal soil moisture conditions both influence this fertilizer efficiency. In larger scale field trials fertilizer efficiency can be measured using indirect methods where a control of no P is compared with plus P treatments, but this measurement is susceptible to interference from other factors (disease, soil type change etc.) and a lack of response does not mean that the fertilizer did not contribute P to the crop (Hardarson 2008). These methods do not provide a direct measure of the contribution of P to plants or grains from background or fertilizer sources.

In this study, we used radioisotopes of P to directly measure fertilizer efficiency at seven sites across the Mallee and Eyre Peninsula cropping regions of Southern Australia. We compared the effect of decile three (lowest 30% rainfall of all seasons) and decile eight (highest 20% rainfall of all seasons) simulated rainfall on single-year fertilizer efficiency by growing plants under rain-out shelters. This technique allows for the determination of total P removal in plants and grains and a fertilizer efficiency value (or amount of fertilizer used in year added) that may be used to calculate subsequent year fertilizer application rates.

Seasonal conditions and P status can influence the relationship between fertilizer P and topsoil and subsoil P uptake by crops (Kuhlmann and Baumgartel 1991).. In this study, we further examined the topsoil and subsoil contribution to plant P uptake and P fertilizer efficiency in response to wet and dry conditions to test the hypothesis that in dry conditions a plant might push more roots into the subsoil and access nutrients from deeper in the profile, due to the inaccessibility of nutrients in the dry topsoil

MATERIALS AND METHODS

There were seven field sites selected for this study. The uptake of P fertilizer from soils was directly measured in wheat (*cv. Axe*) using a radioisotope method, under wet (decile eight) and dry (decile three) in-season conditions. The seven field sites were Karoonda (two soil types), Wanbi, Halidon, Langhorne Creek, Wharminda and Minnipa in the low rainfall cropping zone of South Australia (Figure 1). These soil types ranged from neutral to alkaline pH and P deficient (Langhorne Creek and Wanbi) to sufficient (Karoonda, Halidon, Wharminda and Minnipa) using the diffusive gradient in thin film phosphorus soil test (CDGT-P) values (Table 1).

Figure 1: Distribution of sites in South Australia.

Phosphoric acid fertilizer containing a radioactive tracer was used to directly track the uptake of fertilizer into the wheat plants. The P fertilizer was added at 15 kg P/ha as phosphoric acid. There was a control of no P fertilizer for comparison and all treatments received 20 kg N/ha as urea and 2.5 kg Zn/ha as zinc sulfate at sowing. The Karoonda, Halidon and Wanbi sites received a further 50 kg N/ha at Zadoks 30 (late tillering).

Table 1: Soil properties

Site	Langhorne Creek	Karoonda (Deep Sand)	Karoonda (Sand/ Clay)	Halidon	Wanbi	Minnipa	Wharminda
pH (H_2O) topsoil (0-10 cm)	7.5	6.6	6.5	6.9	8.8	8.6	6.8
pH (H_2O) subsoil (15-50cm)	7.7-rock	7.1-7.1	7.0-9.0	7.6-8.8	8.8-rock	8.8-8.8	8.8-rock
Carbonate (%)	<0.2	<0.2	<0.2	<0.2	6.1	1.6	<0.2
Colwell P* (mg/kg)	52	26	29	54	28	41	35
CDGT-P* (µg/L)	58	206	241	75	30	91	114

*Critical value for Colwell P is 15-20 mg/kg for light textured soils (Peverill *et al.* 1999) while for CDGT-P (diffusive gradient in thin films phosphorus soil test) it is 60 µg/L (Mason *et al.* 2010).

The wheat plants were sown into soil at 50% of field capacity (ideal sowing moisture) to ensure even establishment. The plants were then watered weekly to simulate decile three and decile eight conditions (deciles calculated from 100 year rainfall data) to represent wet sowing-dry growth phase and wet sowing-wet growth phase scenarios. It was quite difficult at times to achieve the decile three growing conditions due to the prevalence of good subsoil moisture reserves in 2010.

Wheat (*cv. Axe*) plants were grown until Zadoks 47 (head in the boot) and harvested by hand. Measurements were made of wheat plant dry weight and total P and P fertilizer content determined using P radioactivity in plant digestions. It is recognised that there is a difference in P use efficiency in different cultivars of wheat and the cultivar Axe was selected in this instance because it has a short growing season. A short growing season variety was required due to the rapid decay of the radioisotope that limited the length of the experiment to three months. It was expected that Axe wheat would be near completion of the P uptake phase of the growth cycle within three months (root uptake of P tends to be limited from flowering onwards (Nayakekorala and Taylor 1990)).

A double spike P radioactive procedure was applied to measure the contribution of fertilizer P, topsoil and subsoil P to plant nutrition at three of the sites (Karoonda deep sand, Halidon and Minnipa). In this experiment the P fertilizer was labelled with one P isotope and then another isotope of P was used to label the topsoil. A treatment was included where a physical barrier was used to prevent roots growing into subsoil, and using this treatment subsoil P uptake was determined by difference (similar to the concept developed by Shierlaw and Alston (1984)). This experiment was performed under decile three and eight simulated rainfall conditions.

RESULTS AND DISCUSSION

Plant Response to Phosphorus Fertilizer

At three of the sites, the addition of P was found to increase the shoot dry weight, while the remaining four sites were not dry weight responsive to fertilizer. The decile eight rainfall conditions increased shoot dry weight compared with decile three at three of the sites. At the remaining sites there was no difference between the simulated low and high rainfall treatments in dry weight. This may have been because the roots were able to access subsoil moisture and so the topsoil watering treatments did not affect shoot growth.

Phosphorus Fertilizer Efficiency

The P fertilizer efficiency was found to be higher in the decile eight treatments in all except two soils. The highest P fertilizer efficiency at decile three and eight was found in P deficient soil. The highest P fertilizer efficiency difference between decile three and eight rainfall was 13% in a sandy but not P deficient soil. Across the seven sites, the P fertilizer efficiency was in the order of 3-30% of P added. At P application rates of 10-20 kg P/ha, which is the normal range of application rates in this region, a fertilizer efficiency of 3-30% equates to 0.3-6 kg P/ha being used in the year the fertilizer is applied. The remaining unused fertilizer may have residual value in subsequent seasons, the quantity being dependent on climatic and soil conditions.

Topsoil and Subsoil Phosphorus Uptake

Although none of the three subsoil experiment sites showed a dry weight response to the addition of P fertilizer, the P fertilizer still made a significant contribution to total plant P uptake varying from 7-10% of total plant P at Minnipa, 17-23% of plant P at Karoonda, up to 43-44% of total plant P at Halidon. The contribution of subsoil P to plant P nutrition was increased by adding P fertilizer to topsoil, especially at Halidon and Karoonda. The very low contribution of the subsoil to crop P uptake at Minnipa may be related to the high subsoil pH (pH 8.8 cv. pH 7.1-7.6 for Karoonda, Table 1), which can both inhibit the availability of P and indicate the presence of other subsoil constraints such as boron and sodicity (which is currently being tested).

CONCLUSIONS

In general the amount of P fertilizer added to soils that was used by the crop plant was greater with above average, compared with below average rainfall (decile three = 3-25%; decile eight= 10-34%). The fertilizer efficiency in soils ranged from 3-30% with a more P deficient soil not necessarily having a higher P fertilizer efficiency. For growers, this means that in a dry season less of the fertiliser P added will be used by the crop in that season. Also, the bulk of P taken up by the plants, even in wet seasons, derives from residual P pools, highlighting the importance of fertility monitoring and maintenance using soil testing to assess the P supply capacity of soils. In addition, subsoils can contribute significant amounts of P to crop nutrition (where P is present in the subsoil) and this is enhanced, not reduced, by addition of fertiliser P ("a priming effect"). In hostile subsoils (e.g. Minnipa), the contribution of subsoil P to crop nutrition is only measurable when there is adequate rainfall (and not in dry conditions as expected).

ACKNOWLEDGEMENTS

Funding for this work was from South Australian Grains Industry Trust and Australian Research Council (LP0882492). Thanks to MAC and the Hunt family for providing land and watering for EP sites and to the Loller, Obst and Schober families for providing land for Mallee sites. Thanks to Bill Davoren, Anthony Whitbread, Rick Llewllyn, Glenn McDonald and Bill Bovill for collaboration in the Mallee. We gratefully acknowledge Colin Rivers and Caroline Johnston for technical support, Sean Mason for DGT analyses and Erik Smolders and Yibing Ma for discussions about the topsoil-subsoil experimental design.

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In-Season Precision Applications of Fluid Fertilizer to Optimize Cotton Productivity and Nitrogen Use Efficiency - 2009

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Abstract

Current nitrogen (N) fertility recommendations maybe need to be modified because of the significant yield increases resultant from new cotton cultivars and improved management practices. On the other hand, however, it is essential to develop innovative approaches that can manage N fertilizer more efficiently to increase grower profitability due to substantially increased N prices. The objectives of this study for 2009 were to determine the optimal N fertilizer application rates for high-yielding cotton production systems in Tennessee and investigate the relationships among lint yield, canopy Normalized Differential Vegetation Index (NDVI), and leaf N. A field strip-plot experiment was conducted on six private farms in Crockett, Fayette, Gibson, Haywood, Lake, and Lauderdale Counties in west Tennessee in 2009. Five N application rate treatments of 0, 40, 80, 120, and 160 lb N/acre were evaluated as side dress N in large field strip plots (38-ft wide running the length of the field) in a randomized complete block design with three replicates. Soil nitrate and ammonium prior to cotton planting and after harvest, leaf N at early bloom, and lint yields and quality at harvest were determined on an individual plot basis for all locations. The location in Gibson County was also used for precision N management research. Each strip plot at this location was divided into eight 100-ft long sub plots. Soil nitrate and ammonium prior to cotton planting and after harvest, canopy NDVI and leaf N at early, mid, and late bloom stages, and lint yields at harvest were measured on a sub plot basis. Results from the large strip-plot experiment show applying 40 to 80 lb/a N via side dressing seems to be adequate to meet plant N requirement during the mid season. Lint yield responses to N applications were statistically significant at Fayette, Gibson, Haywood, Lake, and Lauderdale locations, and were nearly significant at Crockett. Application of about 80 lb/a N (including preplant and side dress N) per season should be adequate for optimal cotton yields at these locations. The precision N experiment at Gibson shows significant correlations of lint yield with canopy NDVI and leaf N at early, mid, and late bloom stages. Canopy NDVI is not a strong indicator of plant N nutrition during early to late bloom. There was no significant global spatial autocorrelation of residual lint yields (N treatment effects on yields excluded) within the test field based on Moran's I statistic. The LISA cluster map shows that there were some significant local clusters of residual lint yields (N treatment effects on yields excluded) within this test field. Specifically, there were six sub plots with high residual yields surrounded by high residual yield neighbors, four high residual yield sub plots were surrounded by low residual yield neighbors, and two sub plots with low residual yields were surrounded by low residual yield neighbors. Overall, there was no significant global but some significant local spatial dependence of lint yields relating to the characteristics of this test field.

Introduction

Presently, nitrogen (N) fertilizers are recommended to be applied at 30-60 lb N/acre on bottom soils and 60-80 lb N/acre on upland soils before or at cotton planting in Tennessee. These recommendations have been used for decades without any major modifications. Because of the significant yield increases resultant from new cotton cultivars and improvements in management practices, there is a need to re-evaluate the current N recommendations to see whether N application rates are adequate for new cultivars to reach their optimal yield potentials.

On the other hand, however, there is an urgent need to develop innovative approaches that can manage N fertilizer more efficiently to increase grower profitability due to substantially increased N prices during the last several years. Overall, there are two major factors limiting N use efficiency in the current cotton N management systems. Firstly, the current N management systems were developed based on a state or regional scale, and they have no capability to cope with spatial variability within individual fields. Under the current systems, cotton producers use a uniform N fertilizer rate for the entire field or even the entire farm, which often results in under- and over-applications of N. Secondly, large doses of N are usually applied early in the season (preplanting or at planting) before cotton plants can effectively uptake and utilize it; this puts the applied N at high risk to environmental losses. In order to solve these two problems, there is a need to develop new N management systems that can generate variable-rate N recommendations for different areas within a field and emphasize the application of N in the mid season.

Measuring crop N nutrition status during the season by optically sensing crop canopy seems to be a viable precision N management tool for variable-rate N applications within the field, emphasizing N application in the mid season, and minimizing the cost of N application. Researchers have utilized on-vehicle, real-time optical sensing of crop canopy to generate Normalized Differential Vegetation Index (NDVI) to assess crop N nutrition status. This approach enables on-the-go diagnoses of crop N deficiency, real-time applying N fertilizer at variable rates, and precisely treating each area sensed without processing data or determining location within a field beforehand. Research on wheat and corn has shown an about 15% increase in N use efficiency and some significant yield increases with this approach. So far, precision N research has been focused on wheat and corn. Little investigation has been documented on cotton.

The objectives of this study were to: 1) determine the optimal N fertilizer application rates for high-yielding cotton production systems in Tennessee; 2) investigate the relationship between lint yield and NDVI, and between NDVI and crop N nutrition status; and 3) if there is a significant relationship among cotton yield, NDVI, and crop N nutrition, then algorithms will be developed for variable-rate N applications within a field, based on the relationship between lint yield and NDVI. The algorithms for variable-rate N applications will be compared with the uniform-rate N application system in terms of N fertilizer use and lint yield. In 2009, our work focused on the Objectives 1 and 2.

Overall, if this project has been carried out successfully, it will provide accurate N fertilizer recommendations for high-yielding cotton production systems. It will also generate appropriate algorithms for in-season variable-rate N applications within a field on cotton. All these can significantly reduce N fertilizer consumption and improve cotton productivity, and thus increase grower profitability.

Materials and Methods

A field strip-plot experiment was conducted on six private farms (only five farms were proposed in the original proposal; we used six locations in case one of those locations may not work out well) in west Tennessee in 2009. The six cooperative farmers were Ryan Gorley (Crockett County), Bill Walker (Fayette County), Jeff Dodd (Gibson County), Bradley Booth (Haywood County), John Lindamood (Lake County), and Eugene Pugh (Lauderdale County). Cotton was the previous crop for all the locations. The producer in Gibson County applied 40 lb/a N across the test field as preplant N in the form of chicken litter before cotton planting. At Haywood, 50 lb/a N was applied to the test field as preplant N. No preplant N was applied at the other locations. A composite soil sample (10 cores) was taken at a depth of 2 ft. from each strip plot using a Concord hydraulic soil probe for estimating nitrate and ammonium in the soil profile from all locations except Fayette (we did not have enough time to sample this location) prior to the initiation of side dress N treatments but after the preplant N application if any. In order to save the time on soil sampling, we also used these soil samples for the analyses of other nutrients/properties (such as pH, organic matter, P, K, etc.), although we know a 6 to 8 in. soil sample is usually used for testing these nutrients/properties.

Five N application rate treatments of 0, 40, 80, 120, and 160 lb N/acre were evaluated as side dress N in large field strip plots (38-ft wide strips running the length of the field) at all six locations in a randomized complete block design with three replicates. The dates of cotton planting and N treatment implementation for all locations are presented in Tables 1 and 2. Cotton was planted in 38" rows at all locations. All locations were managed using the recommended best management practices except the N treatments (Tables 1 and 2). A composite leaf sample (10 blades + petioles) was collected from the most newly fully developed leaves at the early bloom stage on a strip plot basis from all locations (Tables 1 and 2); all these leaf samples were analyzed for N concentrations using our own LECO Tru-Spec Analyzer. Cotton was harvested using the farmer's cotton picker in November at each location. A composite seedcotton sample was collected from each strip plot for determining cotton fiber quality attributes. A post-harvest soil sample was collected at a 2-ft depth from Gibson and Haywood Counties. However, post-harvest soil sampling has not been finished at the other locations due to wet weather conditions. Analysis *of variance (ANOVA) for each measurement was conducted with a randomized complete block model using SAS statistical software (SAS Institute, Cary, North Carolina). Treatment means were separated using the protected LSD method. Probability levels less than 0.05 were designated as significant. The N fertilizer rate for achieving maximum lint yields was estimated for each location using a quadratic partial regression model.*

The location in Gibson County was also used for precision N management research. Each strip plot at this location was divided into eight 100-ft long sub plots. A composite soil sample was taken at a depth of 2-ft. for nitrate and ammonium and other nutrients/properties in the soil profile on a sub plot basis prior to treatment initiation. Canopy NDVI data were collected from each sub plot at the early, mid, and late bloom stages using the GreenSeeker® (NTech Industries, Inc., CA) RT 200 Data Collection and Mapping System (Tables 1 and 2). A composite leaf sample (10 blades + petioles) was collected on a sub plot basis for three times exactly at the same dates when NDVI data were taken. All these leaf samples were analyzed for N concentrations using our own LECO Tru-Spec Analyzer. The GPS positions for the field corners were measured on August 12 using a GPS hand held unit. Cotton harvest was completed on a sub plot basis in November for each sub plot by harvesting the central six rows of cotton. A post-harvest soil sample was collected for soil nitrate and ammonium at a 2-ft depth from each sub plot. The pre-plant and post-harvest soil samples were analyzed for relevant soil nutrients/properties.

Correlations of lint yield with canopy NDVI and leaf N concentrations and the coefficient of variation (CV) for each strip plot were estimated using SAS Statistical Software v.9.1. Spatial variations of lint yield, canopy NDVI, leaf N, preplant soil N, and post harvest soil N within the experiment were visualized in GIS maps using ArcView v.9.3. A quadratic regression of lint yield was conducted using the classic and spatial error models in GeoDa 0.9.5-i (Beta) with a weight matrix created using a 2nd order queen's contiguity model that includes all lower contiguity orders. In order to evaluate the spatial dependence of lint yield relating to the characteristics of the test field (not to N treatments), we removed the effects of side dress N treatments on lint yields from the lint yields data using the spatial error model, and we used the residual lint yields (which were obtained in the spatial error model in GeoDa and in which N treatment effects on lint yields have been excluded) to make Moran's I statistic and scatter plot and the Localized Indicators of Spatial Autocorrelation (LISA) cluster map. Moran's I statistics and scatter plot and the LISA cluster map of residual lint yields were created in GeoDa using the 2nd order queen's contiguity model that includes all lower contiguity orders.

<u>Results and Discussion</u>

Large Strip-Plot Experiment

Initial Soil Fertility

The major fertility properties in the top 2 ft. of soil prior to treatment initiation at each location are presented in Table 3. These fields had soil pH ranging from 5.6 to 6.1, and organic matter of

0.8 to 1.3%. Gibson location had the highest available N (NO_3-N + NH_4-N) content of 15.4 ppm in the top 2 ft. of soil, while Crockett site having the lowest available soil N of 7.1 ppm. Estimated N release (ENR) from the soil varied with locations; it was 45.1 lb/a N at Crockett and 31.5 lb/a N at Lauderdale, representing the highest and lowest levels, respectively, out of all locations.

Mid-Season Leaf N Responses to Side Dress N Applications

Significant increases of early-bloom leaf N concentrations, ranging from 17 to 78%, with N applications were observed in 2009 compared with the 0 lb/a N control across all locations except Lauderdale (Table 4). Leaf N differences among the 40, 80, 120, and 160 lb/a treatments were statistically significant at Fayette and Gibson, but insignificant at other locations. Generally, the 2009 results suggest that applying 40 to 80 lb/a N via side dressing is adequate to meet plant N requirement during the mid season. It was out of our expectation that although 40 to 50 lb/a N was applied before planting at Haywood and Gibson locations, the preplant applied N did not seem to affect leaf N responses to side dress N applications relative to those at other locations without receiving any preplant N.

Lint Yield Responses to Side Dress N Applications

Lint yield responses to N applications were statistically significant at Fayette, Gibson, Haywood, Lake, and Lauderdale locations, and were close to significant at Crockett in 2009 (Table 5). The general patterns of lint yield responses to N application rates were similar across all locations. At Fayette, lint yields increased as N application rate went up from 0 to 80 lb/a; however, there was no further significant yield increases with the applications of 120 and 160 lb/a. At Crockett and Gibson, 80 lb/a N or above generally resulted in significantly higher yields over the 0 lb/a control. At Haywood, Lake, and Lauderdale, applying 40 lb/a or above had significant yield increases over 0 lb/a; 40 lb/a produced statistically similar lint yield as 80, 120, and 160 lb/a suggesting that 40 lb/a of side dress N is adequate for cotton production at these three locations. Because 40 and 50 lb/a N were applied before cotton planting at Gibson and Haywood, respectively, our results suggest 80 to 90 lb/a are needed for the maximum yields at these two locations. Overall, the application of about 80 lb/a N (including preplant and side dress N) per season should be adequate for optimal cotton yields at these locations in 2009, which indicates that the current N fertilizer recommendations (60 to 80 lb/a N for upland soils, and 30 to 60 lb/a N for bottom soils) by University of Tennessee may still be appropriate for cotton production with yields below 1400 lb/a in Tennessee.

Precision N Management Experiment

Correlations of Lint Yields with Canopy NDVI and Leaf N

The correlations of lint yield with canopy NDVI were statistically significant at early, mid, and late bloom stages, and became stronger as the season moved forward from early to late bloom (Table 6). The correlations of lint yield with leaf N were significant at early, mid, and late bloom stages, and became weaker as the season moved forward from early and mid bloom to late bloom (Table 6). Although correlations of leaf N with canopy NDVI were significant at early, mid, and late bloom stages, but the determination coefficient (R^2) was low; which suggests that canopy NDVI is not a strong indicator of plant N nutrition during early to late bloom (Table 6).

Spatial Analyses

GIS Maps of lint yields, canopy NDVI, leaf N, preplant soil N, and post-harvest soil N at Gibson are presented in Fig. 1 to 9, respectively. The lint yield map shows that although N application rate had impacts on lint yields, NDVI, and leaf N, spatial variations in lint yield did exist within most strip plots. It seemed lint yield had a better correlation with canopy NDVI at the late bloom stage (August 24) than early and mid bloom stages, which is in agreement with the relevant R^2 values in Table 6. The preplant soil N map shows that the variations of soil available N (NO_3-N + NH_4-N) was high within the test field prior to treatment initiation. The post harvest soil N map indicates that the side dress N treatments implemented early in the season did not show evident impacts on soil available N after cotton harvest, which suggests that residual N from the N treatments was ignorable in the soil after harvest.

In order to examine the spatial dependence of lint yields within the test field at Gibson location, we conducted a quadratic regression of lint yields with side dress N application rates using the classic model in the GeoDa software, and we observed significant spatial dependence of lint yields within the test field (data not presented). Then the spatial error model in GeoDa was used to conduct the quadratic regression of lint yields with side dress N rates; the output was presented in Table 8. It shows that the quadratic relationship of lint yields with side dress N application rates was significant on a sub plot basis.

In order to visualize the spatial dependence of lint yield relating to the characteristics of the test field (not to N treatments), we used the residual lint yields (which were obtained in the spatial error model in GoeDa and in which N treatment effects on lint yields have been excluded) to make Moran's I statistic and scatter plot and LISA cluster map. Moran's I statistic and scatter plot and LISA cluster map are presented in Fig. 10, and 11, respectively.

Moran's I and scatter plot evaluates global spatial autocorrelation. Moran scatter plot provides a visual exploration of global spatial autocorrelation. The four quadrants in the Moran scatter plot provide a classification of four types of spatial autocorrelation: high-high and low-low for positive autocorrelation; low-high and high-low for negative spatial autocorrelation. The value listed at the top of the graph is the Moran's I statistic. Fig. 10 shows that there was no significant ($p= 0.623$) spatial autocorrelation of residual lint yields (N treatment effects on yields excluded) within the test field.

The LISA cluster map estimates local spatial autocorrelation. It contains information on only those locations that have significant spatial autocorrelation. Four types of spatial autocorrelations are colored in four different colors: dark red for high-high, dark blue for low-low, pink for high-low, and light blue for low-high. These four categories correspond to the four quadrants in the Moran scatter plot. The LISA cluster map in Fig. 11 shows that there were some significant local clusters of residual lint yields (N treatment effects on yields excluded) within this test field. Specifically, there were six sub plots with high residual yields surrounded by high residual yield neighbors, four high residual yield sub plots were surrounded by low residual yield neighbors, and two sub plots with low residual yields were surrounded by low residual yield neighbors.

Spatial Variations within Strip Plot

Coefficients of variation (CV) were generally low for canopy NDVI and leaf N within the strip plots at early, mid, and late bloom stages (Table 7). The CV values were greater with preplant soil N, postharvest soil N fertility, and lint yields, particularly with preplant soil N (Table 7). Since all the sub plots within a strip plot received the identical N treatment, the CV value for each strip plot in Table 7 reflects the spatial variations within that strip plot.

Acknowledgments

This project was supported in part by Cotton Incorporated Cooperative Agreement No. 09-497TN, managed by Dr. Bob Nichols. We appreciate the cooperative farmers: Ryan Gorley (Crockett County), Bill Walker (Fayette County), Jeff Dodd (Gibson County), Bradley Booth (Haywood County), John Lindamood (Lake County), and Eugene Pugh (Lauderdale County) for allowing us to conduct tests on their farms. We also appreciate the technical cooperation of the Textile Service Laboratory of Cotton Inc. Technical assistance was provided by Bob Sharp, James Warren, Tracy Bush, Matt Ross, Dereck Eison, and others.

Table 1. Major operations performed for Crockett, Fayette, Haywood, Lake, and Lauderdale locations.

	Crockett	Fayette	Haywood	Lake	Lauderdale
List of operations performed	**Date performed**	**Date performed**	**Date performed**	**Date performed**	**Date performed**
Planting	5/19/09		5/17/09	5/19/09	5/17/09
Collected 2-ft. pre-plant soil samples	6/2/09	N/A	6/19/09	6/3/09	6/18/09
Side address liquid nitrogen treatments	6/19/09		6/25/09	6/22/09	6/23/09
Collected early-bloom leaf samples	7/21/09	7/24/09	7/21/09	7/24/09	7/24/09
Dried and ground all leaf samples					
Harvested all strip plots for yield	11/3/09	11/20/09	11/5/09	10/26/09	11/14/09
Seed cotton samples pulled for lint quality analysis	11/3/09	11/20/09	11/5/09	10/26/09	11/14/09
Collected 2-ft. post-harvest soil samples			11/9/09		
Dried and ground all soil samples					
Shipped soil samples for analysis	12/14/09		12/14/09	12/14/09	12/14/09
Analyzed all leaf samples for % N in our lab.	12/15/09	12/15/09	12/15/09	12/15/09	12/15/09

Table 2. Major operations performed for Gibson Location.

