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Missouri Fertilizer and Ag Lime Distributors

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Researchers, being overtly curious people with a penchant to find out why or how to do it better, normally have a list of topics that they want to research. Perhaps you have a topic that is particularly perplexing to you? These people could very well be those to ask why? If they don't know, then perhaps you will have just suggested the next burning question that will become the object of new research. Any questions or ideas? If you do, send them too us at:

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Agricultural Lime

Progress Reports
2013

Liming to Reduce Ergovaline Concentration in Toxic Tall Fescue Pastures

Investigators: Craig Roberts, Robert Kallenbach, and John Lory, University of Missouri

Objective and Relevance

Most pastures in Missouri are covered with common tall fescue, a perennial grass that is infected with a toxic fungus. The toxins, such as the ergot alkaloid ergovaline, causes a disorder called fescue toxicosis. Fescue toxicosis costs the Missouri beef industry $160 million each year by reducing reduce calf gains, milk production, and pregnancy rate.

Modern recommendations for tall fescue management involve "alkaloid management," which requires a set of practices that can reduce production and ingestion of ergovaline. These practices include livestock rotation among fields, dilution of tall fescue in the pasture by interseeding legumes, feeding of supplements, and ammoniation of hay. The practices may also include liming, as good soil fertility encourages legume growth and therefore dilutes the toxicity in a pasture.

It is critical to know if liming affects ergovaline production. Research has shown that ergot alkaloids toxins are unstable in alkaline environments and can be reduced when hay is treated with ammonia. Also, they break down when an alkaline reagent is used on the extract in the laboratory. To date, no research has been published that explores the effect of lime on ergot alkaloids concentrations.

The main objective is to determine the effect of soil pH on ergovaline concentration in toxic tall fescue. Because it is unknown where ergovaline occurs in the canopy, a **sub-objective** is to analyze the tillers in 2" segments.

Procedures

This research is being conducted on the Tom Roberts farm near Alton, MO. This farm was selected because it is primarily 'Kentucky-31' tall fescue established more than 20 years ago and is representative of most other farms in Missouri and surrounding states. On 14 October 2011, tillers from this field were tested for tall fescue endophyte using enzyme-linked immunosorbent assay (Hill, 2005); the results verified that the field was 95% infected with the endophyte. The field had been soil-sampled on 29 July 2011 and determined to have an average soil pH of 5.5.

Accomplishments for Year 1 (2012)

In December 2011, 16 plots measuring 10 x 20 feet were marked with a two-foot buffer separating the replicates (Fig. 1 and 2). Treatments were randomly assigned as non-treated control or treated with limestone, and it was replicated 8 times. Also in December 2011 each plot was tested and limestone surface applied (Table 1.) The limestone used was from Doss and Harper, West Plains, MO with an effective neutralizing material (ENM) rating of 368; each plot received enough limestone to meet the ENM requirements from individual plot soil tests.

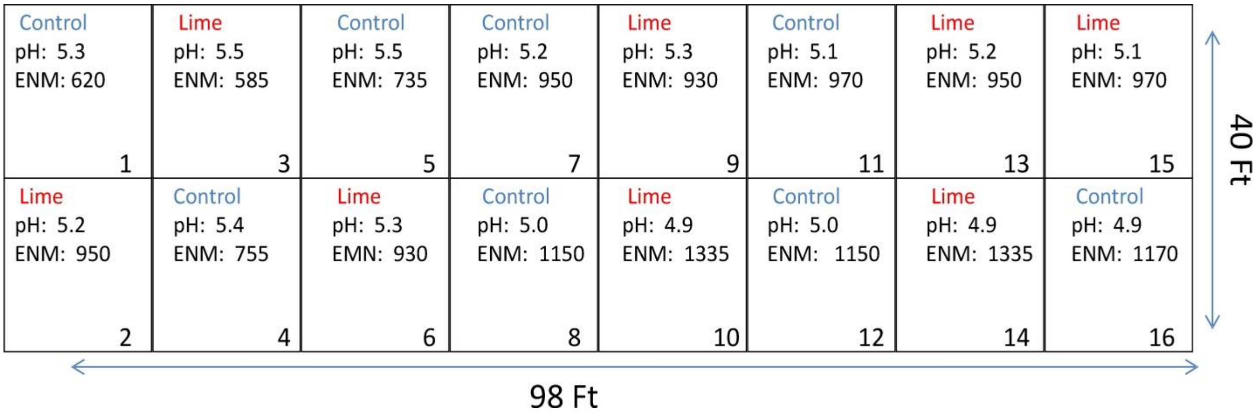

Figure 1. Plot layout of liming study located near Alton, MO with lime and pH data shown. The plots are 10 x 20 feet with 2-foot buffer strips (not shown).

Table 1. Soil test results for experimental site in Allton, MO. Dec 2011.

Lab No.	Sample I.D.	Treat-ment	pHs	N.A. meq/ 100g	O.M. %	Bray 1 P lb/a	Ca lb/a	Mg lb/a	K lb/a	CEC meq/ 100g
C1222709	1 0 - 1/2	Control	5.4	2.5	6.0	43	1486	371	284	8.1
C1222710	1 1/2 - 1		5.2	2.5	3.4	31	1227	290	300	7.2
C1222711	1 1 – 3		5.1	3.0	2.2	17	1324	282	297	7.9
C1222712	5 0 - 1/2	Control	5.4	3.0	6.2	110	1509	371	261	8.7
C1222713	5 1/2 - 1		5.4	3.0	3.4	133	1288	283	274	7.8
C1222714	5 1 – 3		5.4	3.0	2.3	145	1403	281	246	8.0
C1222721	11 0 - 1/2	Control	5.1	3.5	6.6	93	1335	345	274	8.6
C1222722	11 1/2 - 1		5.0	3.5	3.1	109	1055	241	279	7.5
C1222723	11 1 - 3		4.9	3.5	1.6	99	1129	233	260	7.6
C1222715	6 0 - 1/2	Lime	5.9	1.5	5.5	134	1459	402	265	7.2
C1222716	6 1/2 - 1		5.4	3.0	3.0	145	1398	316	276	8.2
C1222717	6 1 – 3		5.2	3.5	2.2	181	1523	281	317	8.9
C1222718	10 0 - 1/2	Lime	6.4	0.5	6.0	120	1571	499	244	6.8
C1222719	10 1/2 - 1		5.5	2.5	2.8	150	1186	355	309	7.3
C1222720	10 1 - 3		4.9	4.0	1.9	181	877	204	283	7.4
C122272	14 0 - 1/2	Lime	6.3	1.0	6.2	104	1632	530	254	7.6

4										
C122272 5	14 1/2 - 1		5.4	3.0	2.8	137	1231	369	294	8.0
C122272 6	14 1 - 3		4.8	4.0	1.8	139	1057	248	257	8.0

Figure 2. Plots for liming study established on the Tom Roberts farm near Alton, MO.

On 18 May 2012, plots were fertilized with nitrogen at the rate of 40 lb acre and with P and K to soil test. Annual grass weeds were controlled by spraying pendimethalin (Prowl H2O) at a rate of 4 pints acre-1 in early spring. Broadleaf weeds were controlled with picloram and 2,4-D (Grazon P+D) at a rate of 2 pints acre-1. During spray application a non-ionic surfactant was used.