List of operations performed	Date performed
Planting	5/8/09
Collected 2-ft. pre-plant soil samples	6/25/09
Side dress liquid nitrogen treatments	6/25/09
Collected early-bloom leaf samples	7/20/09
Collected mid-bloom leaf samples	8/4/09
Collected late-bloom leaf samples	8/24/09
Recorded canopy NDVI @ early-bloom	7/20/09
Recorded canopy NDVI @ mid-bloom	8/4/09
Recorded canopy NDVI @ late-bloom	8/24/09
Dried and ground all leaf samples	
Harvested center 6 rows of sub-plots for yield	11/6/09
Collected 2-ft. post-harvest soil samples	11/25/09
Dried and ground all soil samples	
Shipped soil samples for analysis	12/14/09
Analyzed all leaf samples for % N in our lab.	1/13/10

Table 3. Basic soil properties for test fields prior to the initiation of this study.

County	TEC (me/100g)	pH (H_2O)	OM (%)	NO_3-N (ppm)	NH_4-N (ppm)	ENR (lb/a)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	S (ppm)	B (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)
Crockett	10.7	5.6	1.3	2.8	4.3	45.1	46.1	120.1	1114.9	109.0	24.4	0.5	187.9	145.5	1.2	1.2
Gibson	14.1	5.9	1.1	8.1	7.3	41.6	16.1	107.3	1483.6	250.5	29.0	0.4	145.5	135.7	1.1	1.7
Haywood	12.4	5.7	1.1	7.9	3.8	41.7	21.5	132.3	1132.9	222.9	38.8	0.5	174.7	138.3	1.2	0.9
Lake	16.5	6.1	1.1	8.0	3.9	41.7	45.0	174.3	2147.0	241.6	13.4	0.5	246.2	45.7	2.3	1.9
Lauderdale	11.8	5.5	0.8	7.0	3.9	31.5	35.7	88.6	1092.9	183.9	16.1	0.7	250.1	103.5	1.8	1.8

Table 4. Responses of early bloom leaf N concentrations to side dress N application rates. *

N rate	Crockett		Fayette		Gibson		Haywood		Lake		Lauderdale	
(lb/a)	Conc. (%)	Increase (%)	Conc. (%)	Increase (%)	Conc. (%)	Increase (%)	Conc. (%)	Increase (%)	Conc. (%)	Increase (%)	Conc. (%)	Increase (%)
0	2.24b		2.07c		2.78d		3.05b		3.5b		3.58	
40	3.34a	49.1	3.14b	51.7	3.54c	27.3	3.82a	25.2	4.35a	24.3	3.94	10.1
80	3.79a	69.2	3.25ab	57.0	3.56bc	28.1	4.18a	37.0	4.09a	16.9	3.93	9.8
120	3.83a	71.0	3.31ab	59.9	3.76a	35.3	4.1a	34.4	4.45a	27.1	3.86	7.8
160	3.74a	67.0	3.69a	78.3	3.69ab	32.7	4.36a	43.0	4.47a	27.7	3.97	10.9
Sig.	0.0008		0.0003		<0.0001		0.0097		0.0062		0.4753	

* Values in column followed by the same letter are not significantly different at 0.05 probability level.

Table 5. Lint yield responses to side dress N application rates.

N rate	Crockett		Fayette		Gibson		Haywood		Lake		Lauderdale	
(lb/a)	lb/a	%	lb/a	%	lb/a	%	lb/a	%	lb/a	%	lb/a	%
0	951		877.7d		1045b		727b		1108.3c		1092.3c	
40	1152	21.1	993.7c	13.2	1242.7ab	18.9	1029a	41.5	1279.7a	15.5	1203.7ab	10.2
80	1278.7	34.5	1114ab	26.9	1442a	38.0	1069.7a	47.1	1284.3a	15.9	1209.7a	10.7
120	1143.7	20.3	1031bc	17.5	1352.3a	29.4	1158a	59.3	1165.3b	5.1	1152.3b	5.5
160	1222	28.5	1173a	33.6	1433a	37.1	1161.7a	59.8	1275a	15.0	1179.3ab	8.0
Sig.	0.0932		0.0009		0.0322		0.0086		<0.0001		0.0053	

* Values in column followed by the same letter are not significantly different at 0.05 probability level.

Table 6. Correlations among lint yield, canopy NDVI, and leaf N at Gibson.

Dependent variable (Y)	Independent variable (X)	R^2	r	p
Lint yield	NDVI_7-20-09	0.278	0.528	<0.0001
Lint yield	NDVI_8-4-09	0.427	0.653	0.0602
Lint yield	NDVI_8-24-09	0.505	0.711	<0.0001
Lint yield	Leaf N_7-20-09	0.396	0.629	<0.0001
Lint yield	Leaf N_8-4-09	0.367	0.606	<0.0001
Lint yield	Leaf N_8-24-09	0.260	0.509	<0.0001
Leaf N_7-20-09	NDVI_7-20-09	0.192	0.438	0.0039
Leaf N_8-4-09	NDVI_8-4-09	0.355	0.596	0.0047
Leaf N_8-24-09	NDVI_8-24-09	0.114	0.338	0.0011

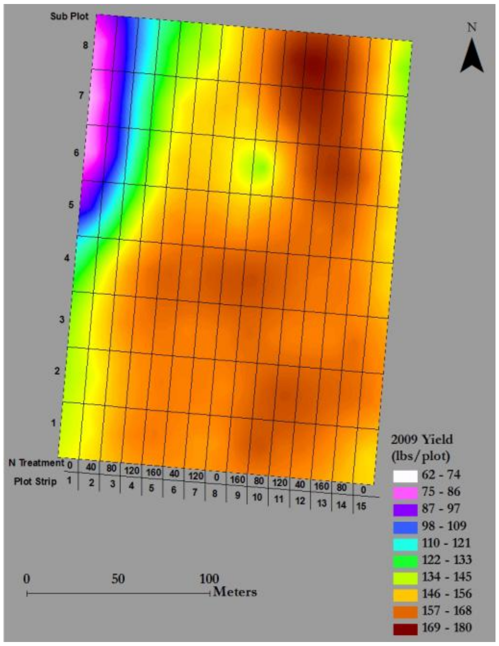
Table 8. Regression summary of output using spatial error model.

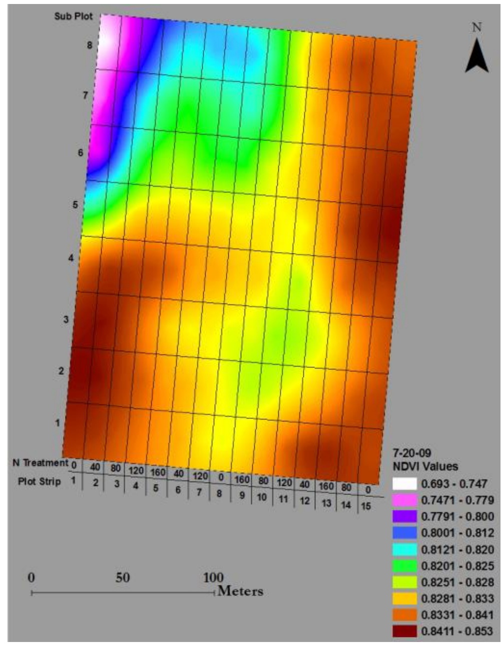
Variable	**Coefficient**	**Std.Error**	**z-value**	**Probability**
CONSTANT	111.945	8.384583	13.35129	0.0000000
N	0.6533547	0.1883389	3.469036	0.0005224
N*N	0.002522847	0.001113112	-2.26648	0.0234219
LAMBDA	0.4996764	0.1757293	2.843444	0.0044630

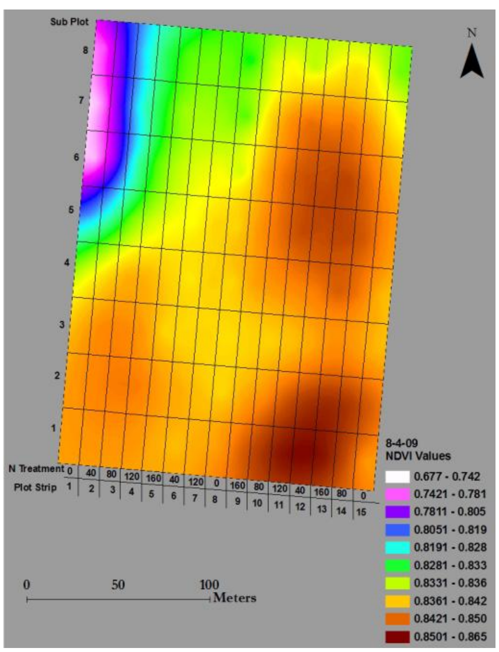
Table 7. Coefficient of variation (%) of preplant soil N, canopy NDVI, leaf N, lint yield, and post-harvest soil N within strip plot at Gibson.

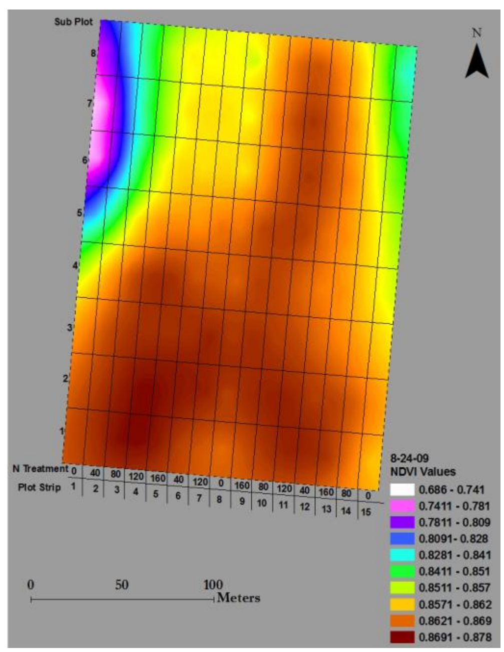
Strip plot	N rate	Preplant soil N	NDVI_7-20-09	NDVI_8-4-09	NDVI_8-24-09	Leaf N_7-20-09	Leaf N_8-4-09	Leaf N_8-24-09	Lint yield	Post harvest soil N
1	0	65.3	7.9	8.1	7.3	14.4	5.3	9.7	29.1	27.1
2	40	28.2	4.0	4.7	3.1	4.2	5.3	9.8	13.0	19.4
3	80	42.5	2.8	1.5	1.8	5.2	16.5	7.3	11.9	10.4
4	120	24.9	1.8	2.1	1.5	0.0	3.4	4.1	3.9	11.7
5	160	24	2.1	1.9	1.1	2.0	1.5	5.5	3.3	13.8
6	40	51.2	3.3	1.7	2.1	3.3	10.4	8.3	7.5	14.2
7	120	21.2	2.2	1.1	1.4	3.6	4.6	5.3	6.9	11.6
8	0	22.3	3.3	4.5	4.6	12.7	6.3	5.8	9.8	11.4
9	160	26.9	2.7	0.9	1.1	4.4	3.5	5.1	23.8	17.4
10	80	29.1	1.8	2.3	1.0	2.8	6.5	5.8	7.0	8.5
11	120	25.8	3.9	5.0	1.6	2.8	4.5	6.7	7.3	17.6
12	40	24	2.2	0.0	1.3	3.2	9.4	4.1	6.9	20.7
13	160	17.5	2.2	1.1	1.3	2.6	2.9	4.4	6.7	11.6
14	80	22.1	0.8	1.2	1.7	5.1	6.5	6.9	5.3	19.5
15	0	30.2	1.1	3.0	3.7	12.2	7.3	10.9	16.4	11.2

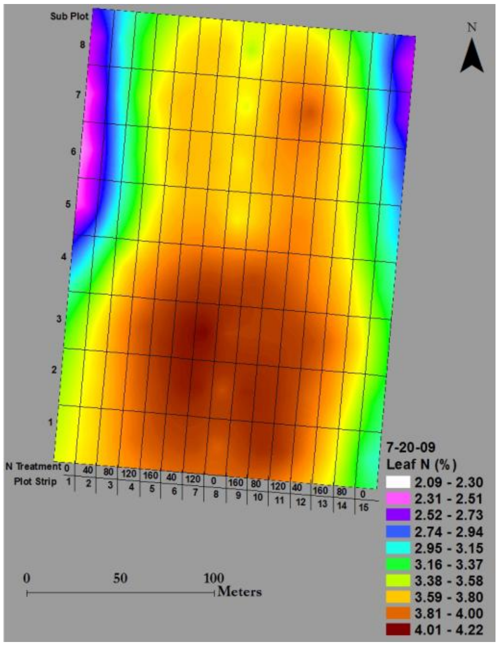
Fig. 1 to 9. Maps of lint yields, canopy NDVI, leaf N, preplant soil N, and post-harvest soil N at Gibson.

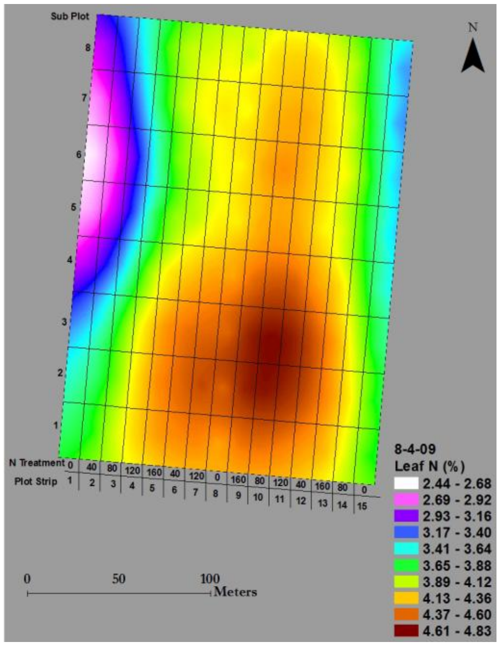


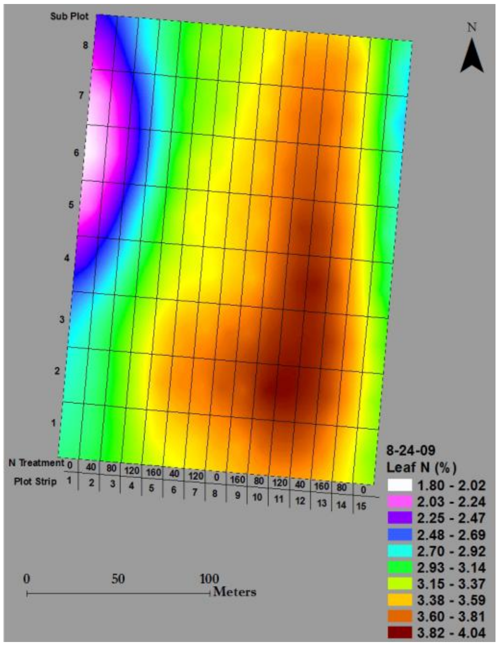


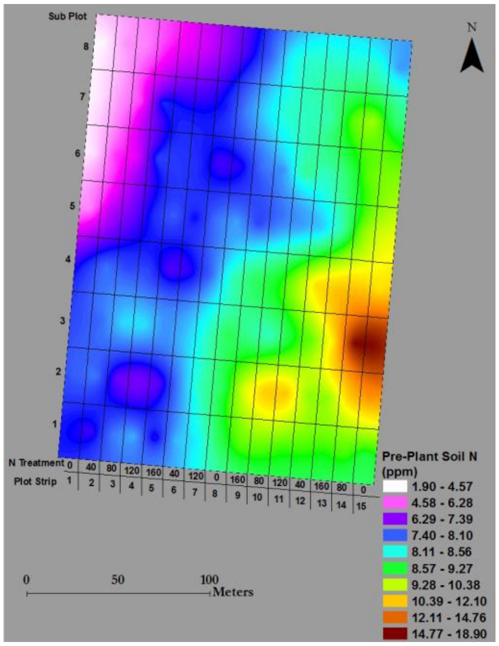





Sub Plot
N
N Treatment 0 40 80 120 160 40 120 0 160 80 120 40 160 80 0
Plot Strip 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0 50 100 Meters
7-20-09
Leaf N (%)
2.09 - 2.30
2.31 - 2.51
2.52 - 2.73
2.74 - 2.94
2.95 - 3.15
3.16 - 3.37
3.38 - 3.58
3.59 - 3.80
3.81 - 4.00
4.01 - 4.22


Sub Plot
N
N Treatment 0 40 80 120 160 40 120 0 160 80 120 40 160 80 0
Plot Strip 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0 50 100 Meters
8-4-09
Leaf N (%)
2.44 - 2.68
2.69 - 2.92
2.93 - 3.16
3.17 - 3.40
3.41 - 3.64
3.65 - 3.88
3.89 - 4.12
4.13 - 4.36
4.37 - 4.60
4.61 - 4.83


Sub Plot
N
N Treatment 0 40 80 120 160 40 120 0 160 80 120 40 160 80 0
Plot Strip 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0 50 100 Meters
8-24-09
Leaf N (%)
1.80 - 2.02
2.03 - 2.24
2.25 - 2.47
2.48 - 2.69
2.70 - 2.92
2.93 - 3.14
3.15 - 3.37
3.38 - 3.59
3.60 - 3.81
3.82 - 4.04



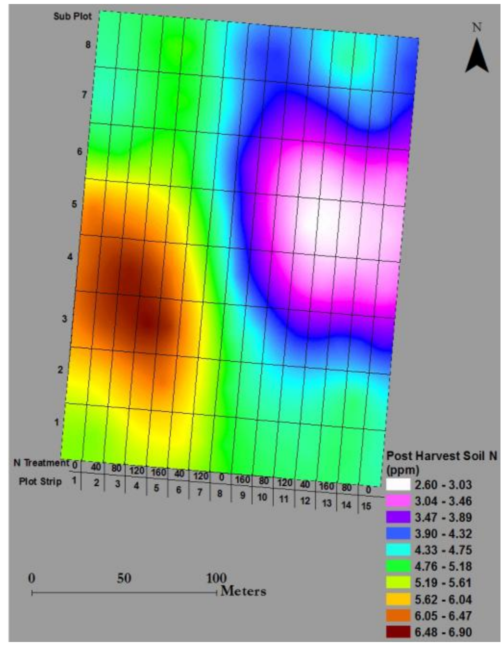


Fig. 10. Moran's I and scatter plot of residual lint yield (N treatment effects on yields excluded) at Gibson.

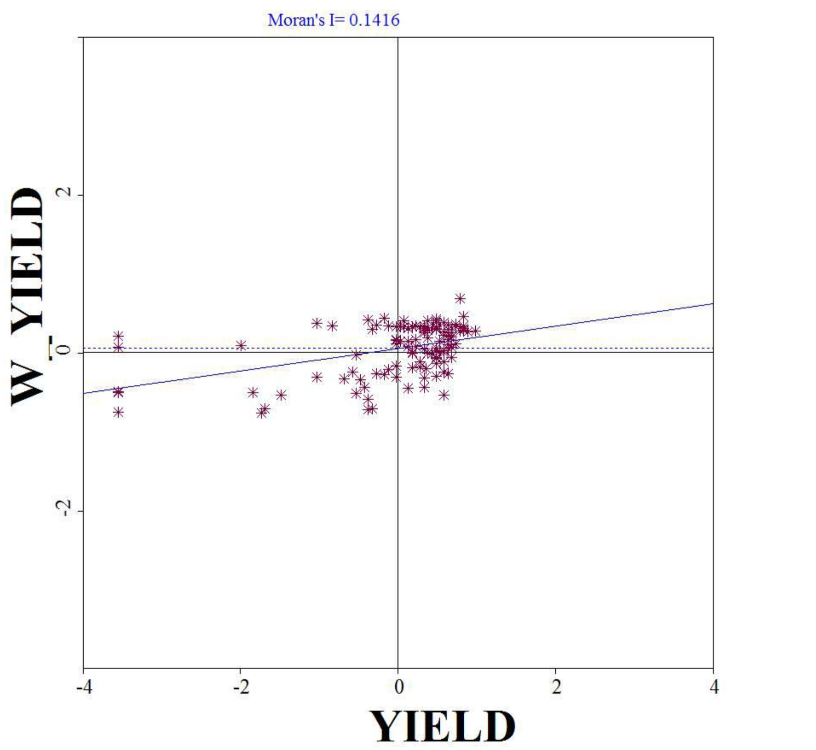
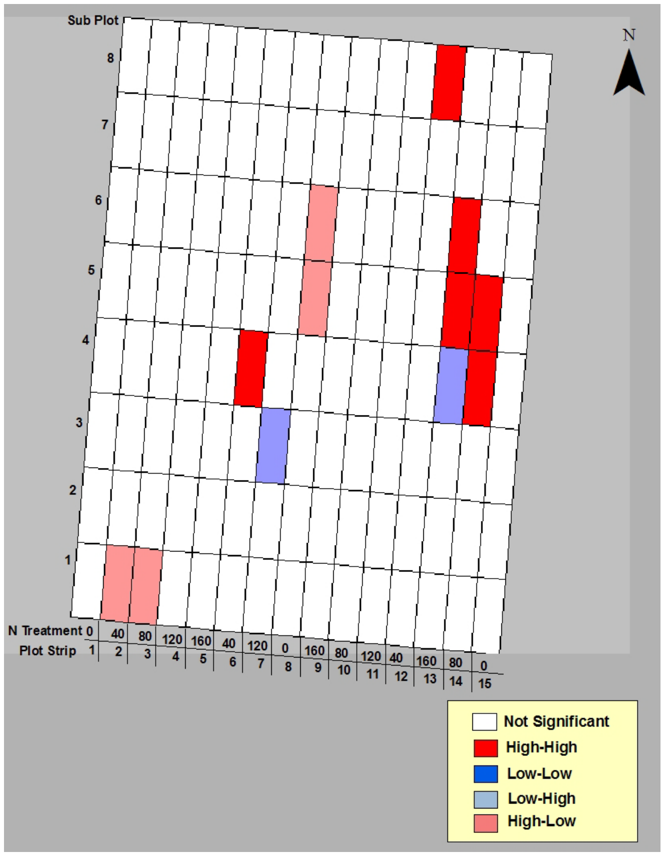


Fig. 11. LISA cluster map of lint yield (N treatment effects on yields excluded) at Gibson.



In-Season Precision Applications of Fluid Fertilizer to Optimize Cotton Productivity and Nitrogen Use Efficiency - 2010

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Abstract

Current nitrogen (N) fertility recommendations should possibly be modified because of the significant yield increases resultant from new cotton cultivars and improved management practices. On the other hand, it is essential to develop innovative approaches that can manage N fertilizer more efficiently to increase grower profitability due to substantially increased N prices. The objectives of this study for 2010 were to determine the optimal N fertilizer application rates for high-yielding cotton production systems in Tennessee and investigate the relationships among lint yield, canopy Normalized Differential Vegetation Index (NDVI), and leaf N. A field strip-plot experiment was conducted on five private farms in Fayette, Gibson, Haywood, Lake, and Lauderdale Counties in west Tennessee in 2010. Five N application rate treatments of 0, 40, 80, 120, and 160 lb N/acre were evaluated as side dress N in large field strip plots (38-ft wide running the length of the field) in a randomized complete block design with three replicates. Soil nitrate and ammonium prior to cotton planting and after harvest, leaf N at early bloom, and lint yields and quality at harvest were determined on an individual plot basis for all locations. The location in Gibson County was also used for precision N management research. Each strip plot at this location was divided into eight 100-ft long sub plots. Soil nitrate and ammonium prior to cotton planting and after harvest, canopy NDVI and leaf N at the early square and early, mid, and late bloom stages, and lint yields at harvest were measured on a sub plot basis. Results from the large strip-plot experiment showed applying 40 to 80 lb/a N via side dressing seemed to be adequate to meet plant N requirement during the mid season. Lint yield responses to N applications were statistically significant at Fayette, Haywood, and Lauderdale locations, and were nearly significant at Lake. Application of about 70 to 100 lb/a N (including pre-plant and side dress N) per season should be adequate for optimal cotton yields at these locations. The precision N experiment at Gibson showed weak correlations of lint yield with canopy NDVI and leaf N in 2010. Canopy NDVI was not a strong indicator of plant N nutrition during early square to late bloom. There was significant global spatial autocorrelation of residual lint yields (N treatment effects on yields excluded) within the test field based on Moran's I statistic. The LISA cluster map showed that there were some significant local clusters of residual lint yields within this test field. Overall, there was significant global and some significant local spatial dependence of lint yields relating to the characteristics of this test field.

Introduction

Presently, nitrogen (N) fertilizers are recommended to be applied at 30-60 lb N/acre on bottom soils and 60-80 lb N/acre on upland soils before or at cotton planting in Tennessee. These recommendations have been used for decades without any major modifications. Because of the significant yield increases resultant from new cotton cultivars and improvements in management practices, there is a need to re-evaluate the current N recommendations to see whether N application rates are adequate for new cultivars to reach their optimal yield potentials.

On the other hand, there is an urgent need to develop innovative approaches that can manage N fertilizer more efficiently to increase grower profitability due to substantially increased N prices during the last several years. Overall, there are two major factors limiting N use efficiency in the current cotton N management systems. Firstly, the current N management systems were developed based on a state or regional scale, and they have no capability to cope with spatial variability within individual fields. Under the current systems, cotton producers use a uniform N fertilizer rate for the entire field or even the entire farm, which often results in under- and over-applications of N. Secondly, large doses of N are usually applied early in the season (pre-planting or at planting) before cotton plants can effectively uptake and utilize it; this puts the applied N at high risk to environmental losses. In order to solve these two problems, there is a need to develop new N management systems that can generate variable-rate N recommendations for different areas within a field and emphasize the application of N in the mid-season.

Measuring crop N nutrition status during the season by optically sensing crop canopy seems to be a viable precision N management tool for variable-rate N applications within the field, emphasizing N application in the mid-season, and minimizing the cost of N application. Researchers have utilized on-vehicle, real-time optical sensing of crop canopy to generate Normalized Differential Vegetation Index (NDVI) to assess crop N nutrition status. This approach enables on-the-go diagnoses of crop N deficiency, real-time applying N fertilizer at variable rates, and precisely treating each area sensed without processing data or determining location within a field beforehand. Research on wheat and corn has shown an about 15% increase in N use efficiency and some significant yield increases with this approach. So far, precision N research has been focused on wheat and corn. Little investigation has been documented on cotton.

The objectives of this study were to: 1) determine the optimal N fertilizer application rates for high-yielding cotton production systems in Tennessee; 2) investigate the relationship between lint yield and NDVI, and between NDVI and crop N nutrition status; and 3) if there is a significant relationship among cotton yield, NDVI, and crop N nutrition, then algorithms will be developed for variable-rate N applications within a field, based on the relationship between lint yield and NDVI. The algorithms for variable-rate N applications will be compared with the uniform-rate N application system in terms of N fertilizer use and lint yield. In 2010, our work focused on the Objectives 1 and 2.

Overall, if this project has been carried out successfully, it will provide accurate N fertilizer recommendations for high-yielding cotton production systems. It will also generate appropriate algorithms for in-season variable-rate N applications within a field on cotton. All these can significantly reduce N fertilizer consumption and improve cotton productivity, and thus increase grower profitability.

Materials and Methods

A field strip-plot experiment was conducted on five private farms in western Tennessee in 2010. The five cooperative farmers were Bill Walker (Fayette County), Jeff Dodd (Gibson County), Bradley Booth (Haywood County), John Lindamood (Lake County), and Eugene Pugh (Lauderdale County). The experiment in 2010 was conducted on the same field with the same plot layout as in 2009 at each location. The producer in Gibson County applied 40 lb/a N across the test field as pre-plant N in the form of calcium nitrate (27% N) before cotton planting. Nitrogen fertilizer at 20, 50, 30 lb/a N was applied to the test field as pre-plant N at Fayette, Haywood, and Lauderdale, respectively. A composite soil sample (10 cores) was taken at a depth of 2 ft. from each strip plot using a Concord hydraulic soil probe for estimating nitrate and ammonium in the soil profile from all locations in Fall 2009 or Spring 2010 prior to the pre-plant N application if any and initiation of side dress N treatments .

Five N application rate treatments of 0, 40, 80, 120, and 160 lb N/acre were evaluated as side dress N in large field strip plots (38-ft wide strips running the length of the field) at all five locations in a randomized complete block design with three replicates. The dates of cotton planting and N treatment implementation for all locations are presented in Tables 1 and 2. Cotton was planted in 38" rows at all locations. All locations were managed using the recommended best management practices except the N treatments (Tables 1 and 2). A composite leaf sample (10 blades + petioles) was collected from the most newly fully developed leaves at the early bloom stage on a strip plot basis from all locations (Tables 1 and 2); all of these leaf samples were analyzed for N concentrations using our own LECO Tru-Spec Analyzer. Cotton was harvested using the farmer's cotton picker in September or October at these locations. A composite seedcotton sample was collected from each strip plot for determining cotton fiber quality attributes. One replicate of cotton seed samples (5 samples per location) was collected from each location, and the five locations were treated as five replicates for seed N analyses. A post-harvest soil sample was collected at a 2-ft depth from Fayette, Gibson and Lake Counties. However, post-harvest soil sampling has not been completed at the other locations due to dry weather conditions. Analysis of variance (ANOVA) for each measurement was conducted with a randomized complete block model using SAS statistical software (SAS Institute, Cary, North Carolina). Treatment means were separated using the protected LSD method. Probability levels less than 0.05 were designated as significant. The N fertilizer rate for achieving maximum lint yields was estimated for each location using a quadratic partial regression model.
The location in Gibson County was also used for precision N management research. Each strip plot at this location was divided into eight 100-ft long sub plots. A composite soil sample was taken at a depth of 2-ft. for nitrate and ammonium in the soil profile on a sub plot basis prior to treatment initiation. Canopy NDVI data were collected from each sub plot at the early square and early, mid, and late bloom stages using the GreenSeeker® (NTech Industries, Inc., CA) RT 200 Data Collection and Mapping System (Tables 1 and 2). A composite leaf sample (10 blades + petioles) was collected on a sub plot basis for four times at about the same dates when NDVI

data were taken (Tables 1 and 2). All leaf samples were analyzed for N concentrations using our own LECO Tru-Spec Analyzer. Cotton harvest was completed on a sub plot basis in September for each sub plot by harvesting the central six rows of cotton. A post-harvest soil sample was collected for soil nitrate and ammonium at a 2-ft depth from each sub plot.

Correlations of lint yield with canopy NDVI and leaf N concentrations and the coefficient of variation (CV) for each strip plot were estimated using SAS Statistical Software v.9.1. Spatial variations of lint yield, canopy NDVI, leaf N, and post-harvest soil N within the experiment were visualized in GIS maps using ArcView v.9.3. A quadratic regression of lint yield was conducted using the classic and spatial error models in GeoDa 0.9.5-i (Beta) with a weight matrix created using a 2nd order queen's contiguity model that includes all lower contiguity orders. In order to evaluate the spatial dependence of lint yield relating to the characteristics of the test field (not to N treatments), we removed the effects of side dress N treatments on lint yields from the lint yields data using the spatial error model, and we used the residual lint yields (which were obtained in the spatial error model in GeoDa and in which N treatment effects on lint yields have been excluded) to make Moran's I statistic and scatter plot and the Localized Indicators of Spatial Autocorrelation (LISA) cluster map. Moran's I statistics and scatter plot and the LISA cluster map of residual lint yields were created in GeoDa using the 2nd order queen's contiguity model that includes all lower contiguity orders.

Results and Discussion

Mid-Season Leaf N Responses to Side Dress N Applications

Significant increases of early-bloom leaf N concentrations, ranging from 6 to 73%, with N applications were observed in 2010 compared with the 0 lb/a N control across all locations except Gibson (Table 3). Leaf N differences among the 40, 80, 120, and 160 lb/a treatments were statistically significant at Fayette and Haywood, but insignificant at other locations. Generally, the 2010 results suggest that applying 40 to 80 lb/a N via side dressing is adequate to meet plant N requirement during the mid season. It was out of our expectation that although 20 to 50 lb/a N was applied before planting at Fayette, Haywood, and Lauderdale locations, the pre-plant applied N did not seem to affect leaf N responses to side dress N applications relative to those at Lake without receiving any preplant N.

Lint Yield Responses to Side Dress N Applications

Lint yield responses to N applications were statistically significant at Fayette, Haywood, and Lauderdale locations, and were close to significant at Lake in 2010 (Table 4). The general patterns of lint yield responses to N application rates were similar across those locations. At Fayette, lint yields increased as N application rate went up from 0 to 80 lb/a; however, there was no further yield increases with the application of 120 or 160 lb/a. At Haywood and Lauderdale, applying 40 lb/a or above had significant yield increases over 0 lb/a; 40 lb/a produced statistically similar or even higher lint yield compared with 80, 120, and 160 lb/a, suggesting that 40 lb/a of side dress N is adequate for cotton production at these two locations. Because 50 and 30 lb/a N were applied before cotton planting at Haywood and Lauderdale, respectively, our results suggest 70 to 90 lb/a are needed for the maximum yields at these two locations. Overall, the application of about 70 to

100 lb/a N (including pre-plant and side dress N) per season should be adequate for optimal cotton yields at these locations in 2010, which indicates that the current N fertilizer recommendations (60 to 80 lb/a N for upland soils, and 30 to 60 lb/a N for bottom soils) by University of Tennessee may be a bit too low for cotton production in Tennessee.

Seed N Responses to Side Dress N Applications
Unlike leaf N, seed N responses to side dress N applications were statistically insignificant across the five locations in 2010 (Fig. 1). There were some numerical small increases in seed N concentration as N application rate went up from 0 to 120 lb/a; however, there was no further increase with the application of 160 lb/a.

Post-Harvest Soil N Responses to Side Dress N Applications
So far, post-harvest soil sampling has been completed at Fayette, Gibson and Lake locations, and has not been finished at other locations due to dry soil conditions. Post-harvest N responses to N applications were statistically significant at Lake, but were not significant at Fayette or Gibson (Table 5). At Lake, post-harvest soil N increased as N application rate went up from 0 to 160 lb/a. Applying 160 lb/a had significantly higher soil N content at harvest than application of 0, 40, or 80 lb/a.

Precision N Management Experiment

Correlations of Lint Yields with Canopy NDVI and Leaf N
The correlations of lint yield with canopy NDVI were statistically significant at early, mid, and late bloom stages (Table 6). The correlations of lint yield with leaf N were significant at early square and mid and late bloom stages (Table 6). There was no significant correlation of leaf N with canopy NDVI regardless of growth stage (Table 6). Overall, the determination coefficient (R^2) values were lower for the above correlations in 2010 compared with those in 2009; which suggests that the correlations of lint yields with canopy NDVI and leaf N vary with years.

Spatial Analyses
GIS Maps of lint yields, canopy NDVI, leaf N, and post-harvest soil N at Gibson are presented in Fig. 2 to 11, respectively. The lint yield map shows that spatial variations in lint yield did exist within most strip plots. It seemed lint yield had a better correlation with canopy NDVI at the early bloom stage (July 20) than other growth stages, which is in agreement with the relevant R^2 values in Table 6. The post harvest soil N map indicates that the side dress N treatments implemented early in the season did not show evident impacts on soil available N after cotton harvest, which suggests that residual N from the N treatments was ignorable in the soil after harvest.

In order to examine the spatial dependence of lint yields within the test field at Gibson location, we conducted a quadratic regression of lint yields with side dress N application rates using the classic model in the GeoDa software, and we observed significant spatial dependence of lint yields within the test field (data not presented). Then, the spatial error model in GeoDa was used to conduct the quadratic regression of lint yields with side dress N rates; the output was presented in Table 7. It shows that the quadratic relationship of lint yields with side dress N application rates was significant on a sub plot basis.

In order to visualize the spatial dependence of lint yield relating to the characteristics of the test field (not to N treatments), we used the residual lint yields (which were obtained in the spatial error model in GoeDa and in which N treatment effects on lint yields have been excluded) to make Moran's I statistic and scatter plot and LISA cluster map. Moran's I statistic and scatter plot and LISA cluster map are presented in Fig. 12, and 13, respectively.

Moran's I and scatter plot evaluates global spatial autocorrelation. Moran scatter plot provides a visual exploration of global spatial autocorrelation. The four quadrants in the Moran scatter plot provide a classification of four types of spatial autocorrelation: high-high and low-low for positive autocorrelation; low-high and high-low for negative spatial autocorrelation. The value listed at the top of the graph is the Moran's I statistic. Fig. 12 shows that there was significant ($p = 0.003$) spatial autocorrelation of residual lint yields (N treatment effects on yields excluded) within the tested field.

The LISA cluster map estimates local spatial autocorrelation. It contains information on only those locations that have significant spatial autocorrelation. Four types of spatial autocorrelations are colored in four different colors: dark red for high-high, dark blue for low-low, pink for high-low, and light blue for low-high. These four categories correspond to the four quadrants in the Moran scatter plot. The LISA cluster map in Fig. 13 shows that there were some significant local clusters of residual lint yields (N treatment effects on yields excluded) within this tested field. Specifically, there were six sub plots with high residual yields surrounded by high residual yield neighbors, two low residual yield sub plots were surrounded by low residual yield neighbors, seven sub plots with low residual yields were surrounded by low residual yield neighbors, and two high residual yield sub plots were surrounded by low residual yield neighbors.

Spatial Variations within Strip Plot

Coefficients of variation (CV) were generally low for canopy NDVI and leaf N within the strip plots at the early square and early, mid, and late bloom stages (Table 8). The CV values were greater with lint yields and postharvest soil N fertility (Table 8). Since all the sub plots within a strip plot received the identical N treatment, the CV value for each strip plot in Table 8 reflects the spatial variations within that strip plot. The CV results of 2010 showed the same trends as those of 2009.

Acknowledgments

This project was supported in part by Cotton Incorporated Cooperative Agreement No. 09-497TN, managed by Dr. Bob Nichols. We appreciate the cooperative farmers: Bill Walker (Fayette County), Jeff Dodd (Gibson County), Bradley Booth (Haywood County), John Lindamood (Lake County), and Eugene Pugh (Lauderdale County) for allowing us to conduct tests on their farms. We also appreciate the technical cooperation of the Textile Service Laboratory of Cotton Inc. Technical assistance was provided by Bob Sharp, James Warren, Tracy Bush, Matt Ross, Dereck Eison, Ngowari Jaja, and others.

Table 1. Major operations performed for Crockett, Fayette, Haywood, Lake, and Lauderdale locations.

	Fayette	Haywood	Lake	Lauderdale
List of operations performed	**Date performed**	**Date performed**	**Date performed**	**Date performed**
Planting	5/15/10	5/8/10	4/29/10	5/27/10
Side-dressed liquid nitrogen treatments	6/15/10	6/14/10	6/16/10	6/18/10
Collected early-bloom leaf samples	7/16/10	7/14/10	7/16/10	7/27/10
Dried and ground all leaf samples	8/5/10	8/5/10	8/6/10	8/6/10
Harvested all strip plots for yield	9/29/10	10/8/10	9/17/10	10/19/10
Seed cotton samples pulled for lint quality analysis	9/29/10	10/8/10	9/17/10	10/19/10
Collected 2-ft. post-harvest soil samples	10/14/10		10/13/10	
Dried and ground soil samples	10/19/10		10/19/10	
Shipped soil samples for analysis	10/25/10		10/25/10	
Analyzed all leaf samples for N in lab.	11/3/10	11/3/10	11/3/10	11/3/10

Table 2. Major operations performed for Gibson Location.

List of operations performed	Date performed
Planted	5/5&14/10
Side dressed liquid nitrogen treatments	6/25/10
Collected early-square leaf samples	6/23/10
Recorded canopy NDVI @ early square	6/23/10
Collected early-bloom leaf samples	7/15/10
Recorded canopy NDVI @ early bloom	7/20/10
Collected mid-bloom leaf samples	8/2/10
Recorded canopy NDVI @ mid-bloom	8/3/10
Collected late-bloom leaf samples	8/16/10
Recorded canopy NDVI @ late-bloom	8/16/10
Dried and ground all sub-plot leaf samples	8/23-25-10
Shipped all leaf samples for analysis	9/17/10
Harvested center 6 rows of each 12 row sub-plot for yield	9/30/10
Collected Seed cotton samples for lint quality	9/30/10
Collected 2 ft. post-harvest soil samples	10/6/10
Dried and ground all soil samples	10/15/10
Shipped all soil samples for analysis	10/25/10

Table 3. Responses of early bloom leaf N concentrations to side dress N application rates. *

N rate	Fayette		Gibson		Haywood		Lake		Lauderdale	
(lb/a)	Conc. (%)	Increase (%)	Conc. (%)	Increase (%)	Conc. (%)	Increase (%)	Conc. (%)	Increase (%)	Conc. (%)	Increase (%)
0	2.58c		3.98		2.49c		3.94b		3.96b	
40	3.27b	26.7	4.15	4.3	3.75b	50.6	4.30a	9.1	4.39a	10.9
80	3.82a	48.1	4.05	1.8	3.98ab	59.8	4.44a	12.7	4.20ab	6.1
120	3.76a	45.7	4.14	4.0	4.22a	69.5	4.43a	12.4	4.43a	11.9
160	4.01a	55.4	4.05	1.8	4.30a	72.7	4.50a	14.2	4.34a	9.6
Sig.	<0.0001		0.3297		<0.0001		0.0110		0.0394	

* Values in column followed by the same letter are not significantly different at 0.05 probability level.

Table 4. Lint yield responses to side dress N application rates.

N rate	Fayette		Gibson		Haywood		Lake		Lauderdale	
(lb/a)	lb/a	%	lb/a	%	lb/a	%	lb/a	%	lb/a	%
0	795.6d		807.7		920.6b		1072.6		950.2c	
40	845.0cd	6.2	862.1	6.7	1148.4a	24.7	1075.4	0.3	1101.1a	15.9
80	1022.2a	28.5	890.2	10.2	1250.1a	35.8	1201.5	12.0	1037.9b	9.2
120	915.6bc	15.1	928.0	14.9	1273.6a	38.3	1129.8	5.3	1058.2ab	11.4
160	991.7ab	24.6	932.0	15.4	1263.0a	37.2	1243.9	16.0	1023.2b	7.7
Sig.	0.0016		0.4929		0.0022		0.0682		0.0022	

* Values in column followed by the same letter are not significantly different at 0.05 probability level.

Table 5. Post-harvest soil N (NH_4^+-N + NO_3^--N) responses to side dress N application rates.

N rate	Fayette		Gibson		Lake	
(lb/a)	ppm	%	ppm	%	ppm	%
0	1.70		5.30		5.30b	
40	1.73	1.8	5.93	11.9	5.30b	0.0
80	2.27	33.5	6.67	25.8	8.01b	51.1
120	2.60	52.9	12.07	127.7	9.77ab	84.3
160	2.30	35.3	10.43	96.8	13.23a	149.6
Sig.	0.1621		0.1436		0.0359	

* Values in column followed by the same letter are not significantly different at 0.05 probability level.

Table 6. Correlations among lint yield, canopy NDVI, and leaf N at Gibson.

Dependent variable (Y)	Independent variable (X)	R^2	R	P
Lint yield	NDVI_6-23-10	0.022	0.148	0.1120
Lint yield	NDVI_7-20-10	0.246	0.496	<0.0001
Lint yield	NDVI_8-03-10	0.137	0.370	<0.0001
Lint yield	NDVI_8-16-10	0.162	0.402	<0.0001
Lint yield	Leaf N_6-23-10	0.064	0.253	0.0059
Lint yield	Leaf N_7-15-10	0.000	0.000	0.9841
Lint yield	Leaf N_8-02-10	0.199	0.446	<0.0001
Lint yield	Leaf N_8-16-10	0.037	0.192	0.0391
Leaf N_6-23-10	NDVI_6-23-10	0.015	0.122	0.1844
Leaf N_7-15-10	NDVI_7-20-10	0.012	0.110	0.2280
Leaf N_8-02-10	NDVI_8-03-10	0.012	0.110	0.2356
Leaf N_8-16-10	NDVI_8-16-10	0.017	0.130	0.1538

Table 7. Regression summary of output using spatial error model.

Variable	Coefficient	Std. Error	z-value	Probability
CONSTANT	77.02386	5.173978	.88678	0.0000000
N	0.3346311	0.1363396	2.454393	0.0141123
N*N	-0.001784412	0.0007971619	-2.238456	0.0251913
LAMBDA	0.343574	.1352886	2.539564	0.0110991

Table 8. Coefficient of variation (%) of canopy NDVI, leaf N, lint yield, and post-harvest soil N within strip plot at Gibson.

Strip plot	N rate	NDVI 6-23-10	NDVI 7-20-10	NDVI 8-3-10	NDVI 8-16-10	Leaf N 6-23-10	Leaf N 7-15-10	Leaf N 8-3-10	Leaf N 8-16-10	Yield	Post-harvest soil N
1	0	18.4	7	8.2	9.1	14	7.3	8.2	6.7	31.6	18
2	40	17.7	4.7	5.2	8.6	12.7	4.9	5.2	6	47.2	32.3
3	80	9.5	5.7	7	7.9	8.5	8.4	4.9	2.6	44.4	18
4	120	14.3	4	4.3	7.6	7.9	4.2	4.9	4.9	24.7	54.1
5	160	7.3	4.2	4.3	6.5	9.5	3.6	3.8	4	17.3	10.9
6	40	7.6	3.8	4.3	3.8	8.3	4.3	7	4.4	11.5	11.4
7	120	10	4.7	5.4	6.4	6.6	4.6	3.1	5.5	16.2	45.8
8	0	4.4	3.6	2.1	3.4	11.5	2.9	4.2	5.3	14.4	24
9	160	7.3	2.7	1.3	2.1	5.9	2.3	5.7	2.2	20.8	58.2
10	80	8.7	3.7	3.6	3.6	7.7	3.9	4.8	4.5	17.4	9.9
11	120	6.5	4.4	4.2	4.5	6.9	2.1	4.4	3	15	33.9
12	40	5.2	5.4	4.2	6.2	7.4	2.2	6.3	4.8	23.9	20.1
13	160	6.6	2.2	2	4.1	5.3	5.3	3.8	4.1	18.7	67
14	80	4.7	2.1	1.2	1.4	4.9	4	2.2	3.2	42.7	27.5
15	0	2.2	1.3	1.4	2.7	10.9	4.9	6.3	6.8	10.5	17.3

Fig. 1. Seed N responses to side dress N application rates.

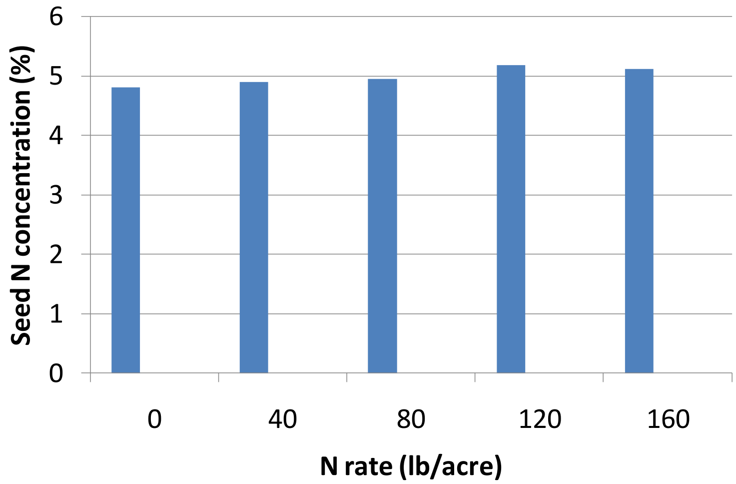
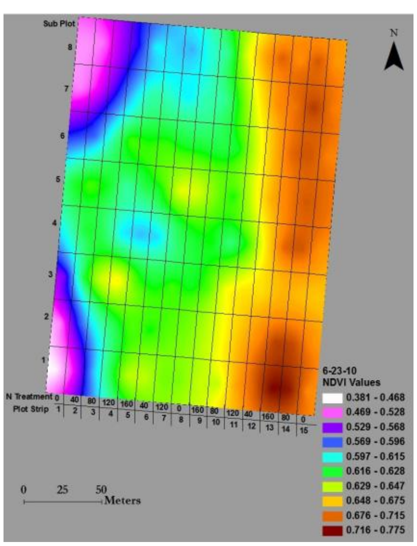
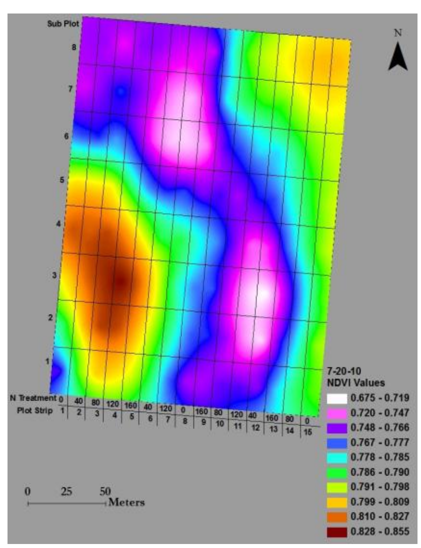
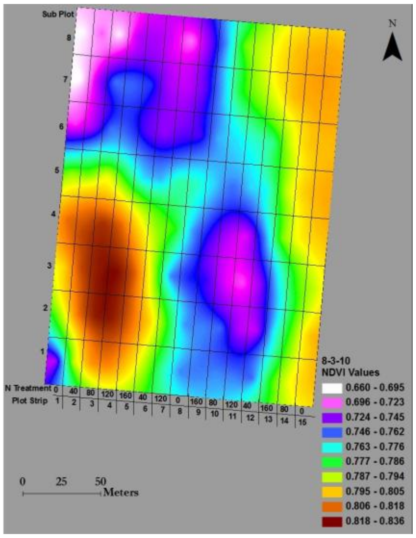


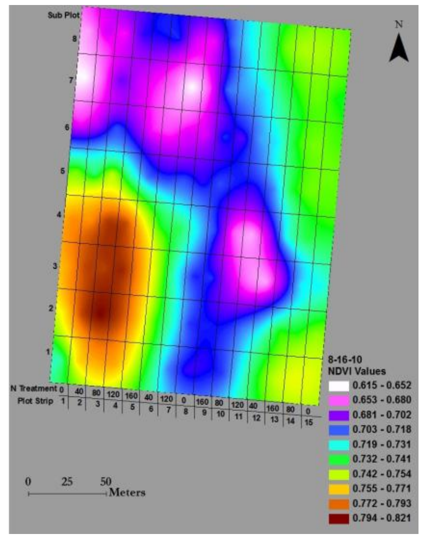
Fig. 2 to 11. ArcView GIS Maps of canopy NDVI, leaf N, lint yields, and post-harvest soil N at Gibson.