Plant tillers were harvested on 4 May for the spring sampling and on 15 October for the fall sampling. The spring sampling date was chosen to harvest plants after “green-up” but before seedhead development. (Seedheads are highly concentrated with ergovaline and can temporarily skew the results.) The fall sampling date was chosen to harvest plants that greened up after summer dormancy but before the killing frost. Individual plant tillers were randomly selected, cut at soil level, and stored in a freezer immediately.

Sample analysis is scheduled for completion in 2013 (Table 2), but some of the analysis was completed in December 2012. Frozen samples were freeze-dried, ground to 1 mm, and analyzed for ergovaline by HPLC. The whole tillers have been analyzed; the tillers were cut into 2-inch segments, and those samples are currently in the laboratory.

Results from whole tillers show no difference in ergovaline between limed-treated plots and non-limed controls. This was expected for year 1; there has not been enough time to have seen a lime effect on soil pH in these plots, in part because of the drought of 2012. Preliminary results also show that spring tillers were less toxic than fall tillers. Thus far, the ergovaline concentrations in the spring are below 400 ppb and concentrations in the fall exceed 800 ppb. The complete data set for years 1 and 2 is on schedule for reporting in December 2013.

Accomplishments for Year 2 (2013)

In 2013, plots were clipped in the spring and fall, freeze-dried and ground, then analyzed for ergovaline concentration. In addition to whole plant samples collected from the treatment and control plots, whole tillers were also collected; these tillers were segmented, freeze-dried, ground, and analyzed for ergovaline. Significance of treatments and interactions were determined by PROC MIXED in SAS.

Effect of Lime

The effect of lime on ergovaline can be seen in Tables 2 – 5 below. Although there were numerical differences, there were no statistically significant effects of year (2012 vs. 2013), season (spring vs. fall), or treatment (lime vs. control) on ergovaline concentrations.

Table 2. Analysis of variance showing no significant effect of season or lime treatment on ergovaline concentration in toxic tall fescue.

Source	**Prob > F**
Season	0.55
Lime	0.55
Season*Lime	0.90

Table 3. Means of ergovaline tall fescue in the fall (averaged over 2012 and 2013) and spring of 2013. Means with the same letter are not significantly different.

Season	**Mean** (ppb)
Fall	516 A
Spring	286 A

Table 4. Means of ergovaline in plots of tall fescue treated with lime and non-treated (control). Means with the same letter are not significantly different.

Treatment	**Mean** (ppb)
Lime	385 A
Control	417 A

Table 5. Means of ergovaline in tall fescue harvested 2012 and 2013. Means with the same letter are not significantly different.

Year	Mean (ppb)
2012	445 A
2013	358 A

Effect of Canopy Segment

Ergovaline was highest ($p < 0.001$) in the lowest 2" of the canopy. The importance of this relates to grazing management in limed pastures. The liming encourages legume growth. However, the legumes are often grazed out, as producers graze pastures too low. The data below, if they hold up, provide more incentive to avoid grazing too low. If pastures are not grazed below a 2" stubble height, 1) legumes would not be grazed out and the producer could benefit from liming, and 2) the cattle would not consume high concentrations of ergovaline.

Table 6. Ergovaline distribution in the vegetative tall fescue canopy in three harvest seasons. Means with the same letter are not significantly different.

Season	Segment (inches from soil surface)	Mean	
Fall 2012	0 - 2	1727	A
	2 - 4	298	B
	4 - 6	232	B
	>6	219	B
Spring 2013	0 - 2	243	A
	2 - 4	148	B
	4 - 6	128	B
	>6	161	B
Fall 2013	0 - 2	515	A
	2 - 4	136	B
	4 - 6	141	B
	>6	121	B

Objectives for Year 3 (2014)

Objectives for the third year are seen below (Table 7), which include plot maintenance, harvesting whole plants in April and October, segmenting the tillers, and chemical (ergovaline) analysis of all whole tillers and all tiller segments. Lastly, the third year objectives involve writing a journal paper and presenting findings at extension meetings in the state.

Table 7. Timetable for research and extension activities.

Year	Activity
2014	Sample plots (April, October)
	Samples segmented and stored in freezer
	Research presented at conference
	Ergovaline analysis
	Manuscript prepared for journal; findings presented via Extension

Proposed Budget for Year 3

Item	Year 3
Research Technician (25%)	$12,187
Benefits	$3,900
Supplies	$2,600
Travel	$1,200
Ergovaline analysis	$8,320
Publications	$800
Total	**29,007**

Justification: The salary and benefits for the **research technician** are based on 25% of a salary of $48,750 and 32% benefits. The research technician will be involved not only in the field and laboratory aspects of the experiment but also in extension presentations. **Supplies** are for all laboratory and field work, including fertilizer, sample bags, mower accessories, weigh boats, clippers, freeze drier oil, grinder parts, and similar supplies. **Travel** includes trips to the research site. **Ergovaline analysis** is based in a per sample charge of $53; samples from years 1 and 2 will be analyzed in year 2 (256 samples x $53 = $13,568).

Benefits of Lime Placement on Grain Yield Response and Remediation of Acid Subsoils

Investigators:
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Objective and Relevance:

An extensive root system is essential for crop plants to tolerate short- and long-term periods of drought that often occur during the growing season in Missouri. Acid subsoils reduce root growth and grain yield. Stratification of pH values is common in claypan soils in Missouri. In soil survey publications, surface soil samples of claypan soils may have optimum pH values; however, the subsoil from 8 to 20 in. may decrease to pH values as low as 3.6, 4.5, and 4.5 for soils such as Putnam, Mexico, and Armstrong, respectively (Ferguson, 1995). In three-paired watershed research, seventy five soil samples from the Ap, AB, and Bt1 horizons had average pH values of 6.6 ($\pm$1.7), 6.3 ($\pm$0.6), and 4.9 ($\pm$1.2), respectively (Udawatta, unpublished). Drainage research plots had subsoil (8-18 in.) pH values from 4.7 to 5.2 (Nelson, unpublished) while other research indicated average subsoil pH values from 29 claypan soils at the 0-6 in., 6-12 in., 12-24 in., and 24-36 in. depths were 6.2, 6.0, 5.0, and 5.1 (Scharf, unpublished). Over 60% of the 29 fields had pH values less than 5 at the 12-24 in. depth. The lowest pH value at any site was 4.4. Acidic subsoils (at or below the 12 in. depth) may be a greater barrier to root growth than physical restrictions in many soils in Missouri.

Research on cotton (Adcock et al., 1999) and alfalfa (Rechcigl et al., 1991) has demonstrated the benefit of deep lime placement. Methods that incorporated lime increased corn grain yields greater than conventional liming techniques using surface applications (Farina and Channon, 1988). In this research, corn grain yields increased 20 bu/a in a dry year while in a wet year grain yield increased 6 bu/a (Farina and Channon, 1988). Low soil pH, 5 to 5.5, is an agronomic and environmental concern. Macronutrient and microbial activity is restricted and phytotoxic levels of exchangeable Al and Mn are common at low soil pH values. In addition, nitrification may be limited in an acidic environment. Nitrogen applications from ammonium-based N fertilizers acidify soils and require agriculture lime applications to neutralize the impact on soil pH. N sources may require 1.8 to 5.4 lb $CaCO_3$ to neutralize acidity depending on the N source. Anhydrous ammonia applications are commonly used throughout the region and may contribute to a decrease in subsoil pH while the surface soil pH is acceptable. A deep lime application may also reduce the impact of low soil pH on root growth and development.