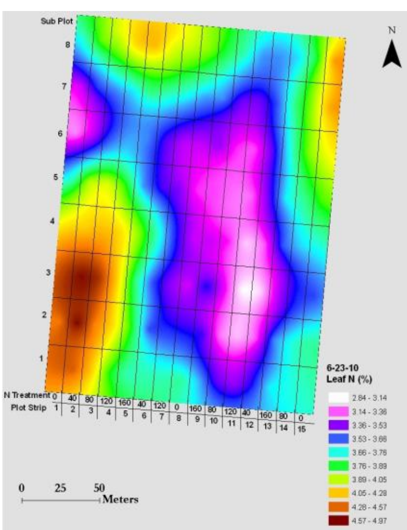




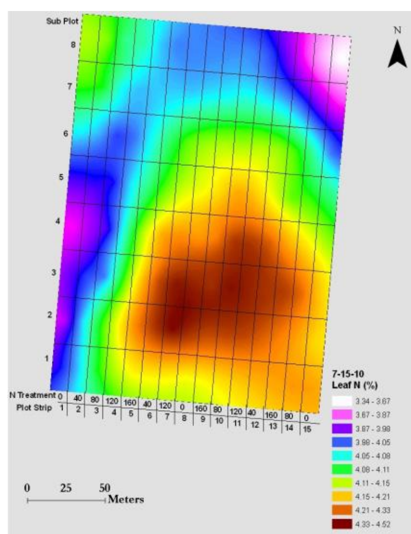
Sub Plot
N Treatment 0 40 80 120 160 40 120 0 160 80 120 40 160 80 0
Plot Strip 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0 25 50 Meters
N
8-3-10
NDVI Values
0.660 - 0.695
0.696 - 0.723
0.724 - 0.745
0.746 - 0.762
0.763 - 0.776
0.777 - 0.786
0.787 - 0.794
0.795 - 0.805
0.806 - 0.818
0.818 - 0.836



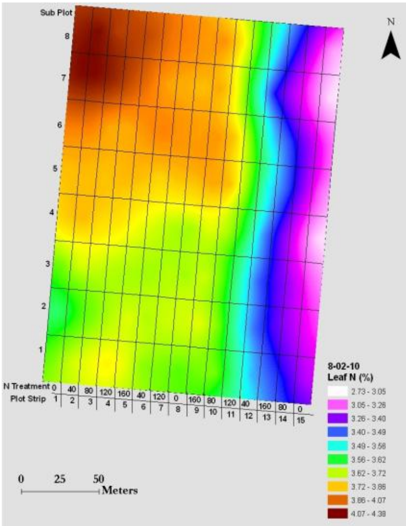
Sub Plot
N Treatment 0 40 80 120 160 40 120 0 160 80 120 40 160 80 0
Plot Strip 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0 25 50 Meters
N
8-16-10
NDVI Values
0.615 - 0.652
0.653 - 0.680
0.681 - 0.702
0.703 - 0.718
0.719 - 0.731
0.732 - 0.741
0.742 - 0.754
0.755 - 0.771
0.772 - 0.793
0.794 - 0.821

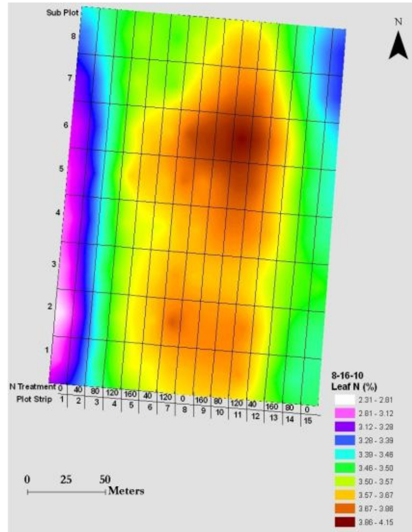


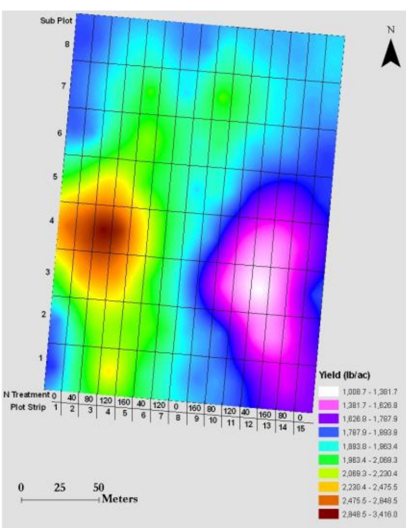
Sub Plot
N Treatment 0 40 80 120 160 40 120 0 160 80 120 40 160 80 0
Plot Strip 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0 25 50 Meters
N
6-23-10
Leaf N (%)
2.84 - 3.14
3.14 - 3.36
3.36 - 3.53
3.53 - 3.66
3.66 - 3.76
3.76 - 3.89
3.89 - 4.05
4.05 - 4.28
4.28 - 4.57
4.57 - 4.97



Sub Plot
N Treatment 0 40 80 120 160 40 120 0 160 80 120 40 160 80 0
Plot Strip 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0 25 50 Meters
N
7-15-10
Leaf N (%)
3.34 - 3.67
3.67 - 3.87
3.87 - 3.98
3.98 - 4.05
4.05 - 4.08
4.08 - 4.11
4.11 - 4.15
4.15 - 4.21
4.21 - 4.33
4.33 - 4.52


Sub Plot
8
7
6
5
4
3
2
1
N
N Treatment 0 40 80 120 160 40 120 0 160 80 120 40 160 80 0
Plot Strip 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
8-02-10
Leaf N (%)
2.73 - 3.05
3.05 - 3.26
3.26 - 3.40
3.40 - 3.49
3.49 - 3.56
3.56 - 3.62
3.62 - 3.72
3.72 - 3.86
3.86 - 4.07
4.07 - 4.38
0 25 50
Meters


Sub Plot
8
7
6
5
4
3
2
1
N
N Treatment 0 40 80 120 160 40 120 0 160 80 120 40 160 80 0
Plot Strip 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
8-16-10
Leaf N (%)
2.31 - 2.81
2.81 - 3.12
3.12 - 3.28
3.28 - 3.39
3.39 - 3.46
3.46 - 3.50
3.50 - 3.57
3.57 - 3.67
3.67 - 3.86
3.86 - 4.15
0 25 50
Meters


Sub Plot
8
7
6
5
4
3
2
1
N
N Treatment 0 40 80 120 160 40 120 0 160 80 120 40 160 80 0
Plot Strip 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Yield (lb/ac)
1,008.7 - 1,381.7
1,381.7 - 1,626.8
1,626.8 - 1,787.9
1,787.9 - 1,893.8
1,893.8 - 1,963.4
1,963.4 - 2,069.3
2,069.3 - 2,230.4
2,230.4 - 2,475.5
2,475.5 - 2,848.5
2,848.5 - 3,416.0
0 25 50
Meters

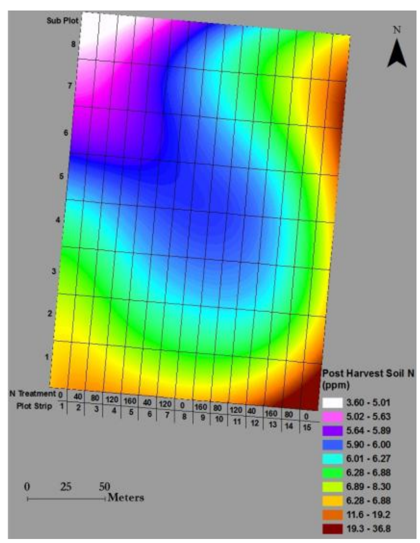

Sub Plot
8
7
6
5
4
3
2
1
N
N Treatment 0 40 80 120 160 40 120 0 160 80 120 40 160 80 0
Plot Strip 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Post Harvest Soil N
(ppm)
3.60 - 5.01
5.02 - 5.63
5.64 - 5.89
5.90 - 6.00
6.01 - 6.27
6.28 - 6.88
6.89 - 8.30
6.28 - 6.88
11.6 - 19.2
19.3 - 36.8
0 25 50
Meters

Fig. 12. Moran's I and scatter plot of residual lint yield (N treatment effects on yields excluded) at Gibson.

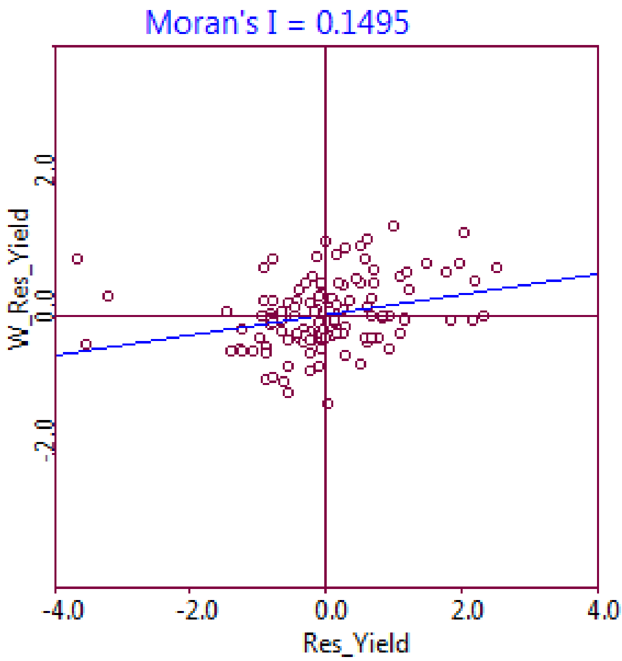
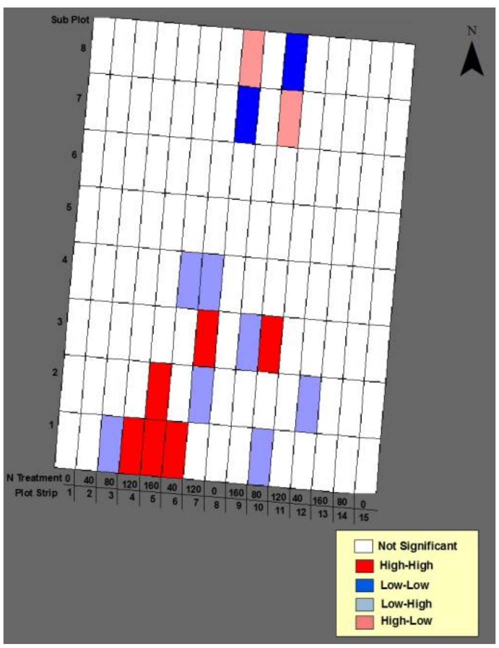


Fig. 13. LISA cluster map of lint yield (N treatment effects on yields excluded) at Gibson.



DOES THE CORN ROOTWORM RESISTANT TRAIT AFFECT NITROGEN USE EFFICIENCY?

Carrie A.M. Laboski2, Todd Andraski[1], and Joe Lauer3

Background

The number of acres planted to corn rootworm (*Diabrotica* spp.) (CRW) resistant corn (*Zea mays* L.) hybrids have increased in recent years. The CRW resistant corn hybrids may have a greater yield potential because of reduced stress from CRW larval feeding resulting in larger root systems. Many agronomists believe higher N rates are needed to achieve the greater yield potential associated with these hybrids. However, larger root systems of CRW resistant hybrids could result in greater N use efficiency and perhaps a reduced N fertilizer need compared to non-CRW resistant hybrids.

Corn yields have increased over time because of improved genetics and management (Duvick, 1984). O'Neill et al. (2004) found that newer corn hybrids exhibited greater grain yield response to applied fertilizer N and greater N fertilizer use efficiency compared to older (1970s) hybrids. Yields under N deficient conditions varied among individual hybrids and these yield differences were not related to hybrid era (older or newer). Their study included only two N rates (0 and 224 lb/a); thus, more detailed analysis regarding variability of the economic optimum N rate between hybrid eras could not be determined. Vanotti and Bundy (1994) reported that optimum N rates for corn were similar at high and low yield levels from a 24-yr corn N rate study conducted from 1967 to 1990 at Lancaster, Wisconsin. They concluded that conditions which promote high corn yields, such as adequate moisture and temperature, improve the efficiency of available N use by the crop and greater amounts of applied N are not needed. Whether the greater yield potential associated newer hybrids have a similar effect on N use efficiency and optimum N rates is unknown.

There is no record in the published literature of research focusing on the N use efficiency and N needs of CRW resistant vs. non-resistant corn hybrids. Research on the integration of corn hybrid traits, including CRW resistance, with various N management systems is in the preliminary stages at the University of Minnesota (Gyles Randall, personal communication). There has been some research conducted on the influence of N fertilizer on CRW larval feeding. Riedell et al. (1996) found that banded-split N applications resulted in a larger root system and greater tolerance to CRW larval feeding damage compared with broadcast-preplant N applications. However, Roth et al. (1995) found that N fertilizer timing (at planting, sidedress, or split) did not affect corn root damage ratings. In other research, leafy and non-leafy corn hybrids, which differ in their leaf canopy and root morphology, were found to respond similarly to N fertilizer (Costa et al., 2002; Subedi et al., 2006). The objective of this study is to determine if corn hybrids with the transgenic corn rootworm resistant gene vary in their N use efficiency and N need compared to non-resistant hybrids.

Materials and Methods

A field research study was conducted in 2008, 2009, and 2010 at the University of Wisconsin Agricultural Research Station at Arlington on a Plano silt loam soil (fine-silty, mixed, superactive, mesic Typic Argiudoll). The study was conducted in a new field each year to avoid previous year treatment

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effects and where corn was planted for several years to increase the probability of moderate to severe corn rootworm pressure. Treatments consisted of eight corn hybrids and six nitrogen rates in a factorial of corn hybrid and N rate in a randomized complete block design with four replications. A description of corn hybrids is shown in Table 1. The corn hybrids included two pairs of hybrid isolines with and without the corn rootworm resistance gene (hybrids 1 and 2; hybrids 3 and 4), two of the overall best non-rootworm resistant hybrids available in Wisconsin (hybrids 5 and 6), and two of the overall best rootworm resistant hybrids available in Wisconsin (hybrids 7 and 8). The goal of using a suite of hybrids is to reflect isoline differences as well as real-world choices that growers make when selecting a hybrid. Unfortunately not all hybrids selected were available in each year of the study. Appropriate hybrid substitutions were made when necessary (Table 1). Nitrogen fertilizer (as NH_4NO_3 in 2008 and UAN-28% in 2009 and 2010) rates ranged from 0 to 200 lb N/acre in 40 lb N/acre increments and was applied early post-emergence broadcast (2008) or band-injected at about a 6-in. depth between rows (2009 and 2010).

Soil test P and K levels were interpreted as either high or excessively high according to Wisconsin nutrient application guidelines (Laboski et al., 2006). Soil pH and organic matter values averaged 7.0 and 3.6%, respectively. The sites were chisel plowed in fall or spring and the seedbed was prepared for planting using a soil finisher in spring. Preplant soil nitrate test (PPNT) samples collected in spring indicated minimal carryover NO_3-N content in the soil profile (0-3 ft) from the previous year. Corn was planted in early May with 30-inch row spacing at 34,000 to 36,000 seeds/acre with 3-gal./a 10-34-0 pop-up starter fertilizer in the furrow (2008) or no starter fertilizer (2009 and 2010) and 4.4 lb/acre of soil insecticide (Force 3G) in a T-band. Conventional herbicides were used to control weeds. Initial plot size was four-rows wide (10 ft.) and 25-ft long in 2008 and 40-ft long in 2009 and 2010. Plot lengths were trimmed to 20-ft in 2008 and 30-ft in 2009 and 2010 and corn plants within each plot were counted and thinned to a uniform stand density (30,350 plants/acre in 2008 and 2009; 34,294 plants/acre in 2010) at the V4 to V5 corn growth stage. Corn rootworm ratings were determined by digging 20 roots of the standard nontransgenic hybrid (#6) planted without soil insecticide. Corn rootworm ratings were conducted in late July. The average rating was 1.12 in 2008, 0.19 in 2009, and 1.50 in 2010 using the 0 to 3 node-injury scale (Oleson et al., 2005). Corn biomass (silage) yield was determined by hand harvesting six plants at physiological maturity. Corn grain yield was determined by harvesting all ears from the middle two rows from each plot using a plot combine in late October or early November. Corn grain yields are reported 15.5% moisture. Grain and silage samples were ground and analyzed for total N content and total N uptake was determined.

For each hybrid in each year, N use efficiency was calculated using the following measures:

Relative yield_{200} = (yield at 0 lb N/a ÷ yield at 200 lb N/a) x 100

Partial factor $\text{productivity}_{160}$ = yield at 160 lb N/a ÷ 160 lb N/a

Agronomic N fertilizer efficiency_{160} = (yield at 160 lb N/a – yield at 0 lb N/a) ÷ 160 lb N/a

Internal N use efficiency_{160} = yield at 160 lb N/a ÷ biomass N uptake at 160 lb N/a

Physiological efficiency_{160} = (yield at 160 lb N/a – yield at 0 lb N/a) ÷ (biomass N uptake at 160 lb N/a – biomass N uptake at 0 lb N/a)

Fertilizer N recovery efficiency_{160} = (biomass N uptake at 160 lb N/a – biomass N uptake at 0 lb N/a) ÷ 160 lb N/a

The 160 lb N/a rate was used in the N use efficiency calculations because that is the experimental N rate closest to the University of Wisconsin recommended N rate of 170 lb N/a. The 200 lb N/a rate was used to calculate relative yield because there were a few hybrids that had a plateau N rate greater than 160 lb N/a. Data were analyzed using PROC MIXED for the appropriate experimental design (SAS Institute, 2002). Significant mean treatment differences were evaluated using Fisher's protected LSD test at the 0.10 probability level. Yield response to N data were fit to quadratic plateau, linear plateau, quadratic and linear models using regression analysis (PROC REG or PROC NLIN). The best fit model based on R^2 value was chosen to represent the response function. The yield at zero N, the plateau N rate (N rate where maximum yield was achieved), and the yield at the plateau N rate were calculated from the response function.

Results and Discussion

The 2008 and 2009 growing seasons with cooler than normal with July 2009 being noteworthy in that the average air temperature was 5.9 degrees below the 30-year average. The 2010 growing season temperatures were slightly warmer than 30-year averages. The 2008 and 2010 growing seasons had above-average precipitation amounts with June and July rainfall at 10.6 (2008) and 9.0 (2010) inches above the long-term average. On the other hand, 2009 was slightly drier than normal in July.

The yield response to applied N for each hybrid in each is shown in Figure 1. The overall yield levels in 2009 were lower than 2008 or 2010 and are likely a result of the cooler growing season in 2009. The yield when no N fertilizer was applied was greatest in 2008, least in 2009, and intermediate in 2010.

There are numerous ways to define N use efficiency (NUE); however only a few are explored in this paper as a means to evaluate the effect of the corn rootworm (CRW) resistance trait on NUE. Relative yield is a measure of how well a hybrid converts mineralized soil N to grain yield. Agronomic N fertilizer recovery efficiency is a measure of how much N fertilizer was converted to grain yield. Internal N use efficiency evaluates the grain yield obtained per pound of N taken up by the crop. There was no significant difference in relative yield, agronomic N fertilizer efficiency, or internal N use efficiency between CRW traited hybrids of an isoline pair compared to non-traited hybrids for any given year (Table 2).

Partial factor productivity is the grain yield obtained per pound of N fertilizer. The non-traited hybrid from the Pioneer isoline pair (hybrid 2) had a partial factor productivity that was significantly greater than the traited hybrid (hybrid 1) in 2009, but was significantly lower in 2010. For all other hybrid pair comparisons in the Pioneer or DeKalb isolines, there was no significant difference. Physiological efficiency is the grain yield increase per increase in total N uptake. The only significant differences in physiological efficiency occurred in 2010; where the CRW traited hybrid had significantly greater physiological efficiency in the Pioneer isoline pair, but had significantly lower physiological efficiency in the DeKalb isoline pair. Fertilizer N recovery efficiency is a measure of how much N fertilizer was recovered in the whole plant. The CRW trait only significantly affected fertilizer N recovery efficiency for the Pioneer isoline pair in 2009 and 2010, where the traited hybrid had significantly greater efficiency in 2009 and significantly lesser efficiency in 2010. When comparing all CRW traited hybrids to all non-traited hybrids, there was no significant difference for any measure of NUE.

For a given hybrid or group of hybrids, there were annual differences between years for the various measures of NUE (Table 2). Overall these data suggest that environment has a greater impact on NUE than the CRW resistance trait.

Using the grain yield response to N fertilizer applied functions, all CRW traited and non-traited hybrids were compared for their effect on yield when no N fertilizer was applied, the N rate where yield plateaued (plateau N rate), and the yield at the plateau N rate (maximum yield) in each year of the study and when all years were combined (Table 4). Overall, CRW traited hybrids yielded significantly more when no N was applied. This suggests that CRW traited hybrids are more effective at using mineralized soil N in a low N environment compared to non-traited hybrids. The plateau N rate was not significantly different for non-CRW hybrids compared to CRW hybrids. There was also no significant trend for CRW-traited hybrids to yield more (greater yield at plateau N rate) than non-traited hybrids.

Summary

There was some variation in yield levels and the plateau N rate between years and between hybrids. Corn rootworm resistant hybrids had greater yield when no fertilizer N was applied, suggesting a greater ability to use mineralized soil N. However, this efficiency in a low N environment did not result in a greater yield level when N was applied or a lower N requirement. There was no significant difference between all CRW traited and untraited hybrids with regard to any measure of N use efficiency. When specific CRW isolines were compared, there was neither a significant difference between traited and untraited hybrids nor a clear trend for traited hybrids to have greater N use efficiency. While in some years there was moderate CRW pressure, the use of insecticide on all hybrids minimized any differences that might have occurred because of choice of CRW management. Popular press articles suggesting a lower N requirement and/or higher yield level for CRW traited hybrids may be basing conclusions on trials where there was poor control of CRW in non-traited hybrids compared to traited hybrids.

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Table 1. Description of corn hybrid used each year of the study. The hybrids include two pairs of hybrid isolines with and without the corn rootworm resistance gene (hybrids 1 and 2; hybrids 3 and 4), two of the overall best non-rootworm resistant hybrids available in Wisconsin (hybrids 5 and 6), and two of the overall best rootworm resistant hybrids available in Wisconsin (hybrids 7 and 8).

Hybrid no.	Hybrid i.d.	Brand	Hybrid	Relative maturity (CRM)	Traits †
1	Bt-CR 1	Pioneer	P35F44	105	HX (CB & CRW); RR2; LL
2	Isoline 1	Pioneer	P35F37	105	RR2
3	Bt-CR 2	DeKalb	DKC52-59	102	YG-VT3 (CB & CRW); RR2
4	Isoline 2	DeKalb	DKC52-62	102	RR2
5	Standard Bt-CB	2008: NK	N58-D1	107	YG (CB)
		2009: NK	N58-D1	107	YG (CB)
		2010: Renk	RK670	103	YG (CB)
6	Standard nontransgenic	2008: Pioneer	35A30	106	None
		2009: Pioneer	35F38	105	None
		2010: Pioneer	35F38	105	None
7	Bt-CR (Mon863) 1	2008: Renk	R698RRYGRW	104	YG (CRW); RR
		2009: DeKalb	DKC55-24 (VT3)	105	YG-VT3 (CB & CRW); RR
		2010: DeKalb	DKC55-24 (VT3)	105	YG-VT3 (CB & CRW); RR
8	Bt-CR (Mon863) 2	Dairyland	Stealth-4006	106	YG (CRW); RR2

† CB, corn borer; CRW, corn rootworm; HX, HerculexXtra; LL, Liberty Link; RR, Roundup Ready; YG, Yield Guard;

Table 2. Effect of corn rootworm (CRW) resistant trait on relative grain yield, partial factor productivity, and agronomic N fertilizer efficiency as determined by hybrid pairs of near isolines (hybrid 1 v 2 and hybrid 3 v 4) and all hybrids with and without the CRW trait.

Hybrid	Relative Yield$_{200}$			Partial Factor Productivity$_{160}$			Agronomic N Fertilizer Efficiency$_{160}$		
	2008	2009	2010	2008	2009	2010	2008	2009	2010
	—— % ——			—— bu/ lb N fertilizer ——			—— Δbu/ lb N fertilizer ——		
1	68a†	54b	49b	1.40a	1.18b	1.49a	0.43b	0.52ab	0.72a
2	72a	56b	44c	1.47a	1.25b	1.44a	0.41b	0.53b	0.78a
P‡	ns	ns	ns	ns	*	*	ns	ns	ns
3	70	60	66	1.54a	1.35b	1.42a	0.45	0.55	0.46
4	74a	53b	60b	1.47a	1.32c	1.43b	0.42b	0.61a	0.57a
P	ns	ns	ns	ns	ns	ns	ns	ns	ns
All CRW	68a	57b	60b	1.45a	1.26b	1.47a	0.44b	0.53a	0.57a
All Non-CRW	67a	53b	54b	1.44a	1.27b	1.43a	0.47b	0.58a	0.62a
P	ns	ns	ns	ns	ns	ns	ns	ns	ns

†Within a row for a given measure of N use efficiency, values with the same lowercase letter are not significantly different (P<0.10) between years.
‡*P*, the significance level (P<0.10) of the column comparison between hybrids is either: ns, not significant; or *, significant.

Table 3. Effect of corn rootworm (CRW) resistant trait on internal N use efficiency, physiological efficiency, and fertilizer N recovery efficiency as determined by hybrid pairs of near isolines (hybrid 1 v 2 and hybrid 3 v 4) and all hybrids with and without the CRW.

Hybrid	Internal N Use Efficiency$_{160}$			Physiological Efficiency$_{160}$			Fertilizer N Recovery Efficiency$_{160}$		
	2008	2009	2010	2008	2009	2010	2008	2009	2010
	—— bu/ lb N uptake ——			—— Δbu/ Δlb N uptake ——			Δlb N uptake/ lb N fertilizer		
1	0.97	1.03	0.94	0.86	0.85	1.09	0.57	0.60	0.67
2	1.00b†	1.10a	0.94c	0.91	0.95	0.89	0.47b	0.54b	0.87a
P‡	ns	ns	ns	ns	ns	*	ns	*	*
3	1.02a	1.05a	0.91b	0.76	0.91	0.68	0.57	0.64	0.66
4	1.01b	1.09a	0.91c	0.66c	1.01a	0.85b	0.66	0.60	0.70
P	ns	ns	ns	ns	ns	*	ns	ns	ns
All CRW	1.01b	1.06a	0.94c	0.81	0.92	0.87	0.58	0.59	0.66
All Non-CRW	1.03b	1.07a	0.92c	0.95	0.95	0.87	0.52b	0.61b	0.74a
P	ns	ns	ns	ns	ns	ns	ns	ns	ns

†Within a row for a given measure of N use efficiency, values with the same lowercase letter are not significantly different (P<0.10) between years.
‡P, the significance level (P<0.10) of the column comparison between hybrids is either: ns, not significant; or *, significant.