Acid-subsoil amelioration has been studied with long-term impacts on soil pH levels (Toma et al., 1999; Farina et al., 2000b). Grain and forage yields increased 29 to 50% even 16 yr. after application (Toma et al., 1999) with increased returns (Farina et al., 2000a). Deep placement of dry lime at 1500 lbs/acre over two years increased soybean grain yields over 4 bu/a and increased profitability $94/acre compared to deep tillage only (Tupper et al. 1987). Farmers have utilized no-till and conventional tillage systems to attain specific production goals. Incorporation of lime may be necessary to realize an immediate (Toma et al. 1999) increase in grain yield. Deep placement of lime utilizing conservation-type knives could accomplish an immediate increase in grain yield, provide zone-tillage, increase subsoil pH, and maintain surface residue. Concerns regarding the practicality and economics of deep incorporation have been expressed; however, numerous producers continue to subsoil claypan soils. Previous MU research has evaluated pH management in the top 6 to 8 inches of soil; however, no research has evaluated deep lime applications or the impact on subsoil properties. This research initiates a long-term evaluation of the impact of addressing subsoil pH correction in no-till and reduced tillage cropping systems. *The objective of this research is to evaluate yield response of corn and soybean to lime placement and the impact on subsoil pH.* We will maintain the field that was established in 2012 and 2013. Corn plots will rotate into soybean while soybean will rotate into corn. A third location was established for 2014 and treatments were applied in the fall of 2013 which is more typical of a deep tillage treatment.

Materials and Methods:

A field trial was established at the University of Missouri Greenley Research Center on a Putnam silt loam that has been in continuous no-till production for over 13 years with an acid subsoil in May 2012 and the fall of 2012 (Table 1). A third research site was established in November 2013. A factorial arrangement of treatments included placement (no-till surface and conservation subsoiler deep placement), crop (corn and soybean), and lime rates (0, 1.5, and 3 tons/acre with 600 lbs effective neutralizing material/ton) to evaluate the response of corn or soybeans within a given year. Pelleted lime (Kelly’s Limestone, Newark, MO) was derived from mined calcium carbonate and magnesium carbonate. A 2% lignosulfonate was utilized as the binding agent for pelletizing. The conservation subsoiler (Case IH 2500 ecolo-til) (Figure 1, left) had custom built shank (Figure 1, right) to deliver and distribute lime to 4 different levels in the soil profile, while delivery and metering was accomplished using a commercial Montag (Figure 1, left) dry fertilizer air delivery system. The selected rates of lime were based on an average subsoil recommendation (high rate), top 6 inches of soil recommendation (low rate), and a non-treated control. A site with a low surface pH was utilized in the experiment (Table 1).

Figure 1. Deep placement applicator with Montag dry fertilizer air delivery system (left) and custom built applicator shank (right).

Precipitation is reported in Table 2 while field management and crop protection chemical applications for corn and soybean are reported in Tables 3 and 4, respectively. This research evaluated soil pH at four depths (0-5, 6-10, 11-15, and 16-20 inches) similar to other research (Farina et al. 2000a, 2000b; Tupper et al., 1987), grain yield, and crop growth characteristics. Soil samples were collected in the fall of 2012 and 2013. Soil samples for 2013 are currently being processed through the University of Missouri Soil Testing Laboratory. Soil sampling depth corresponded to the different distribution drop tubes on the applicator shank.

Figure 2. Soil during application (left), after application (center), and an overhead overview after application (right).

The center two rows of corn were harvested for yield and converted to 15%, while the center 5 ft of the soybean plot was harvested and adjusted to 13% moisture prior to analysis. Grain samples were collected and were analyzed for protein and oil (soybean), and starch, protein, oil (corn) using near-infrared spectroscopy (Foss Infratec 1241 Grain Analyzer, Eden Prairie, MN) (data not presented). All data were subjected to ANOVA and means separated using Fisher's protected LSD at $P = 0.1$.

Results:

The custom built shank effectively distributed lime throughout the soil profile (Figure 2). The modified shank caused more soil disturbance than normal and tillage following application was utilized to smooth the soil surface (Tables 3 and 4) prior to planting. No tillage was used in the surface application only treatments. The site for 2013 was established and treatments were applied on Nov. 27, 2012. An extensive drought occurred in 2012. Precipitation during the 2012 growing was 7.3 inches below normal (Table 3).

Corn plants were 2 to 5 inches taller (July 5) in the deep placed treatments compared to no-till, which persisted until tasseling (August 2) in 2012 (Table 5). Plants were slightly taller for the surface applied lime at 2 ton/acre in 2013, but were shorter in the deep placed lime treatments established in 2013. The site established in 2012 had plant populations that were generally greater in the no-till surface applied treatments compared to the deep ripped/placement treatments in 2012, and no differences were observed in 2013. Deep placement had greater plant populations than surface applied lime at the site established in 2013. There was no treatment effect on soybean height in 2012 or 2013, and there was no treatment effect on plant population in 2012 (Table 6). However, soybean plant population was 30,000 to 31,000 plants/acre greater with surface applied lime at 1.5 ton/acre compared to deep placement at both locations in 2013.

Soil test pH_s in the top 5 inches of soil for the surface applied lime increased in corn and soybean as lime rate increased; however, there was no effect of deep placement on pH_s in the top 5 inches of soil (Table 7). At 6 to 10 inches deep, soil pH_s increased 0.5 points for deep placed lime at 1.5 tons/acre in soybean. No differences were observed 11 to 20 inches deep in the soil profile 6 months after application.

In an extremely dry year (2012), deep placement treatments increased corn yields 4 to 8 bu/acre (Figure 3a). However, no differences in yield among lime treatments were detected. In 2013, grain yield was 14 bu/acre greater for the no-till, non-treated control compared to deep tillage non-treated control, and 9 bu/acre greater for the surface applied lime at 1.5 ton/acre compared to deep placement at 1.5 ton/acre (Figure 3a). Grain yields were not affected by deep placement compared to surface applied lime at the site established in 2013 (Figure 3b).

Deep placement treatments in 2012 reduced soybean yield in the non-treated control and lime at 1.5 ton/acre (Figure 4a), while there was no effect of placement on soybean yield at the 3 ton/acre rate. Grain yields were 2 to 3 bu/ac greater for the no-till, non-treated control and surface applied lime compared to the equivalent deep placement treatments in 2013 (Figure 4a). Limited differences were observed among treatments at the site established in 2013 (Figure 4b).

In dry years (2012 and 2013), slight differences in corn grain yields were observed when comparing no-till surface lime applications compared to deep placement. Deep tillage did not increase soybean yields at the site established in 2012 over the first two dry years of this research.

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Table 1. Initial soil characteristics at different depths for the sites established in 2012 and 2013.

Soil characteristics	0-5 inches	6-10 inches	11-15 inches	16-20 inches
Established in 2012				
pH	5.6 ± 0.2	5.6 ± 0.4	4.6 ± 0.2	4.6 ± 0.2
Neutralizable acidity (meq/100 g)	3.5 ± 2	2.9 ± 1	8.5 ± 1.6	6.8 ± 1.0
Organic matter (%)	2.7 ± 0.3	2.3 ± 0.1	2.3 ± 0.3	2.2 ± 0.2
Bray 1P (lb/acre)	15.5 ± 8.7	4.5 ± 1.3	3.5 ± 1.9	13.0 ± 4.0
Ca (lb/acre)	3950 ± 310	4640 ± 590	4690 ± 630	4450 ± 600
Mg (lb/acre)	441 ± 87	615 ± 169	875 ±123	889 ± 136
K (lb/acre)	159 ± 11	155 ± 25	202 ± 30	206 ± 14
CEC (meq/100 g)	15.4 ± 2.3	17.3 ± 3.2	24.2 ± 3.2	22.0 ± 2.3
Established in 2013				
pH	5.0 ± 0.1	5.0 ± 0.5	4.9 ± 0.7	4.9 ± 0.8
Neutralizable acidity (meq/100 g)	5.1 ± 0.5	4.9 ± 1.9	6.9 ± 4.0	6.8 ± 3.8
Organic matter (%)	3.0 ± 0.6	1.9 ± 0.4	1.8 ± 0.3	1.4 ± 0.4
Bray 1P (lb/acre)	113.5 ± 41.2	17.0 ± 9.6	10.3 ± 3.6	27.5 ± 17.3
Ca (lb/acre)	2535 ± 273	2911 ± 616	3692 ± 1634	3697 ± 1497
Mg (lb/acre)	274 ± 81	370 ± 171	659 ± 403	757 ± 375
K (lb/acre)	530 ± 214	142 ± 42	160 ± 69	208 ± 76
CEC (meq/100 g)	13.3 ± 1.4	13.9 ± 3.3	19.1 ± 6.4	19.4 ± 4.8

Table 2. Monthly precipitation average (10-year) and during the 2012 and 2013 growing seasons at Novelty.

Month	10-year average†	2012	2013
		---------------- Inches	----------------
Apr.	3.9	---	---
May	4.4	---‡	10.3
June	4.9	2.2	3.6
July	3.7	0.7	1.9
Aug.	4.8	3.0	0
Sep.	3.4	3.6	3.1
Total	25.1	9.5	18.9

†Averaged from 2000 to 2009.
‡Planted May 30, 2012

Table 3. Field and management information for the corn sites established at Novelty in 2012 and 2013.

	Established in 2012		Established in 2013
Management information	2012	2013	2013
Plot size (ft)	15 by 80	15 by 80	15 by 75
Hybrid or cultivar	DKC 63-25 VT3	DKC 63-25 VT3	DKC 63-87
Planting date	30 May	14 May	14 May
Row spacing (inches)	30	30	30
Seeding rate (seeds/acre)	30,000	30,000	30,000
Harvest date	12 Oct.	19 Sep.	19 Sep.
Maintenance fertilizer	None	None	None
Nitrogen	60 lbs N/acre (Urea) and 130 lbs N/acre (PCU)	200 lbs N/acre (AA)	120 lbs N/acre (PCU)
Lime	29 May	None	27 Nov
Tillage	Tilloll 2x 30 May Cultipacked 30 May in deep tilled treatments	None	Tilloll 2x 1 May
Weed management			
Burndown	5 June, Verdict (5 oz/acre) + Roundup PowerMAX (32 oz/acre) + NIS (0.25% v/v) + UAN (1 qt/acre)	22 May, Lexar (2.5 qt/acre) + Roundup PowerMAX (32 oz/acre) + COC (1 qt/acre)	22 May, Lexar (2.5 qt/acre) + Roundup PowerMAX (32 oz/acre) + COC (1 qt/acre)
Postemergence	22 June, Roundup PowerMAX (32 oz/acre) + DAS (17 lbs/100 gal) + COC (1 qt/acre) + Callisto (3 oz/acre) + Atrazine (1 qt/acre)	27 June, Roundup PowerMAX (32 oz/acre) + DAS (17 lbs/100 gal) + COC (1 qt/acre) + Callisto (3 oz/acre) + NIS (0.25% v/v)	27 June, Roundup PowerMAX (32 oz/acre) + DAS (17 lbs/100 gal) + COC (1 qt/acre) + Callisto (3 oz/acre) + NIS (0.25% v/v)
Insect management	NA	NA	NA
Disease management	NA	NA	NA

Table 4. Field and management information for the soybean sites established at Novelty in 2012 and 2013.

	Established in 2012		Established in 2013
Management information	2012	2013	2013
Plot size (ft)	15 by 80	15 by 80	15 by 75
Hybrid or cultivar	AG3730 RR2	AG3730 RR2	AG3731 RR2
Planting date	30 May	8 May	16 May
Row spacing (inches)	7.5	7.5	7.5
Seeding rate (seeds/acre)	200,000	200,000	200,000
Harvest date	4 Oct.	9 Sep.	9 Sep.
Maintenance fertilizer	None	None	None
Urea and PCU			
Lime	29 May	None	27 Nov
Tillage	Tilloll 2x 30 May Cultipacked 30 May in deep tilled treatments	None	Tilloll 2x 1 May
Weed management			
Burndown	5 June, Verdict (5 oz/acre) + Roundup PowerMAX (32 oz/acre) + NIS (0.25% v/v) + UAN (1 qt/acre)	22 May, Prefer (2.25 qt/acre) + Roundup PowerMAX (32 oz/acre) + COC (1 qt/acre) + UAN (1 qt/acre)	22 May, Prefer (2.25 qt/acre) + Roundup PowerMAX (32 oz/acre) + COC (1 qt/acre) + UAN (1 qt/acre)
Postemergence	22 June, Reflex (1.25 pt/acre) + Roundup PowerMAX (22 oz/acre) + DAS (17 lbs/100 gal) + NIS (0.25% v/v)	NA	NA
Insect management	NA	NA	NA
Disease management	NA	NA	NA

†Abbreviations: COC, crop oil concentrate; DAS, diammonium sulfate; NA, None applied; NIS, non-ionic surfactant; UAN, 32% urea ammonium nitrate.

Table 5. Corn plant population and heights as affected by no-till surface or deep placed lime (non-treated = 0 ton/acre, low = 1.5 ton/acre, and high 3.0 ton/acre) for sites established in 2012 and 2013.

	2012			2013	
	Height			Height	
Lime placement	July 5	August 2	Population	October 4	Population
	---- Inches ----		No./acre	Inches	No./acre
Established in 2012					
Surface non-treated	36	65	30,100	80	26,700
Surface 1.5 ton/acre	37	64	30,000	81	27,100
Surface 3 ton/acre	34	63	29,200	82	27,400
Deep placement non-treated	39	67	26,000	80	26,900
Deep placement 1.5 ton/acre	38	68	28,000	80	27,700
Deep placement 3 ton/acre	39	67	27,900	79	28,400
LSD (P = 0.1)	2	2	2,200	2	NS
Established in 2013					
Surface non-treated				103	27,000
Surface 1.5 ton/acre				100	24,000
Surface 3 ton/acre				101	26,000
Deep placement non-treated				102	28,800
Deep placement 1.5 ton/acre				99	28,200
Deep placement 3 ton/acre				97	28,800
LSD (P = 0.1)				4	1,700

Table 6. Soybean plant population and heights as affected by no-till surface or deep placed lime (non-treated = 0 ton/acre, low = 1.5 ton/acre, and high 3.0 ton/acre) for sites established in 2012 and 2013.