Table 4. Effect of corn rootworm (CRW) resistant trait on the yield at zero N, plateau N rate, and yield at the plateau N rate. Comparison of all hybrids with and without the CRW trait were based on yield response functions.

Year	Yield at zero N		Yield at plateau N rate		Plateau N rate	
	CRW	Non-CRW	CRW	Non-CRW	CRW	Non-CRW
	——— bu/a ———		——— bu/a ———		——— lb N/a ———	
2008	161	154	235	228	152	139
2009	115	110	206	206	160	164
2010	145a	130b	240	234	165	154
Average of all years	140a	131b	227	223	159	152

†Within a row for a given measure of the N response function, values with the same lowercase letter are not significantly different (P<0.10) between CRW traited and untraited hybrids.

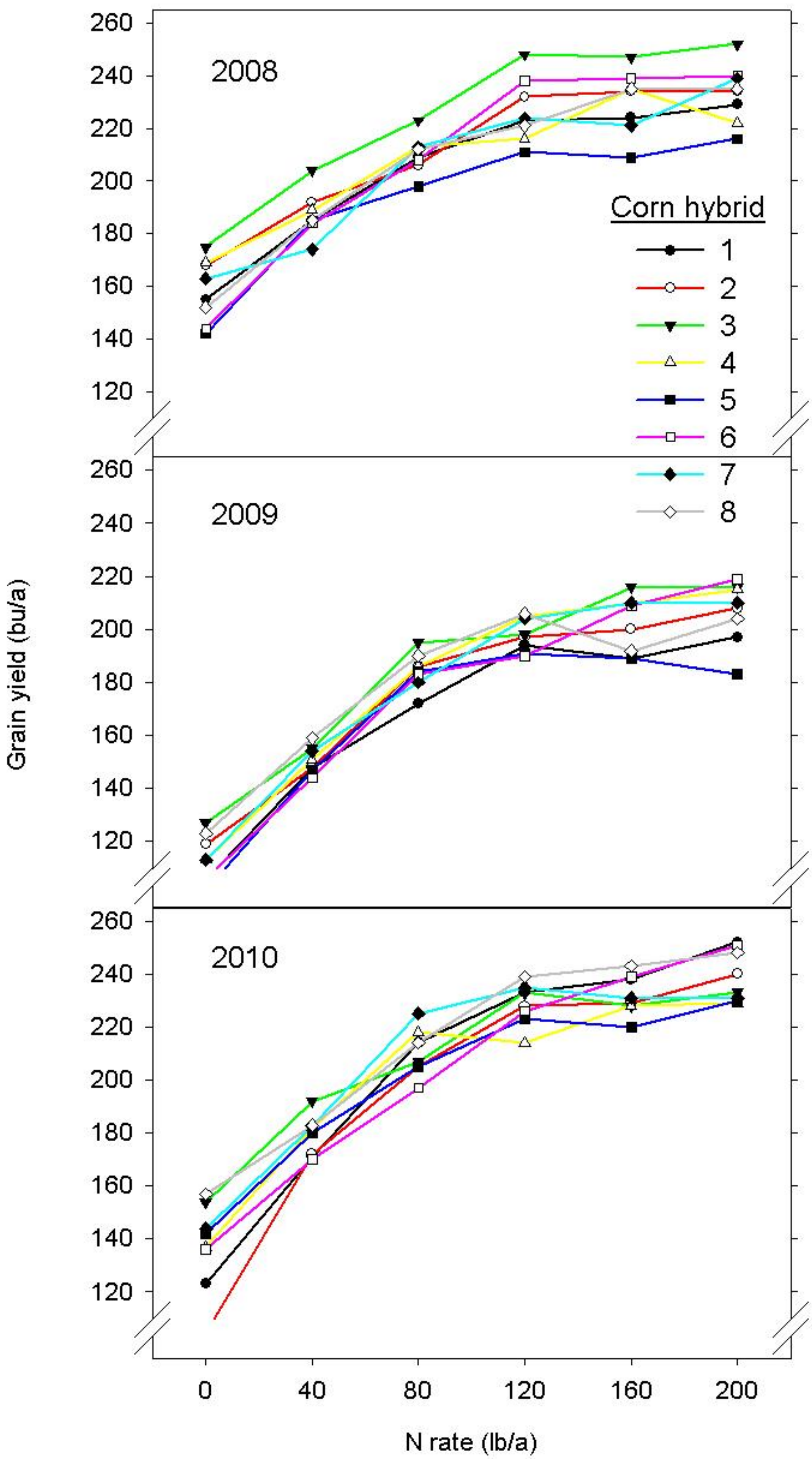

Figure 1. Relationship between N rate and grain yield for eight corn hybrids, 2008 to 2010.

Nutrient Removal by Major Vegetable Crops Grown on Calcareous Soils in s. Texas (2010)

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SUMMARY

Nutrient Removal by Major Vegetable Crops Grown on Calcareous Soils in Texas

The role of fertilizers in improving crop yields under optimum field conditions is well established. However, for certain high-value fruits and vegetable crops (e.g., tomatoes, muskmelons), fertilizer requirements for peak yields can differ from the requirements for optimal quality traits such as taste, texture and shelf-life. Currently, there are no nutrient management guidelines for optimizing produce quality even though certain nutrient elements such as potassium (K) are known to influence quality development. The goal of this 2-yr (2009, 2010) study was to characterize nutrient removal amounts by major vegetable crops grown on calcareous soils in south Texas, in order to develop fertilizer recommendations for quality improvement. Commercial muskmelon (*Cucumis melo* L. Var. *Reticulatus*) fields with contrasting soil types were randomly selected for this study and nutrient removal with harvested fruit was calculated. Fruit yields ranged from 9-16 $t{\cdot}acre^{-1}$ and were generally greater in 2010 than in 2009. In 2009, nutrient removal amounts ranged from 18-37 lbs N/acre, 7-11 lbs P/acre, and 44-90 lbs K/acre, compared to 47-73 lbs N/acre, 9-14 lbs P/acre, and 72-113 lbs K/acre in 2010. Removal amounts were generally higher in fruits from sites with heavy-textured soils compared to fruits from light soils. Fruit soluble solids ranged from 9.8-12% and were generally higher in fruits from heavy soils. Differences in fruit yields between the 2 study years likely reflect prevailing weather conditions during crop development in each growing season. High fruit yields from sites with heavier soils were associated with greater nutrient removals compared to sites with light-textured soils. Differences in fruit quality parameters (soluble solids) were also related to soil type and suggest that supplemental K fertilization would be required, especially on the light soils, to improve fruit quality and perhaps yields.

Keywords: Nutrient removal; fertilization; quality; muskmelon; soil type

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4Published in Proceedings of 2011 Fluid Forum, February 20-22, 2011, Scottsdale, AZ - Fluid Fertilizer Foundation, Manhattan, KS. Based upon work supported in part by the National Institute of Food and Agriculture (NIFA), U.S.D.A. under Agreement No. 2010-34402-17121 "Designing Foods for Health" through the Vegetable & Fruit Improvement Center, Texas A&M Univ., and by the Fluid Fertilizer Foundation/Foundation for Agronomic Research, The International Plant Nutrition Institute, and Tessenderlo Kerley, Inc.

Relatively high levels of fertilizer applications are required to ensure adequate yields and quality of fruits and vegetable crops. During the course of the growing season, crops take up and accumulate various nutrients in biomass, some of which are eventually removed from the site with harvested products. Factors such as crop species, cultivar, yield potential, weather conditions and cultural practices influence the degree of nutrient uptake and removal. Among the essential mineral nutrients, potassium (K) is the element required in the largest amount (after nitrogen) especially in fruit crops (Marschner, 1995). Potassium plays a crucial role not only in boosting yields, but also in improving various quality traits (Usherwood, 1985; Jifon et al., 2009; Lester et al., 2006). Nutrient imbalance, especially inadequate K supply, is often a major factor contributing to the decline in vegetable crop yields and quality even though most soil tests commonly indicate sufficient levels (>150ppm) of soil K (Jifon et al., 2009; Lester et al., 2006). This is often the case in most calcareous soils in Texas and other major vegetable production regions where high levels of soil calcium (Ca) and magnesium (Mg) typically exacerbate the apparent K deficiency problem through competitive nutrient uptake inhibition interactions. Our previous research (Lester et al., 2006) has shown that supplementing soil-derived K with foliar applications can alleviate this apparent K deficiency and enhance quality traits of muskmelons such as sweetness, texture, color, vitamin C and beta-carotene contents (Lester et al., 2006). However, in order to develop foliar K recommendations for improving yield and quality, information regarding crop nutrient removal amounts is essential. Although nutrient removal amounts for many field crops are available, such values for fruit and vegetable crops are rare (Heckman et al., 2003). Furthermore, intensive cultivation, even in the face of improved soil fertility and management practices, tends to deplete soil nutrient pools through crop removal and leaching. In the long-term, a balance between nutrient inputs and crop removal is required. Knowledge of nutrient removal amounts by different crops during a growing season is critical in determining the amounts that must be applied to sustain yields and quality while maintaining soil fertility. The objective of this study was to estimate major nutrient (N, P, K) accumulation/removal amounts in relation to different yield expectations by a fruiting vegetable crop (muskmelons) grown in sites with contrasting soil types (light vs heavy) in S. Texas. During the 2010 growing season we also estimated nutrient removal amounts by a leafy vegetable crop (spinach) and sweet onions. This information is intended to be useful in developing guidelines for nutrient application rates to assure fruit quality and in selecting crop cultivars and species for specific sites based on their nutrient accumulation/removal capacities.

MATERIALS AND METHODS

This trial was conducted during the 2009 and 2010 spring growing seasons (February-May) in commercial fields in the Lower Rio Grande Valley, TX (annual rainfall ~22 inches). Soils are predominantly calcareous (Table 1). Four commercial netted muskmelon (*Cucumis melo* L.) fields differing in soil type were identified and used for fruit sampling. In each year, two of the commercial fields were located in regions (Edinburg and Mission) with predominantly light-textured soils (Brennan fine sandy loam and Delfina fine sandy loam, respectively). The other two sampling sites (Santa Ana and Weslaco) have mostly heavy-textured soil types (Hidalgo sandy clay loam and Harlingen clay, respectively). The fields were direct-planted in early spring (February-March) and managed following standard commercial practices for spring muskmelon production including irrigation, nutrient management, and pest control were followed. Soil samples were collected from each site from the top 30 cm soil layers for residual nutrient analysis prior to planting.

Vegetative tissues (leaves/petioles and stems) were sampled before and after fruit set for chemical analysis. Samples were rinsed with distilled water, dried (70 °C for 48 h), ground in a Wiley mill to pass a 40-µm screen and ashed (500 °C, 5 h), before tissue analysis. During the fruit maturation period, vegetative tissues and matured (full slip), marketable fruits were harvested, weighed and analyzed for mineral contents. Total nitrogen (N) concentration of tissues was analyzed by the Kjeldahl method. Mineral nutrient concentrations (P, K, Ca, Mg,) were analyzed by inductively coupled plasma (ICP) emission spectroscopy, following tissue digestion with nitric acid and hydrogen peroxide. Nutrient removal amounts were estimated from fruit yields, dry matter, and mineral nutrient concentrations.

RESULTS AND DISCUSSION

Tissue mineral concentrations measured at the 12”-vine growth stage were generally within the recommended sufficiency ranges for muskmelons. However, just prior to harvest, the concentrations of major nutrients (N, P, K) were significantly lower than the sufficiency levels as developing fruits became stronger sinks for nutrients and assimilates. In both years, differences were observed in tissue nutrient concentrations among the sampling locations and this was coincident with soil type; tissues sampled from sites with heavy soils tended to have higher nutrient concentrations than those from locations with light textured soils. Average fruit yields ranged from 9-12 $t \cdot acre^{-1}$ and were slightly higher in 2010 compared to 2009 and also at locations with heavy soil types (Santa Ana and Weslaco) than at locations with lighter soil types (Edinburg and Mission). In both 2009 and 2010, yield trends mirrored observations in fruit total soluble solids and mineral nutrient contents (Table 3) especially for fruit potassium concentrations. Fruits from the Santa Ana location had the highest potassium concentrations and this was associated with higher total soluble solids concentrations in fruit (10-12%; Table 3) compared to fruits from the other locations (9-11%). This is consistent with previous greenhouse and field observations on the mineral nutrient factors limiting muskmelon fruit quality (Jifon et al., 2009; Lester et al., 2006). Estimates of nutrient removal amounts ranged from 18-38 lbs/acre for nitrogen, 3-6 lbs/acre for phosphorus, and 35-80 lbs/acre for potassium and also varied significantly among locations (Table 3).

Estimates of macronutrients removed with fruit harvests were generally in 2010 than in 2009. This difference is probably due to poor weather conditions (freeze events) experienced during the 2009 season and the generally low yields in that year. The low removal amounts observed in 2009 could also be due to competitive uptake interactions between calcium, potassium and magnesium (Brady, 1984; Garcia et al., 1999). The 2010 removal estimates were slightly higher than those reported for muskmelons in other regions under ideal growing conditions (IPNI, 2001; Maynard and Hochmuth, 2007). Nutrient removal by sweet onion and spinach also followed a trend determined by soil type and yield level, with greater yields and removal amounts observed on sites with heavy soil textures (Table 4).

Given the very high levels of macronutrient (especially K, Ca, and Mg) reserves in these soils (Table 1), the dramatic decline in tissue macronutrient contents during the late fruit developmental stages suggests that nutrient supply from the soil via root uptake was not enough to prevent these changes. This is plausible if competition for assimilates between roots and maturing fruits limits root activity and water/nutrient uptake. These observations also indicate that cumulative nutrient uptake prior to fruit set was not sufficient to support subsequent fruit development and leaf function during latter developmental stages. Overall fruit yields were within the long-term average values for this region. The close associations between soil texture, fruit mineral nutrient accumulation and TSS highlight the need for a reassessment of fertilizer management practices and sufficiency thresholds aimed at achieving superior fruit quality. Data collected over multiple years under different weather conditions, soil types and yield scenarios will be needed to establish realistic nutrient removal values that can be used to develop fertilizer application guidelines aimed at improving fruit quality.

ACKNOWLEDGEMENTS

This material is based upon work supported in part by the U.S.D.A.-National Institute of Food and Agriculture (NIFA) under Agreement No. 2010-34402-17121- "Designing Foods for Health" through the Vegetable & Fruit Improvement Center, Texas A&M Univ., the Fluid Fertilizer Foundation/Foundation for Agronomic Research, The International Plant Nutrition Institute, and Tessenderlo Kerley, Inc.

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Table 1: Pre-plant soil chemical properties of 0–30 cm soil depth at each study location.

	Soil Texture	Soil Organic Matter (%)	pH	NO_3-N	P	K	Ca	Mg
				(mg·kg^{-1})				
				2009				
Edinburg	light	0.89c	8.2a	33.4c	22.0c	558bc	2805.6b	297.3b
Mission	light	0.97c	8.1a	126.5a	39.0bc	385c	2615.0b	537.8a
Santa Ana	heavy	1.21bc	8.3a	19.5c	46.5b	779a	13807.8a	507.3a
Weslaco	heavy	2.01a	8.3a	78.0b	59.8a	624b	17247.8a	747.3a
				2010				
Edinburg	light	0.96b	7.1b	37.2b	56.1ab	410.6b	2524.3b	307.1b
Mission	light	1.08b	6.9b	19.8c	44.3b	463.1b	2915.3b	601.3a
Santa Ana	heavy	2.03a	8.1a	64.2a	78.6a	801.6a	12602.7a	584.2a
Weslaco	heavy	1.13b	7.9a	45.7ab	86.2a	719.4a	17834.9a	699.2a
Critical limit			6.5	-	50	175	180	50

Means in each column followed by the same letter are not significantly different (P = 0.05). Where no letters follow means, no significant differences were found.

Table 2: Average whole leaf macro- and micronutrient concentrations at early vine development and pre-harvest growth stages of melon (‘Cruiser’) plants at two commercial field sites.

Nutrient	Unit	Edinburg 12" vine	Edinburg Pre-harvest	Weslaco 12" vine	Weslaco Pre-harvest	Sufficiency range
N	(%)	4.2	2.3*	5.1	2.9*	2-5
P	(%)	0.39	0.21*	0.56	0.29*	0.3-0.5
K	(%)	4.3	1.1*	4.9	1.3*	2-5
Ca	(%)	3.5	3.2ns	4.1	3.8ns	2-5
Mg	(%)	0.32	0.49ns	0.42	0.43 ns	0.3-0.5
S	(%)	0.33	0.35ns	0.42	0.48*	0.2-0.5
Fe	ppm	136	152ns	185	179ns	40-100
Mn	ppm	42.8	44.2ns	35.7	66.3*	20-100
Zn	ppm	26.4	28.5 ns	44.6	58.2*	20-60
B	ppm	26.1	27.3 ns	38.7	51.3*	20-80
Cu	ppm	6.8	7.1 ns	7.3	8.4*	5-10

*significant differences in means between early and late development sampling for each site; ns - no significant differences.

Table 3: Average fruits yields, fruit total soluble solids (TSS) and estimates of macronutrients removed with muskmelon fruit harvests at several locations with contrasting soil types.

	Fruit Yield tons/ac	Fruit TSS %	N	P	K	Ca	Mg
					lbs/ac		
					2009		
Edinburg	9.5b	8.9b	18.4c	7.0c	44.1c	24.7b	2.3b
Mission	9.8b	9.6b	21.8bc	8.3bc	52.3bc	27.6b	2.7b
Santa Ana	12.4a	11.2a	37.7a	14.4a	90.5a	40.4a	4.7a
Weslaco	10.2a	11.9a	31.3ab	11.9b	75.0b	38.9a	3.9a
					2010		
Edinburg	10.5a	9.7a	47.0b	9.2b	72.3c	27.1b	2.5b
Mission	11.7a	10.8a	55.8b	10.9b	85.8b	30.6b	2.9b
Santa Ana	12.6a	12.2a	73.5a	14.4a	113.1a	44.4a	5.0a
Weslaco	12.2a	11.1a	72.7a	14.2a	111.8a	42.4a	4.3ab

Means in each column followed by the same letter are not significantly different (P = 0.05). Where no letters follow means, no significant differences were found.

Table 4: Average yields, and macronutrient removal estimates by sweet onions (cv. Sweet Sunrise) and spinach grown on calcareous soils in south Texas.

Crop	Location	Soil texture	Yield tons/ac	N	P	K
					lbs/ac	
Sweet Onion	Weslaco	Heavy	18 a	87 a	26a	109a
	La Feria	Light	15 a	76 a	16b	95ab
Spinach	Weslaco-1	Light	8 a	68 b	9c	88b
	Weslaco-2	Heavy	11 a	72 ab	14b	96a

Means in each column followed by the same letter are not significantly different (P = 0.05). Where no letters follow means, no significant differences were found.

IMPROVING CORN AND SOYBEAN YIELDS WITH STARTER AND FOLIAR FLUID FERTILIZERS

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ABSTRACT

Corn and soybean production under high yield environments can benefit from the combined use of starter and foliar fertilization, including macro and micronutrients. The objective of this study was to evaluate corn and soybean response to starter fluid fertilizers in combination with foliar application of macro and micronutrients to maximize yields. Experiments were conducted in 2010 at two locations for corn and soybean under irrigation. Starter and foliar fertilizer treatments were applied in a factorial arrangement with combinations of N, P, K and micronutrients Fe, Mn, Zn, B, and Cu. Soil samples were collected from each location with samples from each experimental unit. Tissue samples were collected from each plot before foliar fertilizer application and analyzed for the macro and micronutrients included in this study. Plant population, plant height, and grain yield were measured. One location (Clay Center) showed potential yield limitations due to population bellow optimum for both corn and soybean. At both locations, chloride, Fe and Cu showed significant increase in concentration in corn tissue with starter application. Chloride was not part of any treatment but present in the starter fertilizer used for the study. Zinc in corn was also increase significantly in Scandia. Early corn biomass was also increased significantly at both locations with the use of starters. Corn and soybean grain yield was significantly increased with the use of starter N, P, and K, and N,P,K plus micronutrients.

INTRODUCTION

The use of alternative fertilizer application strategies to achieve maximum yields and enhance nutrient use efficiency has been proposed for decades. Often a combination of broadcast and band applications can provide optimum nutrient uptake in low fertility/low soil test conditions. However, under current reduced tillage systems with high yield potential, broadcast nutrients can remain on the soil surface, limiting root contact, or where the soil surface may have been compacted through wheel traffic. When these conditions become more severe, alternative action must be considered.

With the increase in corn and soybean yields due to important genetic improvements, demand for nutrients has also increased. It is likely that the increased utilization of reduced tillage systems and some soil conditions such as high soil pH found in large areas of the Great Plains may decrease the plant-availability of some macro and micronutrients. This may be corrected through some combination of starter and foliar fertilizer application, fertilizer rate adjustment of both macro and micronutrients.

Previous work by Gordon (2008) showed that direct application of P and K to soybeans can have a significant impact on soybean yield, with average increases as high as 34 bu/acre. However, further studies are needed to investigate starter and foliar applications with other nutrients to maximize yields in soybean. On the other hand, in corn, fluid fertilizer placed in a band near the seed at planting has frequently shown positive effects on yield (Rehm and Lamb, 2009). Furthermore, this approach can be especially valuable under conditions of reduced tillage (Kovar and Mallarino, 2001; Haq and Mallarino 2000). In addition, foliar fertilization could in some cases increase nutrient supply at early growth stages when the root system is not well developed. Thus, foliar application of nutrients to corn and soybean in addition to starter fertilizer can help to overcome possible limitations in crop nutrient uptake and increase nutrient use efficiency and yields.

Some soil conditions such as high soil pH and low organic matter may contribute to decrease the supply of micronutrients to crops. Increased nutrient demands from more intensive cropping practices and high yielding potential crops may also require additional micronutrient for optimum yield. Supplementary foliar application of N, P, K, and micronutrients can help to enhance crop yields under these conditions. Consequently, there is an increasing interest from producers about the potential benefits of foliar application of nutrients as complement of their fertilization programs to maximize yields.

The overall objective of this study was to evaluate crop response to starter fluid fertilizers in combination with foliar application of macro and micronutrients to maximize corn and soybean yields. Specific objectives include (1) assessment of corn and soybean grain yield and early growth response to starter application of fluid fertilizers and (2) compare responses with and without additional foliar fertilizers. (3) Verify potential soil parameters that could be related to responses to starter and foliar applied macro and micronutrients. (4) Evaluate tissue testing as a diagnostic tool to explain responses to foliar and starter macro and micronutrient application.

MATERIALS AND METHODS

The experiment was conducted in 2 locations (Scandia and Clay Center) for corn and 2 locations for soybean during 2010 in Kansas. Studies were located under high yield potential irrigated conditions. The field studies consisted of small-plot field research of six rows wide by 50 feet in length. Macronutrients treatments included N, P, and K, and micronutrients included Fe, Mn, Zn, B, and Cu. Starter fluid fertilizer treatments and foliar treatments were applied in various combinations in a factorial arrangement. Three starter treatments (none, N,P,K only, and N,P,K + micros) were combined with three foliar treatments (none, N,P,K only, and N,P,K + micros) for a total of nine treatment combinations.

Starter fluid fertilizers were applied near the seed using a dribble band placement. The foliar fertilizer application was made before the plant begins the rapid increase in nutrient and dry weight accumulation. For corn, foliar application was around the 6-8 leaf grown stage, and for soybean around the 5-7 trifoliate. The procedure for fluid fertilizer application simulated procedures commonly used by producers. Foliar fertilizer was diluted into water and applied with a hand-held CO2-powered sprayer. Fertilizer used for starter application was a 4-10-10 formulation, micronutrients Zn, Cu, and Mn were chelated EDTA. Iron was a chelated HEDTA, and B was derived from boric acid. Foliar N,P,K was applied using a 10-10-10 fertilizer formulation.

Soil samples at the 0-6 inch depth were collected from each individual plot and analyzed for routine soil properties and soil properties that can help identify the likelihood of response to foliar and starter treatments. Analysis included soil organic matter, soil test phosphorus, soil test potassium, and soil pH by standard methods in addition to micronutrients Fe, Mn, Zn, B, and Cu. Tissue samples were collected 1-3 days before foliar treatment for total N, P, K, and micronutrients. At harvest, yield was recorded for each plot and a grain samples were collected. Statistical analysis was completed with the GLIMMIX procedure in SAS 9.2 (SAS Institute, 2000). Plant population was used as covariate in the analysis.

RESULTS AND DISCUSSION

Average soil test levels are presented in Table 1. Plant population bellow-optimum for the Clay Center location (data not shown) indicated potential limitation for grain yield in corn and soybean. At both locations, chloride, Fe and Cu showed significant increase in concentration in corn tissue with starter application (Fig1 and 2). Chloride was not originally part of a fertilizer treatment; however one of the starter fertilizer source (4-10-10) included some chloride. In Kansas, corn (as well as wheat and sorghum) can show yield increase to the application of Cl. Zinc in corn was also significantly increased in Scandia only. Early corn biomass increased significantly at both locations with the use of starter fertilizer (Fig 3).

Corn grain yield was significantly increased with the use of starter N, P,K, and N,P,K plus micronutrients at Scandia and Clay Center. Soybean grain yield was significantly increased with the use of starter N, P,K, and N,P,K plus micronutrients at Clay Center only. Grain yield increase in 2010 with starter fertilizer was similar for treatments with and without the addition of micronutrients in the starter mix. This suggests that the primary crop response is likely from macronutrients. In Scandia, relatively low levels of soil test P suggest that starter P application likely contributed to corn grain yield response.

Based on one year of data is not possible to provide a more in-depth analysis and summary for specific nutrients associated with crop response, including the effect or foliar fertilization for corn and soybean in combination with starter fertilizer.

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Table 1. Average soil test values for Scandia and Clay Center in 2010.