	2012		2013	
Lime placement	Height	Population	Height	Population
	Inches	No./acre	Inches	No./acre
Established in 2012				
Surface non-treated	22	187,000	28	153,000
Surface 1.5 ton/acre	22	205,000	28	157,000
Surface 3 ton/acre	22	161,000	26	166,000
Deep placement non-treated	22	196,000	27	145,000
Deep placement 1.5 ton/acre	21	183,000	26	127,000
Deep placement 3 ton/acre	22	203,000	26	148,000
LSD (*P* = 0.1)	NS	NS	NS	21,000
Established in 2013				
Surface non-treated			31	170,000
Surface 1.5 ton/acre			31	170,000
Surface 3 ton/acre			31	148,000
Deep placement non-treated			28	152,000
Deep placement 1.5 ton/acre			31	139,000
Deep placement 3 ton/acre			31	148,000
LSD (*P* = 0.1)			NS	25,000

Table 7. Soil test pH_s values at 0 to 5, 6 to 10, 11 to15, and 16 to 20 inch depths after corn and soybean harvest for the experimental site established in 2012. Interactions between factors were presented when appropriate.

	pH_s					
	0-5 in.		6-10 in.			
Lime placement	Corn	Soybean	Corn	Soybean	11-15 in.	16-20 in.
Established in 2012						
Surface non-treated	5.4	5.8	4.9	4.7	4.8	4.5
Surface 1.5 ton/acre	5.9	6.6	4.7	4.7	4.7	4.5
Surface 3 ton/acre	6.2	6.4	4.8	4.7	4.7	4.5
Deep placement non-treated	5.7	5.7	4.8	4.7	4.7	4.5
Deep placement 1.5 ton/acre	5.7	5.8	5.0	5.2	5.1	4.5
Deep placement 3 ton/acre	5.4	5.8	4.8	4.7	4.6	4.4
LSD (*P* = 0.1)	----- 0.3 -----		----- 0.4 -----		NS	NS

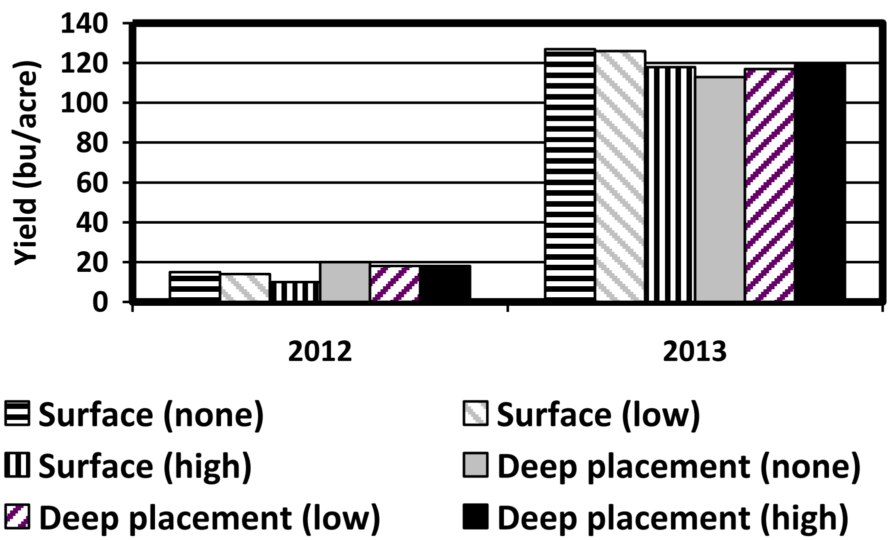

Figure 3a. Corn grain yield response to no-till surface or deep placed lime (none = 0 ton/acre, low = 1.5 ton/acre, and high 3.0 ton/acre) established in 2012. LSD (P = 0.1) was 4 and 9 bu/acre in 2012 and 2013, respectively.

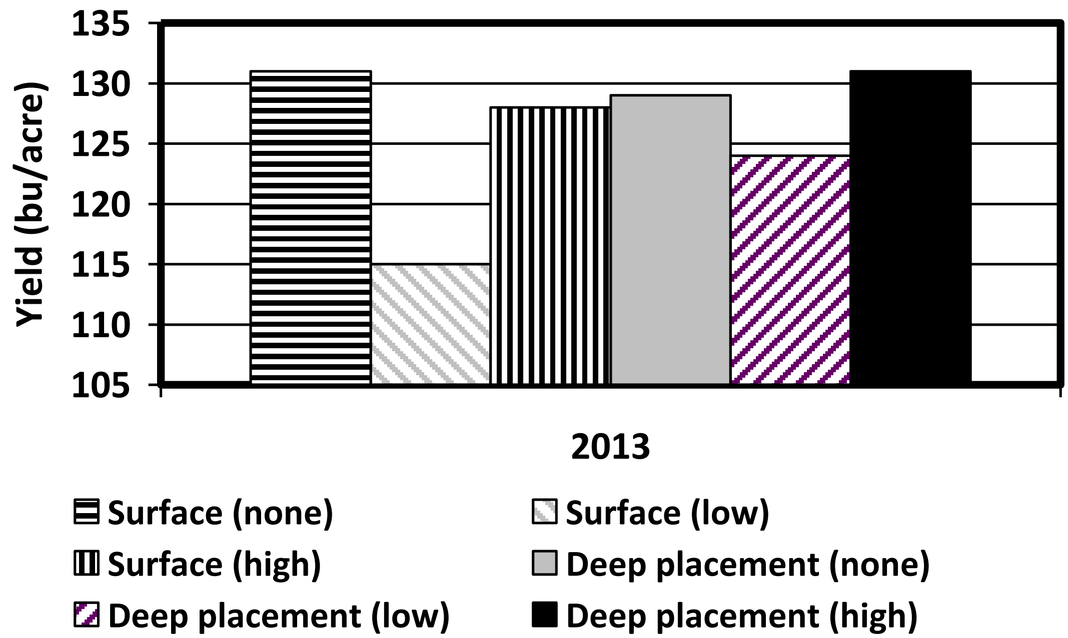

Figure 3b. Corn grain yield response to no-till surface or deep placed lime (none = 0 ton/acre, low = 1.5 ton/acre, and high 3.0 ton/acre) established in 2013. LSD (P = 0.1) was 12 bu/acre in 2013.

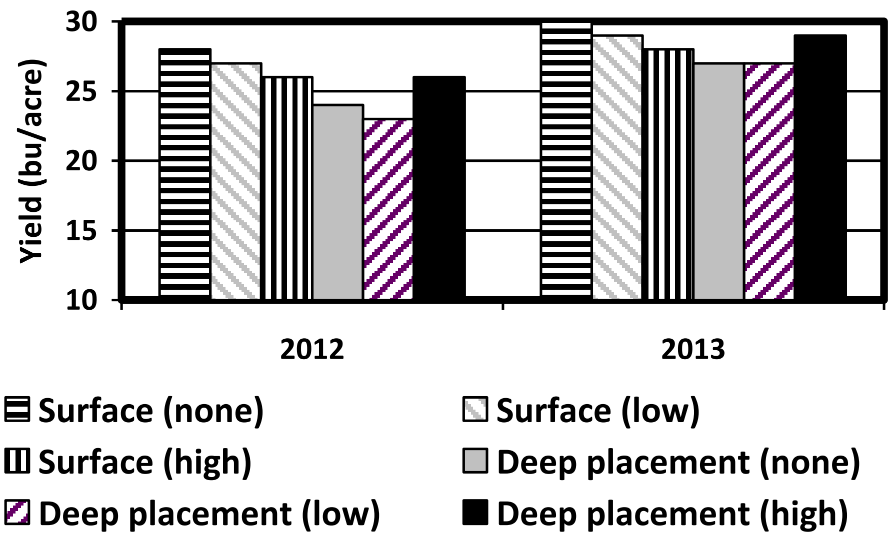

Figure 4a. Soybean grain yield response to no-till surface or deep placed lime (none = 0 ton/acre, low = 1.5 ton/acre, and high 3.0 ton/acre) established in 2012. LSD (P = 0.1) was 2 and 2 bu/acre in 2012 and 2013, respectively.