	Corn		Soybean	
Soil test	Scandia	Clay Center	Scandia	Clay Center
pH	6.7	7.4	7.0	7.1
P (ppm)	21	114	22	34
K (ppm)	460	388	480	255
Zn (ppm)	1.4	2.5	1.2	4.0
Fe (ppm)	31	21	26	16
Mn (ppm)	23	5.9	17	9
Cu (ppm)	0.88	0.36	0.86	0.33
B (ppm)	0.54	0.31	0.67	0.33

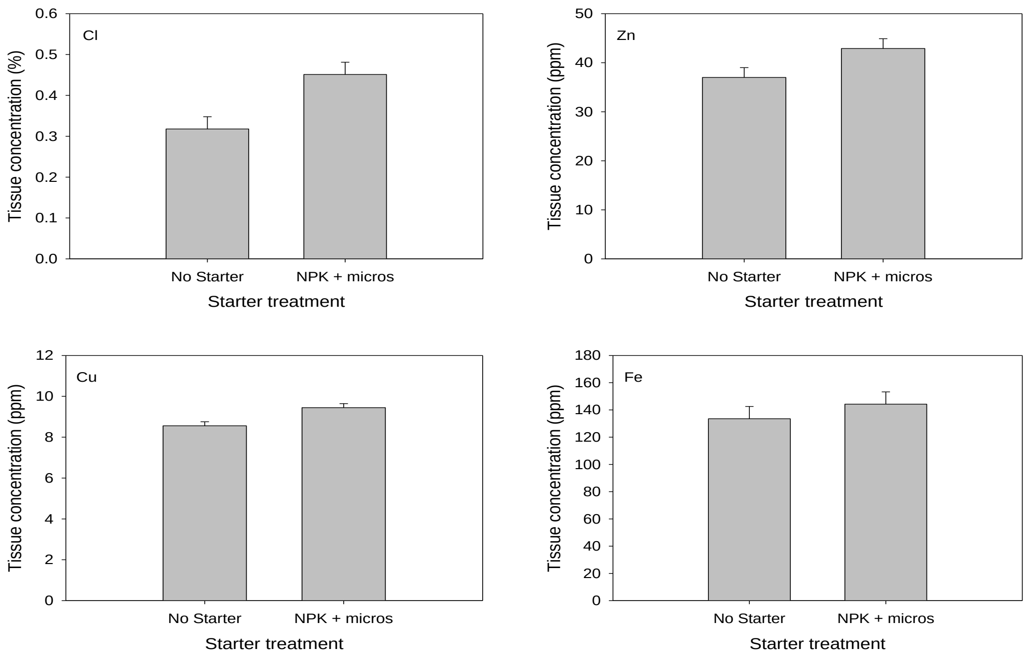

Figure 1. Effect of starter micronutrient application on tissue nutrient concentration in corn. Only nutrients with statistically significant ($p \leq 0.05$) increase is shown here for the Scandia location.

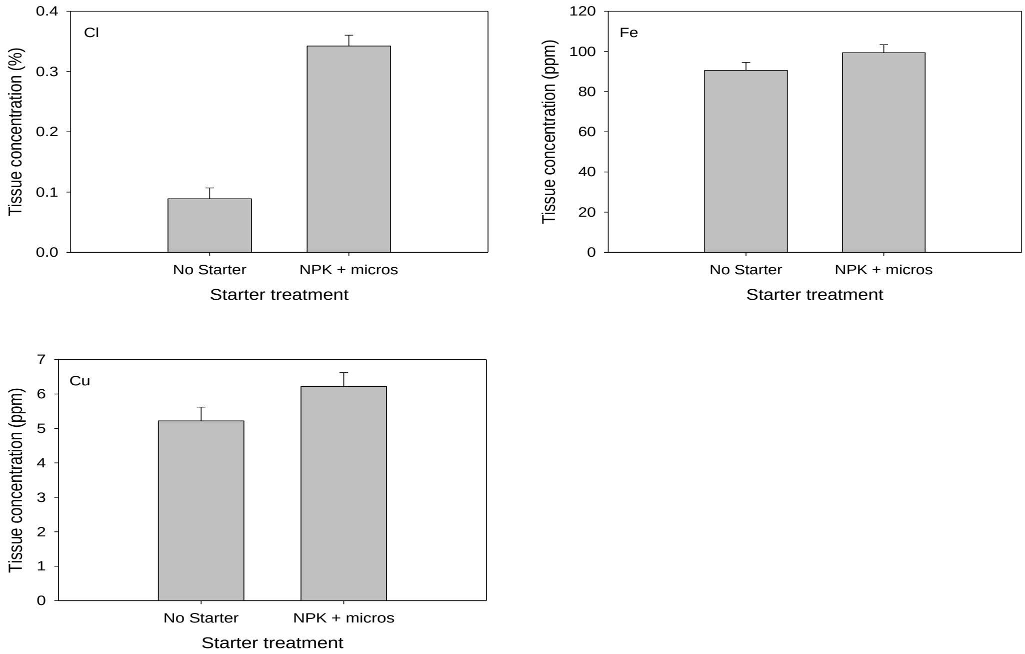

Figure 2. Effect of starter micronutrient application on tissue nutrient concentration in corn. Only nutrients with statistically significant ($p \leq 0.05$) increase is shown here for the Clay Center location.

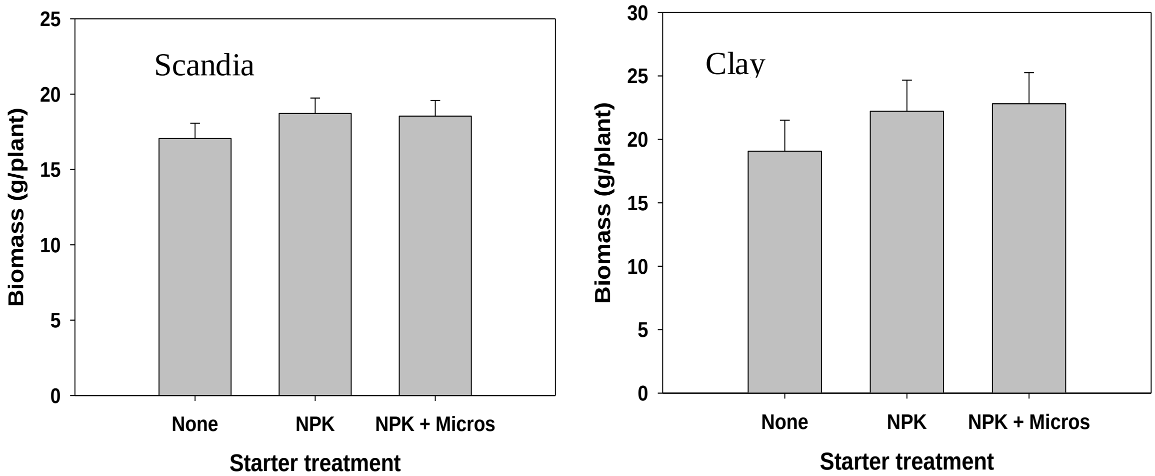

Figure 3. Corn early growth with starter fertilizer application in Scandia and Clay Center.

Table 2. Corn and soybean yield as affected by starter fertilizer application for Scandia and Clay Center in 2010.

	Corn		Soybean	
Starter Treatment	Scandia	Clay Center	Scandia	Clay Center
	- - - - - - - - - - - - - - - - - - bu/a - - - - - - - - - - - - - - - - - -			
None	204 b†	228 b	63 a	56 b
NPK	207 a	231 a	63 a	58 b
NPK + micros	209 a	231 a	65 a	63 a

† Different letters within a column indicate statistically significant differences at $p \leq 0.05$

FLUID FERTILIZER'S ROLE IN SUSTAINING SOILS USED FOR BIO-ENERGY FEEDSTOCK PRODUCTION

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ABSTRACT

The use of corn (*Zea mays* L.) as a bio-energy feedstock has attracted the attention of many producers. Recently, the focus has shifted from grain-based to cellulose-based ethanol production. In addition to biological conversion of corn stover to ethanol, thermal conversion (pyrolysis) of stover is being explored. Regardless of post-harvest processing, the short- and long-term effects of both increasing grain yields and removing stover on soil nutrient cycling, physical properties, and biological activity must be understood to ensure that soil productivity and ecosystem services are maintained. Our objectives for 2010 were to evaluate: (i) the use of surface or subsurface bands of N-P-K-S fluid fertilizers to optimize positional and temporal availability of nutrients; and (ii) the effect of biochar application on P availability and cycling in Clarion-Nicollet-Webster soils. Corn was grown in a field trial under a variety of management systems including 30-inch row spacing with standard fertility management and a twin-row, high-population treatment with increased nutrient additions applied in split-applications. Analysis of whole plants at V6 and ear leaves at mid-silk indicated that management scenario, tillage, and the amount of stover removed from the field with the 2009 harvest did not affect uptake of most nutrients. Nitrogen concentrations in ear-leaf tissue, however, were below the critical value for all treatments. Management scenario and tillage and did not affect corn grain yields, but plots from which corn stover was not removed always yielded less than plots from which ~50% (harvested just below the ear shank) or ~90% (harvested at a stubble height of approximately 4 inches) of the stover was removed. We suspect that this is a short-term effect. The wet growing conditions in central Iowa during June and early July may have caused significant nitrate leaching and denitrification, thus limiting N availability and decreasing yields of all treatments. If wet weather patterns continue, mid-season N applications may become necessary. In a separate controlled-climate chamber study, 20-day-old plants grown in soil with only 100 lb. P_2O_5/A had the highest shoot and root dry matter values, while those grown in soil amended with biochar in 2007 without P fertilizer had the lowest values. Addition of 100 lb. P_2O_5/A numerically increased shoot and root dry matter values regardless of legacy or fresh biochar amendment. Continued generation of plant growth and nutrient uptake data should provide a clearer picture of the value of the biochar, any biochar-fertilizer interactions, and whether legacy or fresh biochar affects the nutrition of juvenile corn in different ways.

INTRODUCTION

The use of corn as a bio-energy feedstock has attracted the attention of many producers, especially in the Cornbelt states. Recently, the focus has shifted from grain-based to cellulose-based ethanol production, with corn stover (stalks and cobs) being an important feedstock material (Bridgwater, 2006). In addition to biological conversion of corn stover to ethanol, thermal conversion (pyrolysis) of stover to bio-oil, syngas, and biochar is being explored as an alternative platform (Laird, 2008). Regardless of post-harvest processing, the short- and long-term effects of both increasing grain yields and removing stover on soil nutrient cycling, physical properties, and biological activity must be understood to ensure that soil productivity and ecosystem services are maintained. Up to this point, the bio-energy industry has been forced to use estimates, such as those offered by Johnson et al. (2006), to determine the amount of crop residues that must remain in the field. Research has shown that the use of no-tillage production can reduce the rate of residue decomposition, thus offering a mechanism to maintain soil organic carbon after removing some portion of the stover (Perlack et al., 2005). A significant amount of research has addressed fertility requirements and nutrient cycling in conventional grain production systems, but only recently has information on bio-energy feedstock systems become available (Heggenstaller et al., 2008; Blanco-Canqui and Lal, 2009). To provide more quantitative fertility guidelines, soil management studies focusing on cropping systems, tillage, fertilizer rates and placement, use of cover crops, and controlled wheel traffic are needed. Because it would be difficult to address all of these variables in a single project, our research focuses on nutrient requirements, specifically phosphorus (P), potassium (K) and sulfur (S), for no-till corn bio-energy production systems.

There is also significant interest in the use of biochar as a soil amendment for sequestering carbon and improving agricultural soil quality. Crop yield increases and improvements in soil physical and chemical properties have been reported, but variability among the responses has been significant (Glaser et al., 2002; McHenry, 2009). Biochars have some plant nutrient content, but nutrient availability can vary widely (Chan et al., 2007; McHenry, 2009). Biochars cannot be considered a substitute for fertilizers. However, Chan et al. (2007) reported that yields of radish (*Raphanus sativus*) increased with increasing rates of biochar in combination with N fertilizer, suggesting that biochar played a role in improving N-use efficiency. Application of biochar to soils may also enhance P availability and improve P-use efficiency. Preliminary research has shown that additions of biochar tend to increase Mehlich 3-extractable P and reduce P leaching when applied in combination with animal manures (D.A. Laird, unpublished data).

The overall goal of this project is to evaluate the use of N-P-K-S fluid fertilizers to enhance corn grain and stover productivity. A secondary goal is to determine the role biochar application plays in nutrient cycling. This project is part of a long-term corn grain and stover removal study that focuses on standard and intensive fertility management, tillage, biochar additions to test the "charcoal vision" (Laird, 2008) for sustaining soil quality while producing bio-energy products, and use of cover crops to build soil carbon and help off-set potential negative impacts of stover removal. Our specific objectives for 2010 were to evaluate (i) the use of surface or subsurface bands of N-P-K-S fluid fertilizers to optimize positional and temporal availability of nutrients, and (ii) the effect of previous and recent biochar application on P availability and cycling in Clarion-Nicollet-Webster soils.

METHODS AND MATERIALS

Biomass Removal Study

The 25-acre field study established in 2008 on the Clarion-Nicollet-Webster soil association at the Iowa State University Agronomy & Agricultural/Biosystems Engineering Research Center (AAERC), southwest of Ames in Boone County, Iowa, was continued. This study focuses on rates of residue removal (0, ~50%, and ~90%), tillage (chisel plow versus no-tillage), a one-time biochar addition (4.32 and 8.25 tons/A), and use of annual and perennial cover crops. One set of plots (40 x 280 ft.) is managed with standard production practices, and a second set of plots is managed in a twin-row configuration with higher inputs. Conventional weed and insect control practices are being followed. The study includes 22 treatments that are replicated four times. Soil samples (0-2 and 2-6 inches) were collected with a hand probe from each plot 23 November 2009, and analyzed for pH, organic matter content, available P, exchangeable K, Ca, and Mg, extractable SO^{4-}, and CEC (Table 1). Pioneer Brand 36V75 corn was planted 27 April 2010. Fertilizer applications in 2010 (Table 2) were based on 2009 grain and stover removals and fall soil test results. Early-season whole-plant samples at the V6 growth stage (3 June 2010) and ear-leaf samples at the mid-silk stage (12 July 2010) were collected and analyzed to determine the nutritional status of the crop. Corn grain and stover were harvested with a single-pass combine with an 8-row head beginning 27 September. Sub-samples of stover and grain are being analyzed for nutrient content so that a more complete nutrient balance can be calculated.

Table 1. Initial soil test levels in two depth increments for the Clarion-Nicollet-Webster soil association in 2010. Range indicates variability among all plots in study.

Soil Test Parameter	Composite	Range	Composite	Range
	0-2 inch		2-6 inch	
Bray-1 P, ppm	50	21 – 103	23	7 – 52
Exch. K, ppm	229	133 – 364	138	76 – 339
Exch. Ca, ppm	2569	1680 – 4120	2730	1510 – 3890
Exch. Mg, ppm	318	212 – 509	334	171 – 547
Extract. S, ppm	5	1 – 10	5.5	2 – 12
pH	5.9	5.4 – 6.6	6.0	5.1 – 6.7
O. M., %	3.7	2.8 – 5.1	3.4	2.6 – 4.8
CEC, cmol(+)/kg	22.3	14.9 – 29.3	22.8	17.0 – 30.9

Biochar Study

Soil samples were collected from the bio-energy field trial site at the Iowa State University AAERC in April 2010. Surface soil (0-6 inches) from two plots was collected. One plot was a control that had standard management, chisel plow tillage, and 90% residue removal. The second was a biochar plot (8 ton/acre, fall 2007) that had standard management, chisel plow tillage, and 90% residue removal. The soil is classified as Clarion loam (fine-loamy, mixed, mesic Typic Haplaquolls). Initial soil physical and chemical properties (Table 3) were determined.

Table 2. Fertilizer management for the conventional and high-input (twin row) systems in 2010.

System	Stover Removal, %	Timing	Source
Conventional		Fall 2009	11-52-0 + 0-0-60
190+68+49+30S	0	Starter	32-0-0 (UAN)
215+79+124+30S	50		12-0-0-26S (ATS)
230+88+188+30S	90	Sidedress	32-0-0 (UAN)
Twin-Row		Fall 2009	11-52-0 + 0-0-60
220+65+46+40S	0	Starter	32-0-0 (UAN)
245+76+118+40S	50		12-0-0-26S (ATS)
260+82+165+40S	90	Sidedress	32-0-0 (UAN)

In order to determine the effect of previous (legacy) and fresh biochar applications in combination with liquid P fertilizer addition, a laboratory/climate chamber experiment was initiated. A commercially available hardwood-based biochar was added to subsamples of unamended soil at 0 and 8 tons per acre. Ammonium polyphosphate (APP, 10-34-0) was then applied to subsamples of biochar-amended soil to provide 100 lb. P_2O_5 per acre. Nitrogen, K, and S fertilizers were also applied to provide adequate amounts of these nutrients. The biochar and fertilizers were thoroughly mixed with the soil. Unamended soil is serving as a control treatment. After the amendments were added, the soils were incubated moist for four weeks. Following incubation, soil solution was displaced and analyzed for P, and Bray 1-P was determined in the treated and untreated soils. Relative changes in the values of these soil supply parameters will be used to compare the effects of the legacy and fresh biochar amendments on the soil supply of P.

Table 3. Initial soil test levels for Clarion loam collected in 2010. Legacy biochar refers to an 8 ton/acre rate applied to this soil in the fall of 2007.

Soil Test Parameter	Control	Legacy Biochar
Bray-1 P, ppm	65 (VH)	50 (VH)
Exchangeable K, ppm	159 (VH)	119 (L)
Exchangeable Ca, ppm	2034	1981
Exchangeable Mg, ppm	206	213
Extractable S, ppm	4	4
pH	5.6	5.7
Organic Matter, %	2.8	2.8
CEC, cmol(+)/kg	15.1	14.8

A pot experiment was then initiated. Pre-germinated corn (Pioneer Brand 36V75) seedlings were planted two per pot, and pots were placed in a controlled-climate chamber with 16 hours of light and 22°C/12°C day/night temperature. Each treatment combination was replicated four times. After 20 days, plants were harvested. Corn roots were separated from soil, and after fertilizing with replacement N (but not P), the same soil returned to each pot. New corn seedlings were planted and allowed to grow another 20 days. In order to investigate the effect of biochar addition on depletion of plant-available P, a third and possibly fourth cycle of growth is planned. At this point, measurements and data analyses are incomplete. Total dry matter production and nutrient uptake from each treatment will be compared. Phosphorus uptake efficiency and utilization efficiency also will be calculated for the various treatments. These data will be used to determine: i) the P fertilizer value of the biochar, ii) if biochar-P fertilizer interactions occurred, and iii) the differences between legacy and fresh biochar as it relates to the P nutrition of the corn. Because of the time and effort involved in carrying out this study, we anticipate concurrent measurements of N, K, and S uptake and utilization efficiencies. We are also monitoring water-use efficiency.

RESULTS AND DISCUSSION

Biomass Removal Study

Plant Nutrition

Management scenario, tillage, and the amount of residue removed from the field with the 2009 harvest did not affect nutrient content of whole plants at the V6 stage, and levels of all primary and secondary macro-nutrients were adequate for optimal growth (Table 4). Nitrogen concentrations were well above the published critical value of 3.5% (Mills and Jones, 1996), suggesting that pre-plant N fertilizer and soil N were sufficient to support the corn crop before additional N was sidedressed six weeks after planting.

At mid-silk in 2010, no differences in ear-leaf nutrient concentrations were detected among the treatments (Table 5). However, N concentrations in the tissue were below the critical values. Phosphorus and K concentrations in ear leaves were within the sufficiency ranges of 0.25% to 0.50% for P and 1.7% to 3.0% for K for all treatments (Mills and Jones, 1996). Sulfur concentrations were also within the sufficiency range of 0.10% to 0.30% (Jones et al., 1990). Low N uptake suggests that the soil supply was not sufficient to meet crop demand by mid-silk. The wet growing conditions in central Iowa during June and early July (Hillaker, 2011) may have caused significant nitrate leaching and denitrification, thus limiting N availability. If wet weather patterns continue, mid-season N applications may become necessary.

Corn Grain and Stover Yield

In 2010, management scenario and tillage and did not affect corn grain yields (Fig. 1). Yields, however, were related to the amount of residue removed from the field with the 2009 harvest. Plots from which corn stover was not removed tended to have lower yields than those from which ~50% or ~90% was removed. This result is similar to 2009 results and contradicts previous work demonstrating yield decreases when plant residues are removed (Blanco-Canqui and Lal, 2009). We suspect that in the short term, higher residues in the soil result in cooler, wetter conditions that negatively affect early-season corn root growth and function. Moreover, when stover was not removed, fertilizer application rates were lower. A combination of less fertilizer N, greater N immobilization because of the residues remaining in the soil, and increased N leaching losses would negatively affect mid-season corn growth and subsequent grain yields.

Although data are still being processed, the amount of dry stover collected was higher for the 90% removal (low cuts) treatments of all management scenarios. However, the wet conditions in central Iowa during the middle of the growing season (Hillaker, 2011) likely limited the performance of all treatments. Whole plants collected at physiological maturity residue samples from the machine harvest are being processed to determine elemental composition, so that the total amount of nutrients removed can be calculated. These values will be used to guide fertilizer recommendations for 2011.

Table 4. Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) critical values and concentrations in whole plants at the V6 growth stage for six management scenarios in 2010. Values (%) are means of 8 to 16 replications depending on treatment. Standard deviations are given below each mean.

Nutrient	Critical Value	Control	Biochar 1†	Biochar 2‡	Twin-Row	Perennial CC§	Annual CC
N	3.50	3.99	3.96	3.90	4.04	3.44	4.03
		0.21	0.14	0.16	0.14	0.18	0.23
P	0.30	0.53	0.55	0.55	0.54	0.54	0.58
		0.03	0.04	0.05	0.03	0.06	0.07
K	2.50	4.24	4.13	4.46	4.13	3.56	4.15
		0.37	0.34	0.35	0.45	0.40	0.32
Ca	0.30	0.54	0.57	0.55	0.56	0.57	0.57
		0.03	0.03	0.03	0.05	0.05	0.07
Mg	0.15	0.39	0.40	0.38	0.39	0.40	0.42
		0.04	0.03	0.03	0.05	0.07	0.04
S	0.20	0.28	0.29	0.28	0.29	0.27	0.27
		0.02	0.01	0.01	0.02	0.02	0.02

†4 tons biochar/A; ‡8 tons biochar/A; §CC = cover crop.

Table 5. Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) critical values and concentrations in ear leaves at mid-silk stage for six management scenarios in 2010. Values (%) are means of 8 to 16 replications depending on treatment. Standard deviations are given below each mean.

Nutrient	Critical Value	Control	Biochar 1†	Biochar 2‡	Twin-Row	Perennial CC§	Annual CC
N	2.70	2.49	2.56	2.55	2.45	2.58	2.57
		0.19	0.45	0.21	0.18	0.13	0.13
P	0.25	0.31	0.30	0.31	0.32	0.33	0.33
		0.03	0.03	0.03	0.04	0.02	0.02
K	1.70	2.14	2.13	2.24	2.13	2.20	2.18
		0.24	0.29	0.20	0.24	0.11	0.18
Ca	0.21	0.44	0.44	0.45	0.44	0.44	0.46
		0.05	0.05	0.04	0.04	0.03	0.02
Mg	0.20	0.25	0.26	0.25	0.25	0.25	0.27
		0.04	0.02	0.03	0.04	0.02	0.03
S	0.10	0.17	0.17	0.17	0.17	0.17	0.18
		0.01	0.01	0.01	0.01	0.01	0.01

†4 tons biochar/A; ‡8 tons biochar/A; §CC = cover crop.

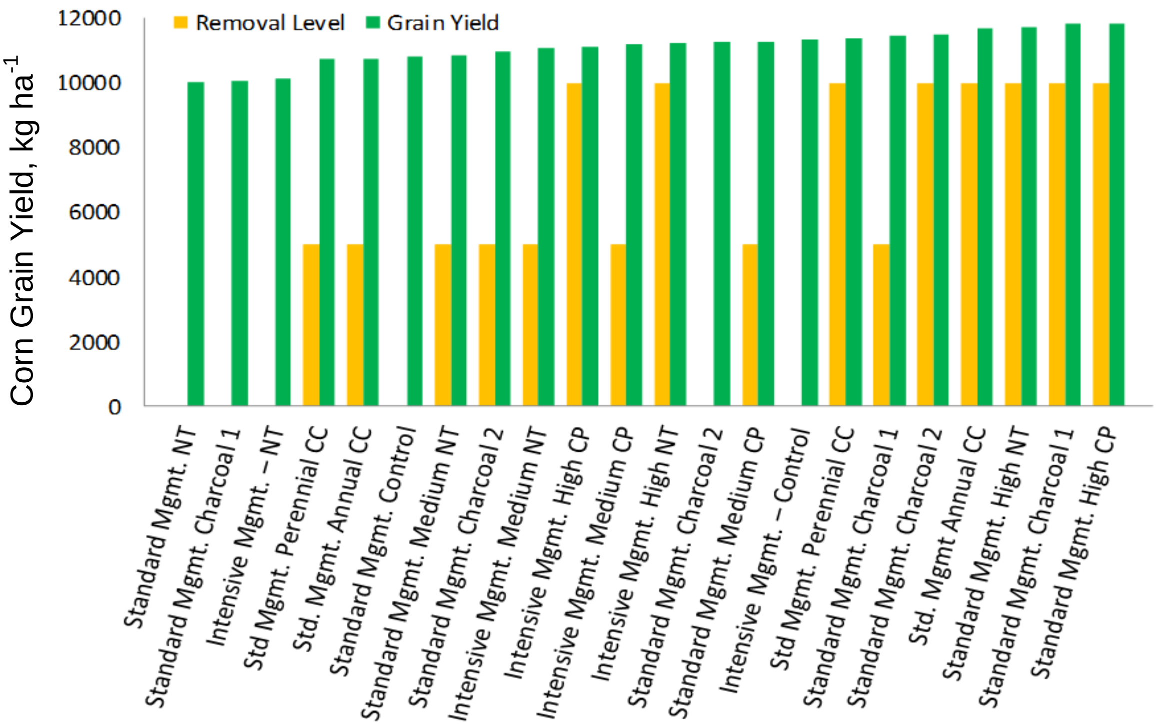

Fig. 1. Corn grain yields as affected by crop management, tillage, stover removal, cover crop, and biochar application in 2010. Yellow bars indicate 0%, 50%, and 90% stover removals, not actual stover yields.

Biochar Study

Shoot and root dry matter data suggest that both biochar and P fertilizer amendments had some effect on corn growth (Table 6). Twenty-day-old plants grown in soil with only 100 lb. P_2O_5/A had the highest shoot and root dry matter values, while those grown in soil amended with biochar in 2007 without P fertilizer had the lowest values. Addition of 100 lb. P_2O_5/A, increased numerical values of shoot and root dry matter accumulation, regardless of biochar amendment. This result is unexpected, given the initial high levels of available soil P (Table 3). Higher root:shoot dry weight ratios were recorded for the legacy biochar treatments, suggesting that the plants were partitioning more resources to root growth, rather than shoot growth. Without plant nutrient content data, however, it is difficult to speculate on the reason for this result. Continued generation of plant growth and nutrient uptake data should provide a clearer picture of the fertilizer value of the biochar, any biochar-fertilizer interactions, and whether legacy or fresh biochar affect the nutrition of juvenile corn in different ways.

Table 6. Corn shoot and root dry matter accumulation and root:shoot ratio as affected by legacy (2007) and fresh (2010) biochar application and phosphorus (P) fertilizer. Plants were harvested after 20 days of growth in a controlled-climate chamber. Values are means of 4 replications. Standard deviations are shown in parentheses.

Treatment	P Fertilizer	Shoot Dry Weight	Root Dry Weight	Root:Shoot
	lb. P_2O_5/A	g	g	
Control	0	2.97 (0.17)	1.68 (0.14)	0.57
	100	3.22 (0.10)	2.08 (0.08)	0.65
2007 Biochar†	0	1.90 (0.10)	1.49 (0.08)	0.78
	100	2.16 (0.15)	1.60 (0.06)	0.74
2010 Biochar†	0	2.33 (0.16)	1.51 (0.05)	0.65
	100	2.46 (0.14)	1.57 (0.18)	0.64

†8 tons biochar/A.

ACKNOWLEDGEMENTS

The authors are grateful to Twin State, Inc., of Davenport, IA, for providing the fertilizer materials for this study. We would also like to thank Olsen's Agricultural Laboratory of McCook, NE, for providing soil analyses, and A&L Great Lakes Laboratory of Fort Wayne, IN, for providing plant tissue analyses.

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Increasing late N availability throughout new products to soybean crops - Season 2009-2010

Fluid Fertilizer Foundation

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Introduction

This report show the results of a second set of site trials designed to evaluate the response to applied N to soybean. Soybean as all other legumes satisfies their needs of N by biological fixation (BF) through a symbiotic association with Rhizobia. As other controversial issues on production agronomy, it is hypothesized that soybean under a potential high yielding environment may suffer some N shortage because BF do not deliver sufficient N to filling grains. This is the same as underutilizing production factors, like light and moisture, under the actual breeding advances due to insufficient N supply by BNF.

The current advances of controlled release fertilizers that allow sometime between the application and the availability of N to crops could be advantageously used to provide an enhanced late N supply to soybean and so increase grain yields. Those N controlled release products can be applied by fluid equipment during early stages of growth synchronized with the herbicide application for weed control.

The results of the experiments shown in this report had the objective to evaluate the effect of increasing late N availability by improving placement/product combinations of fluid N sources on soybean grain yields and N uptake.

The need of good yield potential to express N response could be achieved under a good weather scenario, that was not possible during the last first season. We present the results of the second year of the experiments and a brief discussion in light of a combined analysis pooling these results along with the first season 2008-09.

Materials and Methods

One experiment was conducted in the 2009-2010 season with soybean and carried out at four locations. The experiments were in farmer’s fields and experimental station of INTA at Pergamino. The locations where the trials on wheat were installed were: Mercedes (Corrientes Prov.), Crespo (Entre Rios Prov.) Pergamino (Buenos Aires Prov.) and Acevedo near this last location. The experiment located in the experimental station of INTA, at Mercedes failed due to the flooding after intensive rains after sowing and before emergence.

Although the locations of the experiment are the same as presented in the 2009 report, the sites differed. The tables 1 and 2 below show some agronomic characteristics and soil test values of the top 0-20 cm.

Table 1. Soil fertility characteristics of topsoil of the experimental sites.

Site	*Location*	*pH*	*OM*	*P-Bray*	*S-SO4*
			%		
Crespo	Entre Rios	6,3	3,15	11,3	12,4
Pergamino	NO Bs.As.	5.9	2.54	23.5	17.0
Acevedo	NO Bs.As.	6,1	3,13	11,9	16,6

Table 2. Agronomic characteristics and management dates of the experiments.

Site	Previous crop	Variety /Hybrid	Sowing Date	Starter N-P-K-S
Crespo (ER)	Soybean 1st	A 4404RG	Nov -22	0-30-0-15
Pergamino (Bs.As.)	Corn	A 4613	Oct 27	0-0-0-12
Acevedo (Bs.As.)	Soybean 1st	A4613	Dec-12	11-52-0-0

As reported in 2009, the experiment evaluated four N combinations of source/placement treatments that were compared with a check that did not receive fertilizers and with a control that received a readily available N source (ammonium nitrate: 33-0-0) applied at R1 stage, making a total of ten treatments.

The evaluated sources were slow or controlled release N products, as follow:

- Nitamin®, provided by GPA, a fluid fertilizer with 30 % N, of which 60 % is slow release, and 40 % of N is in amidic form (urea);
- Nitamin Nfusion ™ , provided by GPA[5], a fluid fertilizer with 22 % N, of which 94 % is slow release and the rest being urea;
- A concentrated urea solution (20% N);
- Idem but with the addition of 0.5% of Agrotain®[6], (n-BTPT, an urease inhibitor);

Fluid applications were performed by two methods: 1) Dribbling and 2) Knifing in subsurface bands. A mechanical pump and an applicator bar that holds the nozzles and hoses that deliver the fertilizer blend stream every 0.52 m across the width of the plots at a speed proportional rate by pumping through a hose that fall freely over the soil or is attached to a knife that lead the fluid at 5 cm below soil surface. The rate for all N applications was 40 kg N/ha.
All these sources were applied and placed at the best timing in order to minimize the possibility of interfering with the symbiotic process. Thus, Urea solutions (c & d) , Nitamin ® (a) and Nitamin NFusion™ (b) were knifed and placed at 5 cm below and aside the rows (2" x 2") at V3 stage. A summary of the treatments are shown in the table 3.

5 GPA: Georgia Pacific Ltd. Atlanta GA
6 Agrotain Internacional, St. Louis, MO

Table 3. Summary of the 40 kg N/ha applied in the different treatments.

	Treatment	% N	Timing	Placement
1	Check (No N Fertilizer)	--	--	--
2	Control (Ammonium Nitrate)	33	R1	Broadcast
3	Nitamin®,	29	V3	Knifed 5 cm x 5 cm
4	Nitamin Nfusion	27	V3	Knifed 5 cm x 5 cm
5	Urea solution	22	V3	Knifed 5 cm x 5 cm
6	Idem 5 + 0.5% of Agrotain®	22	V3	Knifed 5 cm x 5 cm
7	Nitamin®,	29	V3	Dribbled
8	Nitamin Nfusion TM	27	V3	Dribbled
9	Urea solution	22	V3	Dribbled
10	Idem 5 + 0.5% of Agrotain®	22	V3	Dribbled

All these treatments were allocated in a randomized block design with four replications. Plots will be 6 or 8 rows spaced 0.52 m (or 0,70 m in Crespo) of 10 m length.

The crops were inoculated and properly fertilized at planting with enough P and S to prevent any possible shortage of essential nutrients (Table 2).

At R5-R6 stage, ten plants were sampled for aboveground biomass production and N content in biomass, so that we can have an estimation of N uptake by combining both numbers. Plants were cut aboveground, weighted, chopped and sampled to send in laboratory for water and N content analysis.

Grain harvest was made at physiological maturity and yield was evaluated by cutting plants of four lineal segments within the plot, each one covering 0,5 m2 making a total area of 2 m^2. The whole aboveground plants were weighed before threshing to evaluate total aboveground dry matter. After threshing, a sample of grain and residues was taken to evaluate humidity content in grain and stover. Plot grain yield was expressed in kg/ha at 13,5 % humidity Grain analyses for N concentration were performed using Kjeldhal technique and protein was calculated used a local factor of 5,71. Nitrogen uptake by grain in kg /ha was calculated as a product of grain yield and N concentration. By subtracting the values of the check, the partial N efficiency for each of the treatment was calculated as increase in grain N accumulation that results from the application of a given rate of fertilizer N.

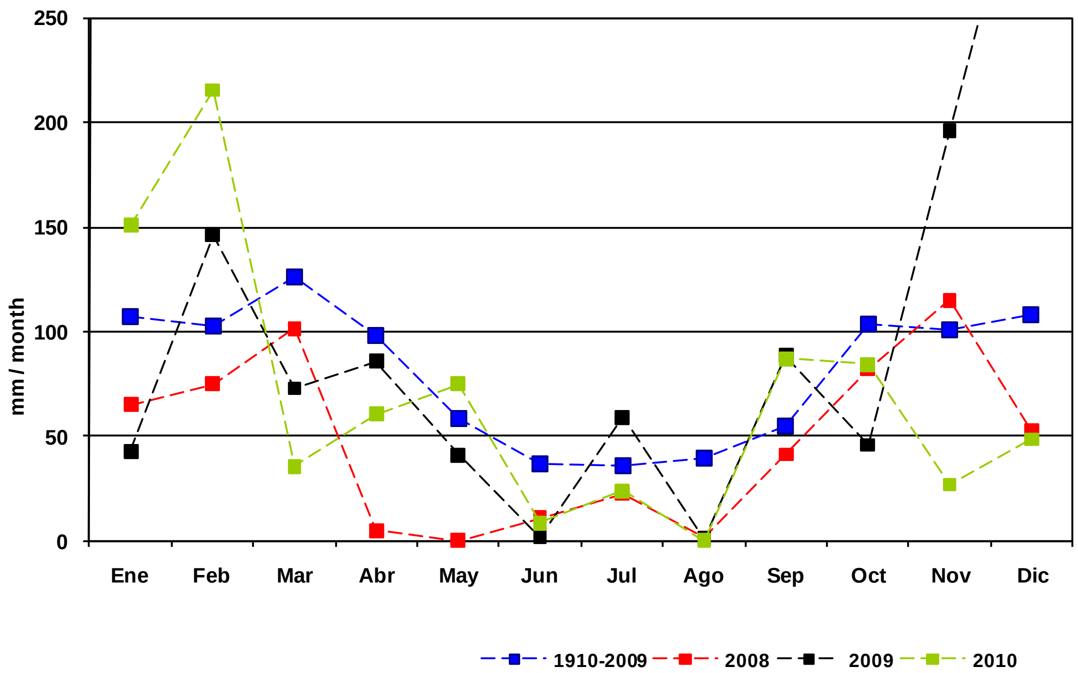
Statistical Analysis

The soybean yield data was statistically analyzed considering the site and treatment and its interaction as well according to the following model: $\mathbf{Y_{ijk}} = \mu + \alpha_i + \beta_{j(i)} + \gamma_k + \alpha\gamma_{ik} + \varepsilon_{ijk}$ Where μ is the overall mean and ε is the experimental error, α, β, and γ are estimators for the site, block and treatment effects respectively. When grain yield were analyzed by site, the corresponding effect and its interactions were withdrawn from the model. Some treatments comparisons were performed as single orthogonal contrast. All data were analyzed using the general lineal model procedures of the SAS statistical software (SAS Institute Inc., 1999-2001).

Results and discussion

Unlike the 2008-2009 season, the prevailing weather scenario was much better with abundant and opportunistic rains. The figure 1 show the accumulated rainfall compared to past year and normal long term climatic series, during the growing time of the soybean crops.

Figure 1. Moontly precipitation of 2008 thru 2010 , and long term (1910-2009) serie at INTA Exp. Stations of Pergamino. (Dec 2099 : 330 mm)



The nodulation expression was checked at early stages of v2-v3, before N applications in all sites by sampling randomly around 10 plants in the site with no signs of limitations of any kind that could have affected N supply to crops. Thus, it is assumed that N fixations performed very well.

The grain yields in general were higher than past season at the same locations due to the better rainfall. But there were strong differences in yield among sites due to the weather and other site characteristics. The sites differed statistically (pr > F = <.0001) but there were not interactions between treatments and sites, (pr > F : 0.5276) indicating a similar performance across the sites. The highest yield was in Acevedo with average of 4,303 kg/ha and the lowest in the nearby Pergamino (2,865 kg/ha), which could be explained by a later sowing time. Average crop yield in Crespo was similar to Pergamino; although the sowing was somehow earlier, this site had less yield potential, which were magnified by extreme rainfall in November (428 mm).

The table 4 and 5 present the grain and biomass yields by site with a summary of the statistical analysis. In spite of the differences in sites, some tendency is observed with sources and incorporation of fertilizers (Fig 2). In general the grain yields and differences due to treatments, were paralleled with biomass yield early stages (R5-R6). There were some treatment differences, but although weak, the higher contrast was observed between the check and the fertilized treatments with either combination of product and way of application.

Table 4. Treatment means and summary of statistical analysis for soybean grain yields across sites in 2009/10.

Treatment / Placement	Pergamino		Acevedo		Crespo	
					Kg /ha	
Check - No N --	2.861	A	3.877	B	2.522	B
Control – AN Broadcast	2.714	A	4.161	AB	2.878	A
Nfusion Knifed	2.874	A	4.694	A	2.855	A
Nitamin Knifed	2.898	A	4.811	A	3.020	A
Urea solution Knifed	2.900	A	4.205	AB	2.878	A
Urea Sol + n-BTPT Knifed	2.854	A	3.917	B	3.055	A
Nfusion Dribbled	2.967	A	4.337	AB	2.847	A
Nitamin Dribbled	2.969	A	4.423	AB	2.882	A
Urea solution Dribbled	3.108	A	4.234	AB	2.801	AB
Urea Sol + n-BTPT Dribbled	2.502	A	4.367	AB	3.011	A
Pr> F $_{\text{treatment}}$	0.37		0.13		0.08	
LSD $_{5\%}$	772		647		306	
CV %	18.6		10,33		7.4	

Table 5. Treatment means and summary of statistical analysis for total aboveground dry matter yields across sites in 2009/10.

Treatment / Placement	Pergamino	Acevedo	Crespo
		Kg ha-1	
Check - No N --	6,182	8,349	5,082
Control – AN Broadcast	5,953	9,288	6,161
Nfusion Knifed	6,116	10,402	5,915
Nitamin Knifed	5,873	10,468	6,107
Urea solution Knifed	5,848	8,936	5,487
Urea Sol + n-BTPT Knifed	6,051	8,428	5,853
Nfusion Dribbled	5,872	9,507	5,733
Nitamin Dribbled	5,775	9,603	6,408
Urea solution Dribbled	6,069	9,016	6,099
Urea Sol + n-BTPT Dribbled	5,200	9,361	6,566
Pr> F $_{\text{treatment}}$	0.9728	0.1276	0.0245
LSD $_{5\%}$	1500.9	1568.6	777
CV %	17.6	11.6	9.0

The gain in grain yield through N fertilization is of a few magnitudes, ranging between 0 to 16 % , or 0, 470 and 390 kg/ha in Pergamino, Acevedo and Crespo. The bigger and lower increase are on the sites with the highest and lowest yields, supporting the hypotheses that a complement of applied N help to get higher yields where the N supply by biological fixation could not satisfy the requirements, and is superfluous where yield is limited by any other reason.

Regarding grain referred as relative yields when pooling all sites, season and locations, the increase over the check range between 5 to 7 % , with few if any differences between fertilized treatments (Fig. 3).

Fig. 2. Treatment means pooling locations for grain and total dry matter yields.

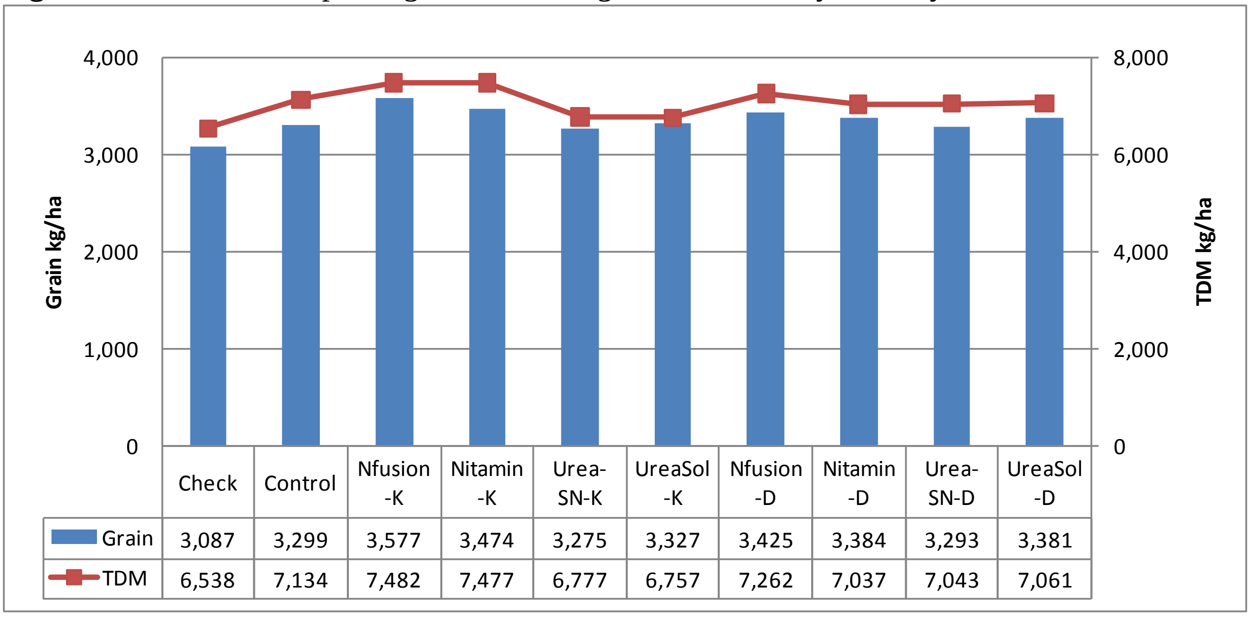
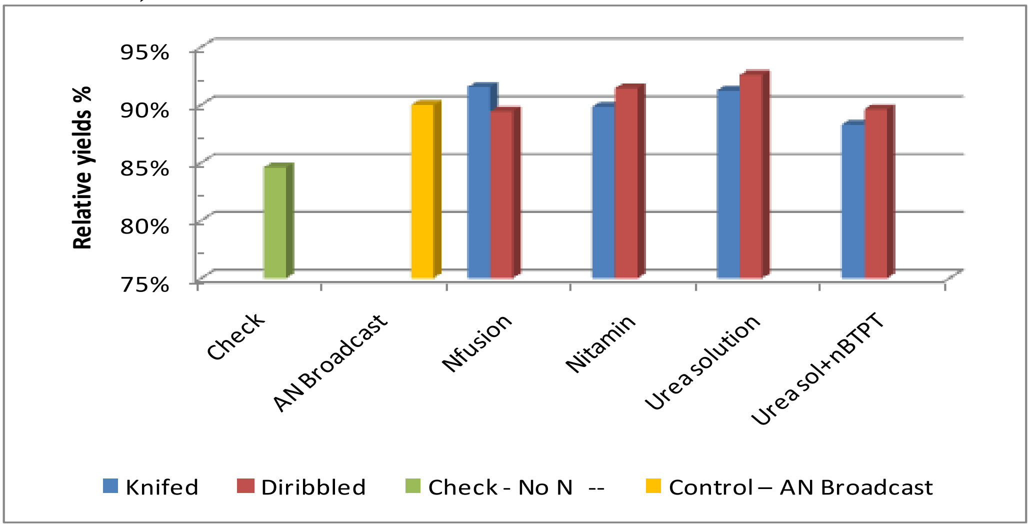


Fig. 3. Treatment means differences of relative yields across location and years. Seven trials 2008-2010).



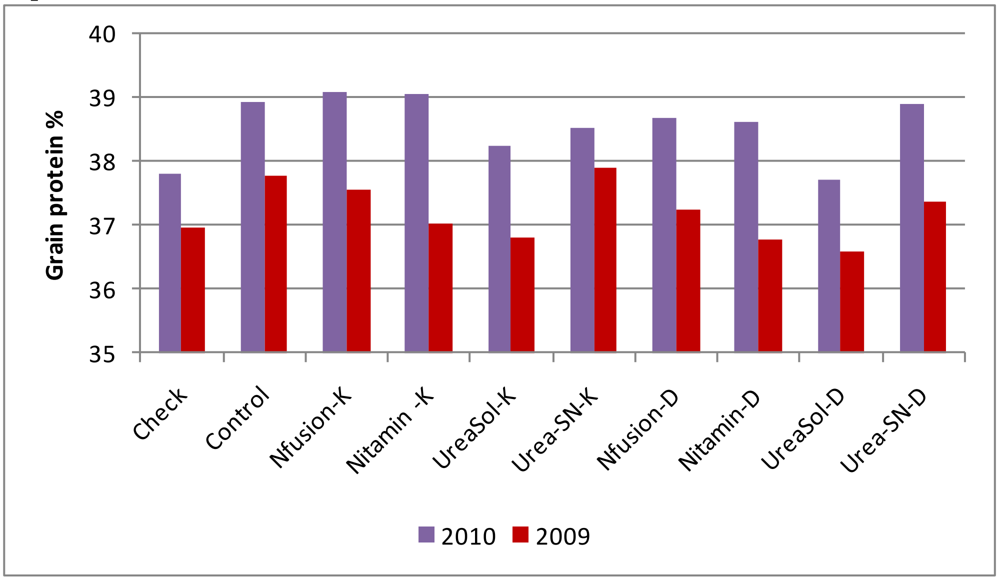
A variable trait quite more affected by fertilizer treatments were protein content in grains. The table 5 shows the treatment means of protein concentration in grain of each site. The values show a good tendency in sources for both dribbled and knifed method of application, which is consistent across seasons (Fig. 4). Control treatment that received AN show a rather high level comparable to better treatments. On the other hand, the check depicts a rather low value.

As with the last year data set, there were a negative correlation between the grain yields and protein content of grains, that is higher protein with lower yields (r = - 0,71 *). However, the relationship is not clear when sites are plotted each other. The Fig. 5 illustrates the relationship between protein and yield and each year-site trial appear as a cluster well differentiated from the others.

Table 5. Treatment means of soybean protein content across locations. Each number is a single composite sample of grains of the four replications. Season 2009-2010.

2010				
	.... % Protein			
Check	37.5	39.5	36.4	37.8
Control	38.1	39.9	38.8	38.9
Nfusion-K	38.7	40.1	38.5	39.1
Nitamin -K	37.5	40.0	39.7	39.1
UreaSol-K	36.6	39.3	38.8	38.2
Urea-SN-K	37.0	39.4	39.2	38.5
Nfusion-D	36.5	39.9	39.6	38.7
Nitamin-D	37.7	39.5	38.7	38.6
UreaSol-D	34.7	38.9	39.5	37.7
Urea-SN-D	37.1	40.2	39.4	38.9

Fig. 4. Treatment means pooling locations for protein content in soybean for 2008 and 2009 experiments.



When transforming the protein values into N%, and estimating the N uptake in grains, the trend reverse, since yields weight more in the product with protein. Thus the tendency of grain N uptake in differences among treatments is diminished (Fig. 6). As a result, N uptake in grains on the check seems similar to those of fertilized treatments.

Fig. 5. Grain protein content as related to grain yield for each year-site trial.

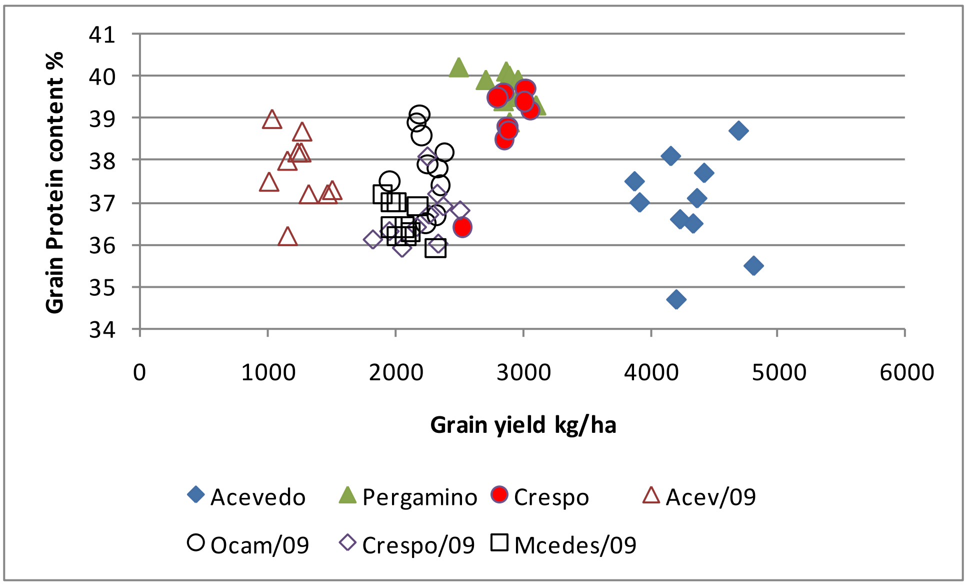
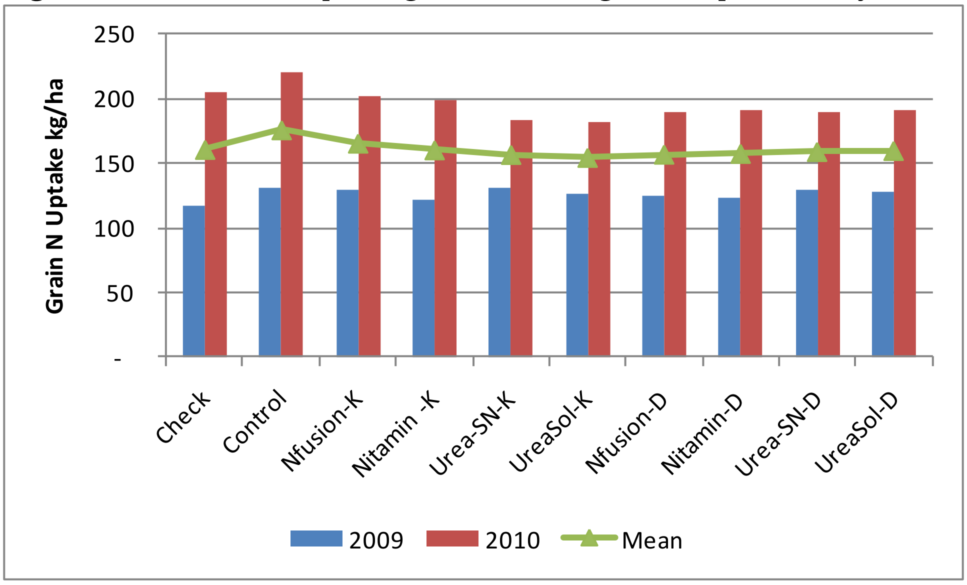


Fig. 6. Treatment means pooling locations for grain N uptake in soybean.