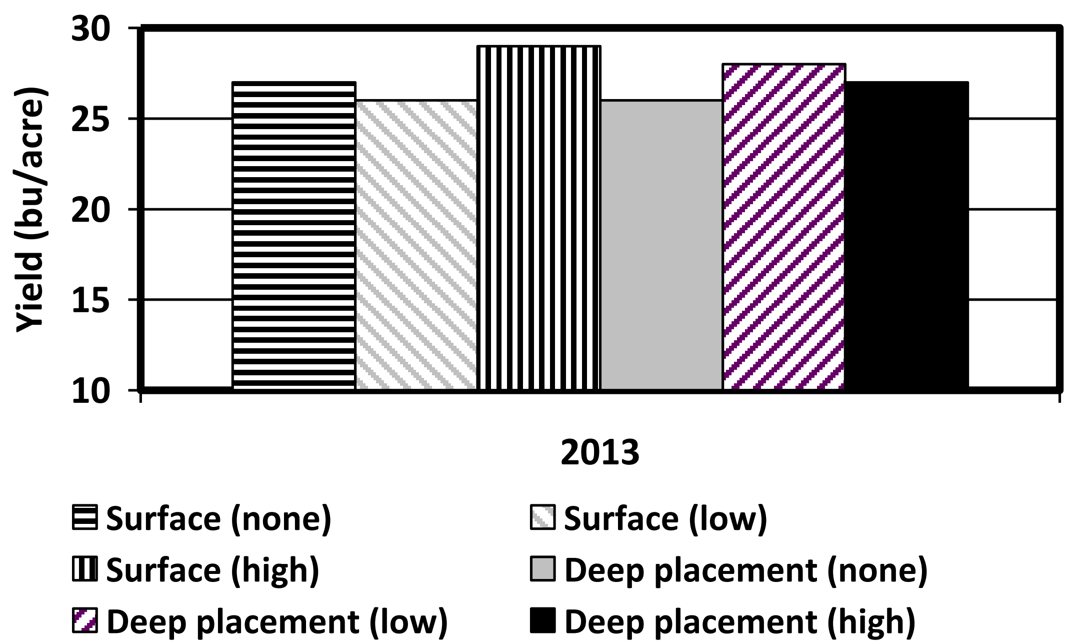

Figure 4b. Soybean grain yield response to no-till surface or deep placed lime (none = 0 ton/acre, low = 1.5 ton/acre, and high 3.0 ton/acre) established in 2012. LSD (P = 0.1) was 3 bu/acre in 2013.

Timetable:

2013	Prepare equipment, sampled soil and applied lime treatments for the final experiment initiated in 2014.
2014	
April-September	Manage plots and demonstrate at local field day
September	Harvest and resample soil
Oct-Dec	Analyze results

Budget:

CATEGORIES	Year 3 (2014)	Total
A. Salaries		
Research Specialist or M.S. Graduate Research Assistant (50%)	$14,670	$42,875
B. Fringe Benefits		
Fringe for graduate student	$2,548	$7,424
TOTAL SALARIES AND FRINGE BENEFITS	$17,218	$50,299
C. Travel		
Travel to field site	$0	$0
To present research findings at National Meetings	$1,200	$2,400
TOTAL TRAVEL COSTS	$1,200	$2,400
D. Equipment	$0	$0
TOTAL EQUIPMENT use and maintenance COSTS	$0	$0
E. Other Direct Costs		
Soil analysis	$5,500	$13,750
Grain analysis	$2,500	$6,500
Publication cost	$750	$1,500
Misc.	$3,500	$10,500
TOTAL OTHER DIRECT COSTS	$12,250	$32,250
TOTAL REQUEST	**$30,668**	**$84,949**

Budget narrative:
Salaries and fringe benefits: Funds are requested for partial support of technical support or a M.S. student.
Presentations, publications, and documentation: This will help defray cost of publication and documentation of results and conclusions as well as assist travel and board for presentation of results
Other Direct Costs: Covers cost of analysis, sample containers, fertilizer, seed, plot preparation, planting, weed control harvesting, flags, soil processing, and other field supplies and operations.

Silicon and Lime as Amendments to Reduce Arsenic in Rice Grain

Gene Stevens, David Dunn, and Matthew Rhine

Introduction

Arsenic (As) and silicon (Si) react almost identically in the soil. In drained fields, arsenate, As [V], and silica ions are adsorbed on oxidized iron particles. When fields are flooded for rice, ferric iron +3 is reduced to the ferrous form +2 releasing As and Si into solution where they can be taken up by rice roots (Smith et al, 1998). For this reason, tissue Si and As content are usually higher in rice than crops such as corn and wheat.

Silicon promotes rice yield while arsenic is detrimental. In rice, Si promotes disease resistance and helps plants withstand stresses such as salinity and dry soil (Matoh et al., 1985; Nolla et al., 2012). Conversely, arsenic in rice tissue reduces yield by producing panicles without grain called straight heads. Breeders are working to identify varieties with lower As content in grain, but fungal diseases may increase due to lower tissue Si. Molecules of arsenite, 4.11 angstroms, and silica, 4.38, are similar in diameter and shape. Since arsenite is slightly smaller, blocking As from passing through root membranes to the xylem also inhibits Si uptake (Ma et al., 2008).

Two proven methods to significantly reduce As in rice grain are silica fertilization and growing rice without flooding (Seyfferth and Fendorf, 2012; Li et al., 2009; Spanu et al., 2012; Norton et al., 2009). Recent research showed that As in rice grain was reduced by applying soluble silica fertilizer. Si competes with As ions for root entry points (Seyfferth and Fendorf, 2012). Liming can help depending on what species of As is present. Raising soil pH decreases arsenate adsorption by iron but increases arsenite, As[III], adsorption (Mahimairaja et al., 2005). Lime and calcium silicate from steel mill slag reduced As in radishes grown in contaminated soil (Gutierrez et al., 2010).

At the Delta Center Soil Lab, low yielding rice grown in 2012 with center pivot was Si deficient. In 2013, we began a study to evaluate available silicon fertilizer sources. The objective of this project is to evaluate the effect of irrigation treatments (aerobic and continuous flooding) and soil amendments of calcium silicate (CaSi) fertilizers on yield and arsenic content of rice grain in Southeast Missouri.

Materials and Methods

These experiments were conducted at three locations: a Tiptonville silt loam (Fine-silty, mixed, superactive, thermic Oxyaquic Argiudolls) in Portageville, MO, a Dubbs silt loam (Fine-silty, mixed, active, thermic Typic Hapludalfs) at Qulin, MO, and a Sharkey clay (Very-fine, smectitic, thermic Chromic Epiaquerts) at Hayward, MO. RiceTec hybrid CLXL745 was planted at 28 kg ha^{-1} at all three locations, with two additional cultivars (Jupiter and CL151) planted at 100 kg ha^{-1} in Hayward, MO to determine if any cultivar differences could be found for As uptake.

At planting, fertilizer treatments including three rates of calcitic lime, three rates of dolomitic lime, and five rates of calcium silicate were applied to bare soil. Nitrogen was applied at first tiller at a rate of 170 kg ha^{-1}. Irrigation treatments varied by location. The Portageville location was sprinkler irrigated, while the Qulin location was flood irrigated at first tiller. The Hayward location had separate flood and flushed (aerobic) treatments. Three additional treatments of potassium silicate were applied at rice boot stage.

Pre-harvest whole plant samples were taken and separated for analysis of arsenic (grain) and silicon (leaves and stem) concentrations. Silicon was analyzed using the University of Florida Si methodology (Elliott and Snyder, 1991), while As was measured using ICP-MS analysis. Plots were harvested at the end of the season for crop yield.

Results

Silicon samples of aerobic rice at Portageville, MO showed an increase in tissue Si as CaSi rate increased (R2 = 0.8666; Figure 1). Silicon concentrations in flooded rice were much higher than aerobic treatments, ranging from 62750 to 73375 mg Si Kg^{-1}. However, silicon content of flooded rice tissue was not significantly different among treatments compared to the untreated check. University of Florida recommends

Si fertilization for tissue samples with less than 34,000 mg Si kg^{-1} (10), which explains why significant differences could be found on aerobic rice, which was deficient of Si, but not flooded rice.

In Qulin, MO, arsenic concentrations of flooded brown rice were significantly reduced following applications of 1000 and 2000 kg Si ha^{-1} compared to untreated checks (P = 0.05; Table 1). Grain As was not reduced from applications of 500 or 1500 kg ha^{-1} on this soil.

Grain As was significantly lower in aerobic rice grown at Portageville, MO compared to flooded rice. However, no significant differences in grain As could be found due to silicon fertilization.

In Hayward, MO, As concentrations of flooded rice were significantly lower than flooded rice at Qulin, MO. Analysis of three cultivars showed no significant difference in grain As, although cultivar CL151 showed numerically reduced As concentrations (Table 2). No significant difference was found due to silicon fertilization in either irrigation system (Table 3).

No significant differences in grain yield could be found among treatment application rates for any location (Table 4). Grain yield of aerobic rice at Portageville, MO was found to be numerically higher with all fertilizer amendments compared to the untreated check. Yield increases ranged from 107 to 1965 kg ha^{-1}. Grain yield of rice in Qulin, MO showed no significant increase from fertilizer amendments. Given that tissue samples on untreated flood rice were found to have sufficient Si, increases in yield were not expected. Also, these fertilizer amendments take time to break down in the soil, meaning that plots may not have fully utilized the applications. These plots will be maintained for two more years to see if any subsequent differences can be found.

When averaged across fertilizer rates, significant differences in grain yield were found at both Qulin and the flooded Hayward location due to the type of fertilizer applied (Table 5). In both cases, the highest yielding treatment came from the addition of dolomitic lime. On the aerobic site at Portageville, MO, the addition of CaSi improved yields by 1109 kg ha^{-1}, although this increase was not statistically significant.

Conclusions

Although these fertilizer amendments did not significantly increase grain yield, their potential effect on As concentrations may prove to have merit on flooded fields. When grain As concentrations were high, as seen at the Qulin location, reductions in As content could be found with applications of CaSi. Applications of CaSi also proved to increase stalk Si content on aerobic fields. However, flooded fields were found to have sufficient levels of Si, so increases in uptake were found. On flooded fields, grain yield was highest with applications of dolomitic lime. This may prove to be a better choice than calcitic lime when additions need to be made during a rice production year.

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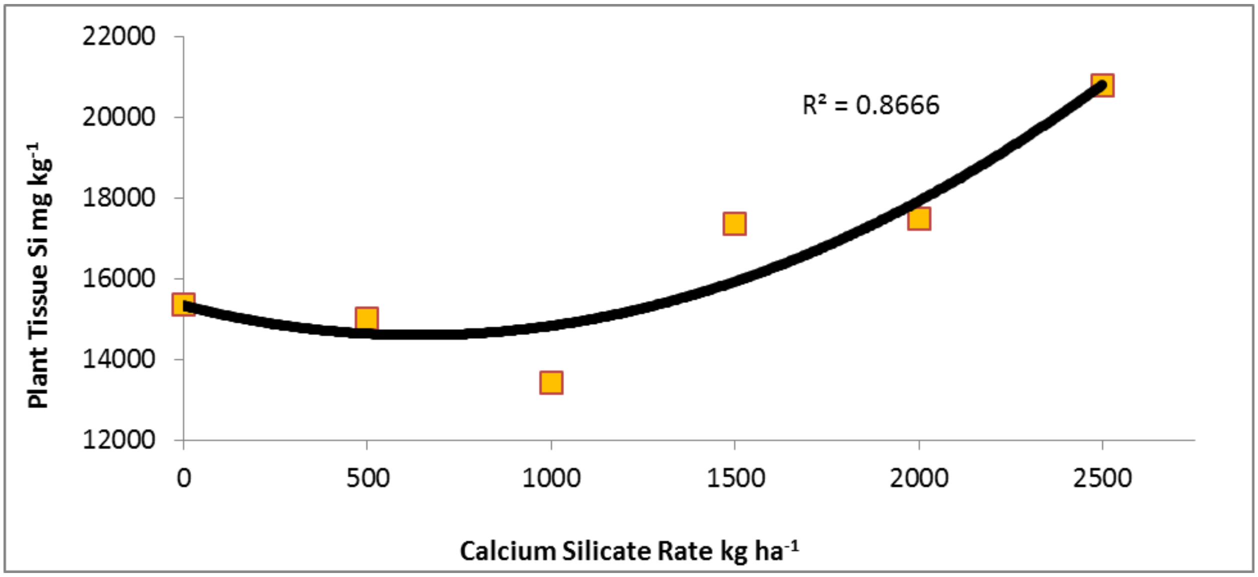

Figure 1. Effect of silicon fertilization rate on rice tissue silicon concentrations from aerobic rice grown under sprinkler irrigation at Portageville, MO.

Table 1. Effect of Irrigation and silicon fertilization on arsenic concentrations of brown rice (CLXL745) grown at Qulin and Portageville, MO in 2013.

	Qulin, MO	**Portageville, MO**
Si Fertilizer	**Flood**	**Aerobic**
kg ha-1	----------Grain As content, ppb----------	
0	205 a	15.8 a
500	202 ab	15.3 a
1000	175 bc	14.0 a
1500	208 a	14.0 a
2000	169 c	15.8 a
2500	190 abc	16.5 a

Table 2. Effect of irrigation and cultivar on arsenic concentrations of brown rice grown at Hayward, MO in 2013.

	Hayward, MO	
	Flood	**Aerobic**
Cultivar	-----Grain As content, ppb-----	
CLXL745	60.4 a	26.8 a
Jupiter	58.5 a	26.8 a
CL151	46.8 a	18.1 a

Table 3. Effect of irrigation and silicon fertilization on arsenic concentrations of brown rice grown at Hayward, MO in 2013.

	Hayward, MO

Si Fertilizer	**Flood**	**Aerobic**
kg ha^{-1}	-----Grain As content, ppb-----	
0	53.8 a	21.5 a
1000	55.6 a	27.3 a
2000	56.3 a	22.8 a

Table 4. Effect of silicon fertilization on rice grain yield across locations in Southeast Missouri in 2013.