Final considerations

The 2009-10 season provided soil moisture conditions to express high yielding potential to soybean crops unlike the past year.

The gains in grain yield due to applied N, although marginal are consistent, but none can be said about differences between treatments or ways of applications.
Neither can be distinguished between the immediate or late N availability. Some treatments allowed for a rather quick availability and others might need some time to mineralize and become available for the soybean crop. Lack of differences between treatments precludes any speculation on this issue.

Acknowledgments

I would like to thank the invaluable help of my collaborators. Ings. Agrs. Gabriel Kuriger, Enrique Figueroa and Francisco Gonzalez Miranda.

Reflectance-based Nitrogen Fertilizer Management for Irrigated Cotton

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Water and nitrogen are the first and second constraints to cotton production in the arid southwestern U.S, respectively (Morrow and Krieg, 1990). Subsurface drip irrigation (SDI) area in cottonland is currently estimated at 300,000 ac, and is growing (Jim Bordovsky, personal communication). Efficiency of water application to cotton in SDI systems is about 90 % (Bordovsky and Lyle, 1998). However, N management research for cotton in SDI has not kept up with the water management research. Improving N fertilizer use efficiency would allow lower rates of N fertilizer to be used by producers without hurting lint yields. The reduced costs of improving efficiency of inputs such as fertilizer would help keep cotton farmers competitive in the world market place. Additionally, residual nitrate (NO_3) can be leached to groundwater and impact water quality. The environment of the West Texas Region is thereby protected when N fertilizer use efficiency is improved.

Timing of N application is an important management tool that can result in improved N use efficiency in cotton. Norton and Silvertooth (1998) reported reduction in N fertilizer needed and increased N use efficiency if pre-plant N was avoided in irrigated cotton in Arizona. Based on that research, the Cooperative Extension of the University of Arizona states that the main window for N applications to cotton is centered at peak bloom or about 2200 heat units (base 60^oF). The rate of N uptake at peak bloom is apparently maximum in cotton (Silvertooth, 2001). Previous research conducted in this area has indicated that improving the timing of N fertilizer injections in SDI cotton systems based on canopy reflectance assessments of in-season N status can save up to 90 lb N/ac, without hurting yields (Bronson et al., 2003; Chua et al., 2003). We also observed in earlier work that modifying the timing of in-season N applications by applying N when chlorophyll meter readings were low, resulted in reduced N fertilizer applications and reduced residual soil NO_3^--N (Chua et al., 2003). However, more research is needed on basing the timing and rates of N fertilizer injections to SDI cotton on spectral reflectance. In the previous work (Chua et al., 2003), our SDI system was not set up for fertigation treatments, but our existing, present SDI system is. In addition to reflectance treatments and their associate reference treatments (i.e. 1.5 * soil test treatment), we added a low, 0.5 * soil test treatment N rate to provide more information on a wide range of N fertilizer inputs.

The objectives of this study were:

1. To assess lint yields and N fertilizer use efficiency with two spectral reflectance based N management strategies compared to soil test-based N management in a SDI cotton system.
2. To assess lint yields and N fertilizer use efficiency of N fertilizer injected into a SDI cotton system at three fixed N rates between early square and mid bloom.

Materials and Methods

The 4-yr study was carried out at the Texas A&M AgriLife Research and Extension Center farm near Lubbock, TX on an Acuff sandy clay loam (fine-loamy, mixed, superactive, thermic, Aridic Paleustoll) (Bronson et al., 2011). Drip tape was in the center of every other furrow at a depth of 12 in. and water flowed at a rate of 1 qt min^{-1} at 15 psi. Irrigations of 0.20 inch were applied on 54 days between emergence and first open boll. All-Tex Apex

B2RF cotton in early June in 2007, and early May in 2008 and 2009. In 2009, FiberMax 9180 and Stoneville 5448 were planted in early May in a randomized block design. Harvest was in October each year. In The experimental design was a randomized complete block design, one-way factorial with three replications or blocks. Blocks consisted of 40, 40-in. rows that were 600 feet long. Each block was divided into five, 8-row plots that were randomly assigned to the five N-fertilized treatments:

N	N rate	Other details
1	0.5 X soil test	Soil test algor = 120 lb N/ac – 2 ft NO_3 – irrig. water
2	1.0 X soil test	Soil test algor = 120 lb N/ac – 2 ft NO_3 – irrig. water
3	1.5 X soil test	Soil test algor = 120 lb N/ac – 2 ft NO_3 – irrig. water
4	Reflectance based	Starts out at 0.5 X, referenced to 1.0X
5	Reflectance based	Starts out at 1.0 X, referenced to 1.5X
6	Zero-N	1 replicate/station only 2007-2009, two reps in 2010

In 2010, the N treatment plots were reduced to 1.0 X soil test, reflectance-1, and zero-N, each for the two cultivars. Each 8-row plot has its own irrigation and fertilizer injection station. Nitrogen fertilizer rate was based on an N requirement for a 2.5 bale/ac yield, which, according to Yabaji et al. (2007) is 125 lb N/ac. The amount of NO_3-N extracted in initial, spring 2007 0.1-acre grid soil samples from 0-24 inches (average 20 lb N/ac), and estimated 20 lb N/ac in irrigation water (12 inches of irrigation with 8 ppm NO_3-N water was anticipated) was subtracted from the 125 lb N/ac requirement to give a growing season N fertilizer requirement to be injected of 80 N/ac for 2007 (Table 1). Nitrogen fertilizer was injected into the SDI system five days a week, between early square and mid bloom. In the reflectance-based strategy 1 treatment, the N injection was initially set to the 0.5*soil test treatment, and in the reflectance-based strategy 2 treatment, the N injection was initially set equal to rate of the soil test treatment N-fertilizer. Every week canopy reflectance measurements were made with a CropCircle radiometer (Holland Scientific Inc., Lincoln, NE) at 40 inches above the canopy on one row per plot. Normalized difference vegetative index (NDVI) was calculated as:

(Reflectance at 880 nm-Reflectance at 590 nm)/(Reflectance at 880 nm+Reflectance at 590 nm)

When the NDVI in the reflectance-based strategy 1 treatments fell significantly below the NDVI in the soil test based management treatment, the N injection rate was increased to the soil test treatment N injection rate. When the NDVI in the reflectance-based strategy 2 treatments fell significantly below the NDVI in the 1.5 * soil test based management treatment, the N injection rate was increased to the 1.5 * soil test treatment N rate. Sulfuric acid (25 % H_2SO_4) was injected continuously to lower the pH of the well water from pH 7.7 to pH 6.8, and prevent precipitation of calcium carbonate and clogging of emitters.

Results and Discussion

Lint yields for the four years exceeded our 2.5 bal/ac yield goal (Tables 1-4). Reflectance strategy 1 resulted in 16 to 50 lb N/ac less N fertilizer injection rates than the soil test-based management. This represents 23 to 50 % savings in N fertilizer. Lint and seed yields did not differ between reflectance and soil test N management treatments. Reflectance strategy-2 resulted 10 lb N/ac more than the soil test treatment, in 2007 only, with no yield benefit. Therefore, after three years of testing reflectance-2 strategy, we abandoned, starting in 2010. 2010 was the first year in which we tested reflectance strategy-1 for two cultivars in one study. Averaged across N treatments, lint and seed yields were significantly higher with ST5458 vs. FM 9180. Never-the-less, the N-fertilizer saving strategy of reflectance-1 saved substantial N (50 lb N/ac) for both cultivars, without hurting yields (i.e. lint and seed yields were similar between soil test-based and reflectance-strategy-1). Recovery efficiency of injected N fertilizer was variable, but high, ranging from 47 to 101 %.

Table 1. First open boll biomass, N accumulation, N fertilizer recovery efficiency, seed and lint yields as affected by nitrogen management, Lubbock, TX, 2007 (adapted from Bronson et al. 2011).

N treatment	N fertilizer injected[1]	Total N uptake	Recovery efficiency	Biomass	Seed yield	Lint yield
	--------- lb N/ac -----		%	--------------- lb/ac ------------------		
1.5*Soil test-based	120	-	-	-	2379 a	1347 a
Reflectance strategy 2	90	131 a	62 a	7666 a	2253 a	1330 a
Soil test-based	80	128 a	65 a	7704 a	2241 a	1326 a
Reflectance strategy 1	62	120 a	72 a	7561 a	2350 a	1372 a
0.5*Soil test-based	40	-	-	-	2270 a	1365 a
Zero-N	0	76 b	-	5362 b	1692 b	1062 b

[1] Injected from 11 July to 11 August

Table 2. First open boll biomass, N accumulation, N fertilizer recovery efficiency, seed and lint yields as affected by nitrogen management, Lubbock, TX, 2008 (adapted from Bronson et al. 2011).

N treatment	N fertilizer injected[1]	Total N uptake	Recovery efficiency	Biomass	Seed yield	Lint yield
	--------- lb N/ac -----		%	-------------- lb/ac ------------------		
1.5*Soil test-based	94	138 a	75 a	7993 a	2553 a	1532 a
Reflectance strategy 2	62	-	-	-	2572 a	1586 a
Soil test-based	62	130 a	101 a	7546 a	2455 a	1495 a
Reflectance strategy 1	46	110 b	94 a	6587 b	2542 a	1538 a
0.5*Soil test-based	31	-	-	-	2129 b	1283 b
Zero-N	0	67	-	4968	1640	1006

[1] Injected from 26 June to 16 July and 5 to 8 August

Table 3. First open boll biomass, N accumulation, N fertilizer recovery efficiency, seed and lint yields as affected by nitrogen management, Lubbock, TX, 2009 (adapted from Bronson et al. 2011).

N treatment	N fertilizer injected[1]	Total N uptake	Recovery efficiency	Biomass	Seed yield	Lint yield
	--------- lb N/ac -----		%	-------------- lb/ac ------------------		
1.5*Soil test-based	72	124 a	47 a	7761 a	2526 a	1527 a
Reflectance strategy 2	48	-	-	-	2487 a	1509 a
Soil test-based	48	114 a	49 a	7670 a	2471 a	1522 a
Reflectance strategy 1	24	109 b	77 a	8058 a	2581 a	1610 a
0.5*Soil test-based	24	-	-	-	2326 b	1487 a
Zero-N	0	90	-	6962	2029	1336

[1] Injected from 26 June to 16 July and 5 to 8 August

Table 4. First open boll biomass, N accumulation, N fertilizer recovery efficiency, seed and lint yields as affected by cultivar and nitrogen management, Lubbock, TX, 2010.

Cultivar	N treatment	N fertilizer injected[1]	Total N uptake	Recovery efficiency	Biomass	Seed yield	Lint yield
		--------- lb N/ac -----		%	-------------- lb/ac ----------------		
FM9180	Soil test-based	89	107 a	60 a	7351 a	2507 a	1435 ab
ST5458	Soil test-based	89	95 a	48 a	7406 a	2426 a	1602 a
FM9180	Reflectance strategy 1	44	-	-	-	2306 a	1351 b
ST5458	Reflectance strategy 1	44	-	-	-	2296 a	1513 ab
FM9180	Zero-N	0	54 b	-	5212 b	1651 b	1001 c
ST5458	Zero-N	0	52 b	-	5345 b	1708 b	1165 bc

[1] Injected from 26 June to 16 July and 5 to 8 August

Conclusion

- Reflectance-based N management strategy1 saved 22, 26, 50, and 51 % N compared to soil test based management during 2007, 2008, 2009, and 2010 respectively.
- Recovery efficiency of daily injection of N between early square and mid bloom was 47 to 101 %.

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Speciation and Potential Availability of Phosphorus in Reduced Tillage System: Placement and Source Effect

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Abstract

Despite various advantages of reduced-till systems, it has been found that surface application of phosphorus (P), leads to an accumulation of P in the surface 0 to 5 cm soil layer and a depletion of available P deeper in the profile. We measured changes in soil pH, resin extractable P and speciation of P at 5 week and 6 month after P application to a soil system that was under long-term reduced tillage. Resin extractable P was lower for broadcast treatments as compared to deep band treatments for both the time periods. Resin extractable P was greater for the liquid P treated soils when compared to the granular P treated soils. Speciation results showed that granular-P fertilizers tended to form Fe-phosphate like products whereas liquid forms found to remain in adsorbed-P like forms in soil after 5-wk of application. Over 6 month time period, reaction products of broadcast-granular and broadcast-liquid and deep band-granular fertilizers transformed to Ca-phosphate- or mixtures of Ca-, Fe-, Al- and adsorbed-phosphate-like forms while deep band-liquid P continued to remain mainly as adsorbed-P like forms.

Introduction

Phosphorus management in reduced tillage systems has been a great concern for farmers. It has been found that P applications, mostly in granular forms, leads to an accumulation of available P on the surface 0 to 5 cm soil layer and a depletion of available P deeper in the profile (Schwab et al., 2006). Deep placement of nutrients below the first 5 to 10 cm of the soils should be superior to other placements when nutrient stratification, coupled with topsoil moisture deficit, reduces nutrient uptake from shallow soil layers (Bordoli and Mallarino, 1998). Inconsistent results have been obtained from the research conducted to study the effects of tillage and deep placement of P fertilizers on grain yields of crops grown in Kansas (Schwab et al., 2006). Knowledge of the dominant solid P species present in soil following application of P fertilizers and linking that to potential P availability would help understand how to manage P in efficiently reduced tillage systems. The objective of this research was to understand the influence of placement (broadcast- vs. deep band-P), fertilizer source (granular- versus liquid-P) and time on reaction products of P under field conditions.

Materials and Methods

A field based study was done at Agronomy North Farm site located in Manhattan, KS. This site has a history of more than five years of reduced tillage. Two P fertilizer sources were granular monoammonium phosphate (granular MAP) and technical grade MAP (liquid MAP). Phosphorus was applied at 75 kg/ha and N as urea was applied at 200 kg N/ha. The treatments were: Urea Broadcast (control), Urea Deep band (control), granular MAP (MAP) Broadcast; granular MAP Deep band; liquid MAP (TGMAP) Broadcast; and liquid MAP Deep band. Experimental design was a randomized complete block design with five replications and the plot size was 5’ x 8’ with 3’ alley between the plots. Broadcast treatments were applied on the surface and gently mixed, whereas deep band treatments were applied approximately at 10 cm depth in two rows per plot. Soil sampling was done at 5 week and 6 months time after treatment application. Each time 30cm long soil cores were extracted using auger and divided into 2.5 cm slices, air dried and sieved <2mm. The wet chemical based analysis included pH (1:5 soil:water), total P (Bremner and Mulvaney, 1982) and resin extractable P (Myers et al., 2005). Resin extractable P was used to estimate plant available P. All date were analyzed using proc mixed procedure using SAS software (SAS 9.1, 2007). Pairwise Bonferroni method was used for pairwise comparisons of all the treatments at α= 0.05 level of significance.

Synchrotron-based bulk x-ray absorption near-edge structure (XANES) spectroscopy analysis (to determine chemical form of reaction products, was performed at sector 9 BM-B, Advanced Photon Source, Argonne, IL, U.S.A. The first derivatives of reduced spectra for the samples were analyzed by linear combination fitting (LCF) using IFEFFIT software (Newville, 2001). Spectra for the various standard compounds were reduced and normalized as for the spectra of the soil samples.

Results and Discussion

Mixed results (lower, higher or no significant difference) were observed for soil pH when comparing differences in soil pH among the urea added control plots and the both urea+ MAP (as granular or liquid MAP) added plots (data not shown). Acidification effects of MAP on soil pH have been reported by many researchers (Moody et al., 1995). However, hydrolysis of urea consumes two moles of protons for each mole of urea hydrolyzed, thereby resulting an increase in pH. So combination of these reactions (nitrification of NH_4^+ and hydrolysis of urea) in turn could result mixed effects on overall soil pH. At five weeks, soil pH in both urea and MAP (as granular or liquid) added zones were significantly lower (by about 0.2 to 0.5 units) than the original soil pH (5.3). However, soil pH of six month samples was higher (by about 0.2 to 0.6 units) when compared to the soils sampled from the same plots (i.e., that received same soil treatment) at 5 weeks. This could most likely be due to neutralization of initial treatment effects on soil pH with time and in-field seasonal variation of soil pH. Broadcast urea control (0 to 2.5 cm) had slightly higher total P concentration (~500 to 620 mg P/kg) when compared to that of deep band control (7.5 to 10 cm) (~400 to 450 mg P/kg), which can be attributed to P stratification due to reduced tillage practice. We used resin extractable P to estimate potential available P in soils. The P supplying power of soils assessed by anionic exchange resins have been shown to correlate satisfactorily with P uptake and P concentration in the biomass. Therefore, resin extractable P can be considered as a reliable index of available P in soils (Myers et al., 1995). At five weeks, in the urea broadcast (control) and urea deep band (control) plots, % resin extractable P concentrations were 3.4 and 9.2, respectively (Figure 1). In the deep band P plots both the granular and liquid treatments, had a significantly higher % resin extractable P in comparison to the No P urea broadcast or urea deep band treatments. At 6 months, only the deep band liquid treatment, had a significantly higher % resin extractable P in comparison to the both no P urea broadcast or no P urea deep band treatments.

Bulk XANES spectra suggested that the majority of P (69.2%) in the broadcast granular MAP treatment at 5 wk was vivianite ($Fe(II)_3(PO_4)_2 \bullet 8(H_2O)$)-like P form (Table 1). The spectra for broadcast liquid MAP- treated soil suggested two major form of P in this soil, strengite ($FePO_4 \cdot 2H_2O$)- like (38.9%) and adsorbed P (43.4%). Similarly, for the deep banded granular-MAP-treated soils at 5 wk, the majority of P (64.5%) existed as vivianite-like form while adsorbed P accounted for the rest. The spectra of the deep band liquid MAP-treated soils suggested 46.7% of vivianite-like P and 53.4% as adsorbed-P (Table 1). Over 6 month time period, reaction products of broadcast-granular MAP and liquid-MAP treated soils were transformed to Ca phosphate-like, Al phosphate-like and Fe phosphate- like forms while the majority of P in deep banded liquid MAP treated soils continued to remain in adsorbed-P like forms. Lindsay (1979) suggested that the formation of sparingly soluble mixed Al- phosphates and/or Fe-phosphates as a possible mechanism restricting P solubility in acid soils. Similarly depending on activity of Ca^{2+} in soil solutions, precipitation of P as Ca-phosphates can also responsible for restricting P solubility in slightly acid, neutral and alkaline soils.

Conclusions

It appears that when liquid MAP is deep placed in no-till soil systems, more P remains in resin extractable P forms for six months after fertilizer application. In contrast, broadcasted P, either in granular or in liquid form, tended to transform into less extractable P forms after five weeks or six months time period. Formation of Fe-, Al-, and/or Ca- P solid species, with different solubilities, may have been the reason for the observed differences in extractability or potential availability of P between broadcasted and deep placed granular and liquid MAP evaluated in this study.

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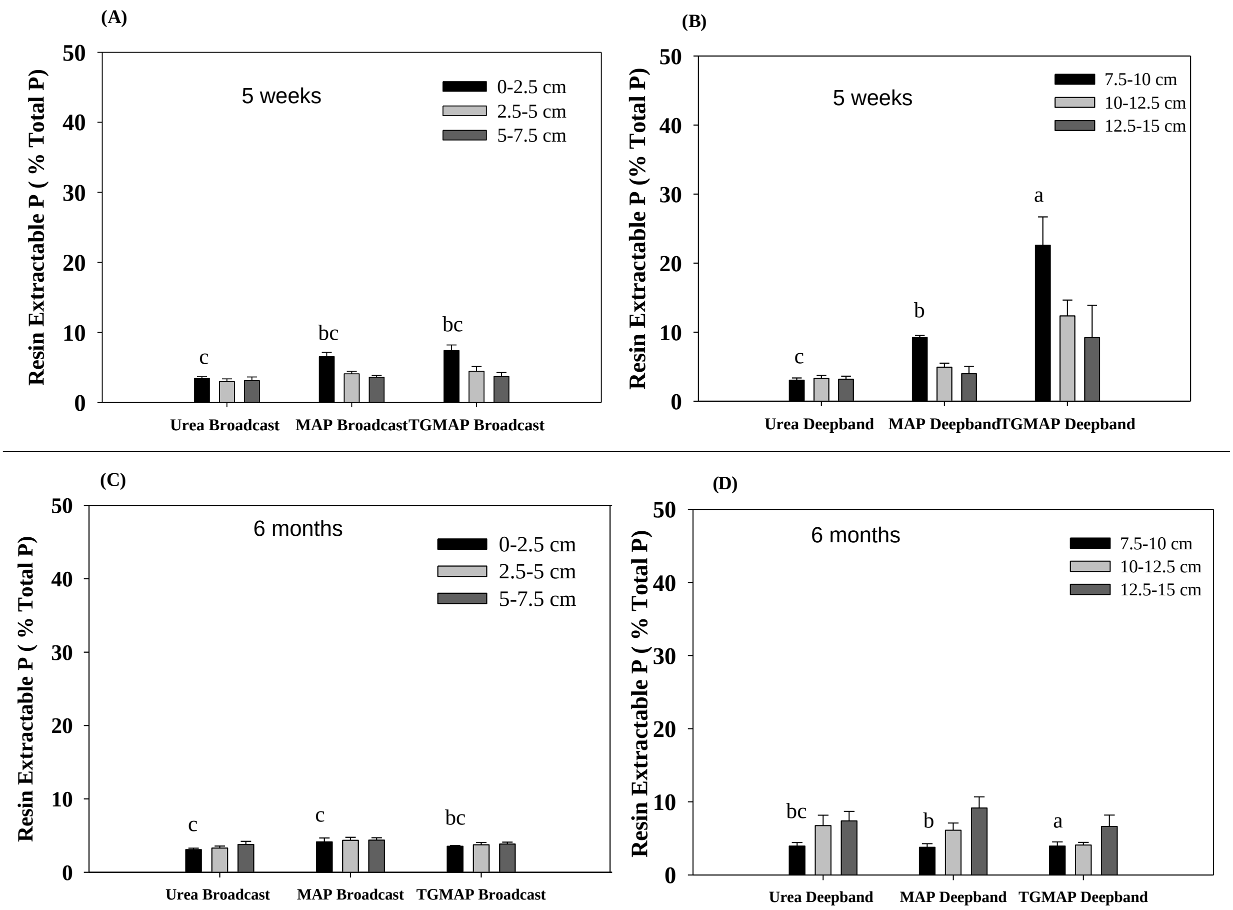

Figure 1. Resin extractable P (as % of total P) in soil sections collected at different distances from the point of fertilizer application. The resin extractable P (as a percent of total P) was calculated dividing resin extractable-P values for each section by the corresponding total P concentration. Error bars represent standard errors of five field replicates. (A) Five weeks broadcast, (B) Five weeks deep band, (C) Six months broadcast, and (D) Six months deep band treatments. Granular MAP= MAP; liquid MAP = TGMAP. Means with the same latter within a time period are not significantly different at $P < 0.05$.

Table 1. Percentages of P species in soils in the fertilized soil sections (0 to 2.5 cm for the broadcast and 7.5 to 10 am for the deep band treatments) determined by linear combination fitting of the first derivative of XANES spectra

Treatment	Al-Phosphates	Ca-Phosphates	Fe(III) Phosphate	Fe(II) Phosphate	Adsorbed P	Red. χ^{2*}
5 weeks						
Urea Broadcast (Control)	-	-	-	57.9	42.1	0.06
Gr. MAP Broadcast	11.3	-	-	69.2	19.5	0.01
Liquid MAP Broadcast	-	17.7	38.9	-	43.4	0.06
Urea Deep band (Control)	40.5	47	-	-	12.5	0.01
Gr. MAP Deep band	-	-	-	64.5	33.5	0.12
Liquid MAP Deep band	-	-	-	46.7	53.4	0.01
6 months						
Urea Broadcast (Control)	60.4	-	-	39.6	-	0.41
Gr. MAP Broadcast	46.3	-	-	-	53.6	0.01
Liquid MAP Broadcast	-	100	-	-	-	1.13
Urea Deep band (Control)	-	53	-	47	-	6.60
Gr. MAP Deep band	-	51.6	-	-	48.4	1.47
Liquid MAP Deep band	-	19.8	-	-	80.3	0.01

$^{*}\chi 2 = \Sigma(\text{fit} - \text{data})/\varepsilon]^2 \ / (N_{data} - N_{components})$ is the reduced chi-square statistic. Here ε □is the estimated uncertainty in the normalized XANES data (taken as 0.01 for all data). The sum is over N_{data} points (185 data points between E=2144 and 2179 eV for all data), and $N_{components}$ is the number of components in the fit.