Amendment	**Rate** kg ha^{-1}	**Portageville, MO Aerobic**	**Qulin, MO Flood**	**Hayward, MO Flood**	**Hayward, MO Flush (Aero)**
		------------------------kg ha-1------------------------			
None	0	6379	16312	10548	10127
Cal Lime	840	6761	14765	10129	9942
Cal Lime	1680	7051	15450	10415	9173
Cal Lime	2520	7691	16456	10337	9385
Dol Lime	840	6895	16158	11632	10322
Dol Lime	1680	7139	17213	10852	9650
Dol Lime	2520	7091	16406	10713	10603
CaSi	500	8344	15901	10104	9910
CaSi	1000	7037	16483	10218	9639
Casi	1500	7424	16080	10264	8957
CaSi	2000	7288	16476	9912	10581
CaSi	2500	7347	17014	10247	10646
KSi	0.20	6486	16318	11221	10441
KSi	0.24	7518	16091	10637	9282
KSi	0.28	6633	16016	10563	9520

Table 5. Effect of amendment type on grain yield across locations in Southeast Missouri in 2013.

Amendment	Portageville, MO Aerobic	Qulin, MO Flood	Hayward, MO Flood	Hayward, MO Flush (Aero)
	--------------------kg ha^{-1}--------------------			
None	6379	16312 ab	10548 abc	10127
Cal Lime	7168	15557 b	10293 bc	9500
Dol Lime	7041	16592 a	11066 a	10192
CaSi	7488	16391 a	10149 c	9947
KSi	6879	16142 ab	10807 ab	9747

2014

Liming to Reduce Ergovaline Concentration in Toxic Tall Fescue Pastures

Investigators: Craig Roberts, Robert Kallenbach, and John Lory, University of Missouri

Objective and Relevance

Missouri are covered with toxic common tall fescue, a perennial grass that supports the 2nd largest beef herd in the US. The toxins, such as the ergot alkaloid ergovaline, causes fescue toxicosis, a disorder that costs the Missouri beef industry $240 million annual ($160 million 10 years ago) by reducing reduce calf gains, milk production, and pregnancy rate.

Recommendations for tall fescue management involve "alkaloid management," which involves livestock rotation among fields, dilution of tall fescue in the pasture by interseeding legumes, feeding of supplements, and ammoniation of hay. These practices limit the amount of toxin produced by the plant and ultimately consumed by the animal. Practices such as liming and soil fertilization encourage legume growth and therefore dilutes the toxic pasture.

It is important to know if liming affects toxin production. Research has shown that ergot alkaloids toxins are unstable in alkaline environments and can be reduced when hay is treated with ammonia. Also, they break down when an alkaline reagent is used on the extract in the laboratory. To date, no research has been published that explores the effect of lime on ergot alkaloids concentrations.

The main objective is to determine the effect of soil pH on ergovaline concentration in toxic tall fescue. Because it is unknown where ergovaline occurs in the canopy, a **sub-objective** is to analyze the tillers in 2" segments.

Procedures

This research has been conducted on the Tom Roberts farm near Alton, MO. This farm was selected because it is primarily 'Kentucky-31' tall fescue established more than 20 years ago and is representative of most other farms in Missouri and surrounding states. On 14 October 2011, tillers from this field were tested for tall fescue endophyte using enzyme-linked immunosorbent assay (Hill, 2005); the results verified that the field was 95% infected with the endophyte. The field had been soil-sampled on 29 July 2011 and determined to have an average soil pH of 5.5.

Accomplishments (2012-14)

In December 2011, 16 plots measuring 10 x 20 feet were marked with a two-foot buffer separating the replicates (Fig. 1 and 2). Treatments were randomly assigned as non-treated control or treated with limestone, and it was replicated 8 times. Also in December 2011 each plot was tested and limestone surface applied (Table 1.) The limestone used was from Doss and Harper, West Plains, MO with an effective neutralizing material (ENM) rating of 368; each plot received enough limestone to meet the ENM requirements from individual plot soil tests.

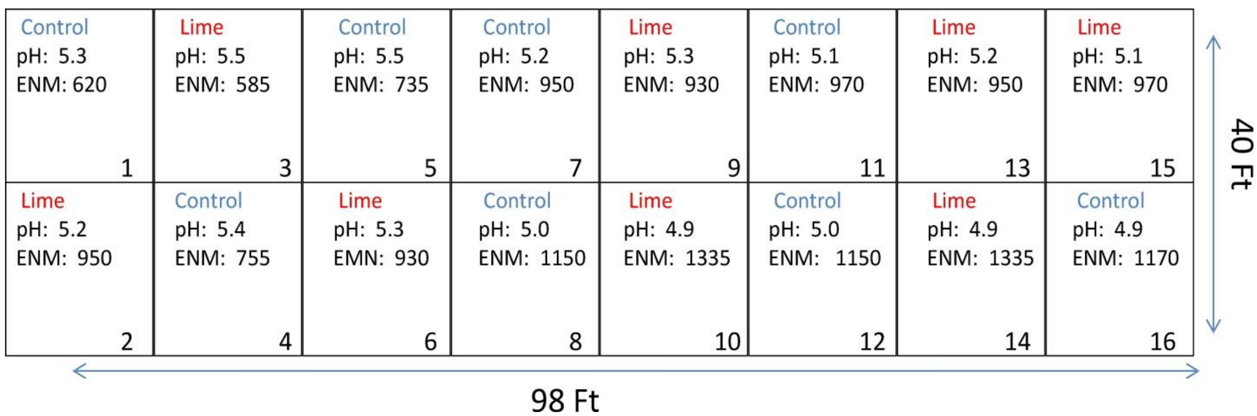

Figure 1. Plot layout of liming study located near Alton, MO with lime and pH data shown. The plots are 10 x 20 feet with 2-foot buffer strips (not shown).

Figure 2. Plots for liming study established on the Tom Roberts farm near Alton, MO.

On 18 May 2012, plots were fertilized with nitrogen at the rate of 40 lb acre and with P and K to soil test. Annual grass weeds were controlled by spraying pendimethalin (Prowl H2O) at a rate of 4 pints acre-1 in early spring. Broadleaf weeds were controlled with picloram and 2,4-D (Grazon P+D) at a rate of 2 pints acre-1. During spray application a non-ionic surfactant was used.

For all three years of 2012-14, plant tillers were harvested on in the spring and fall. The spring sampling date was chosen to harvest plants after "green-up" but before seedhead development. (Seedheads are highly concentrated with ergovaline and can temporarily skew the results.) The fall sampling date was chosen to harvest plants that greened up after summer dormancy but before the killing frost. Individual plant tillers were randomly selected, cut at soil level, and stored in a freezer immediately. Frozen samples were freeze-dried, ground to 1 mm, and analyzed for ergovaline by HPLC. The whole tillers have been analyzed; the tillers were cut into 2-inch segments, and those samples are currently in the laboratory.

Results Summary (2012-14)

Some of the samples are still being ground and prepared for ergovaline analysis. But the three-year summary as of today is below. Limestone treatment was not significantly different from the control ($p = 0.51$). However, fall samples contained higher concentrations ($p > 0.001$) of ergovaline compared to spring samples (Fig. 3). Again, fall 2014 samples have not been returned from the lab and are not included in this analysis. Also, soil pH was altered by the addition of limestone (Fig. 4). However, the first 3 inches received the most benefit from the limestone.

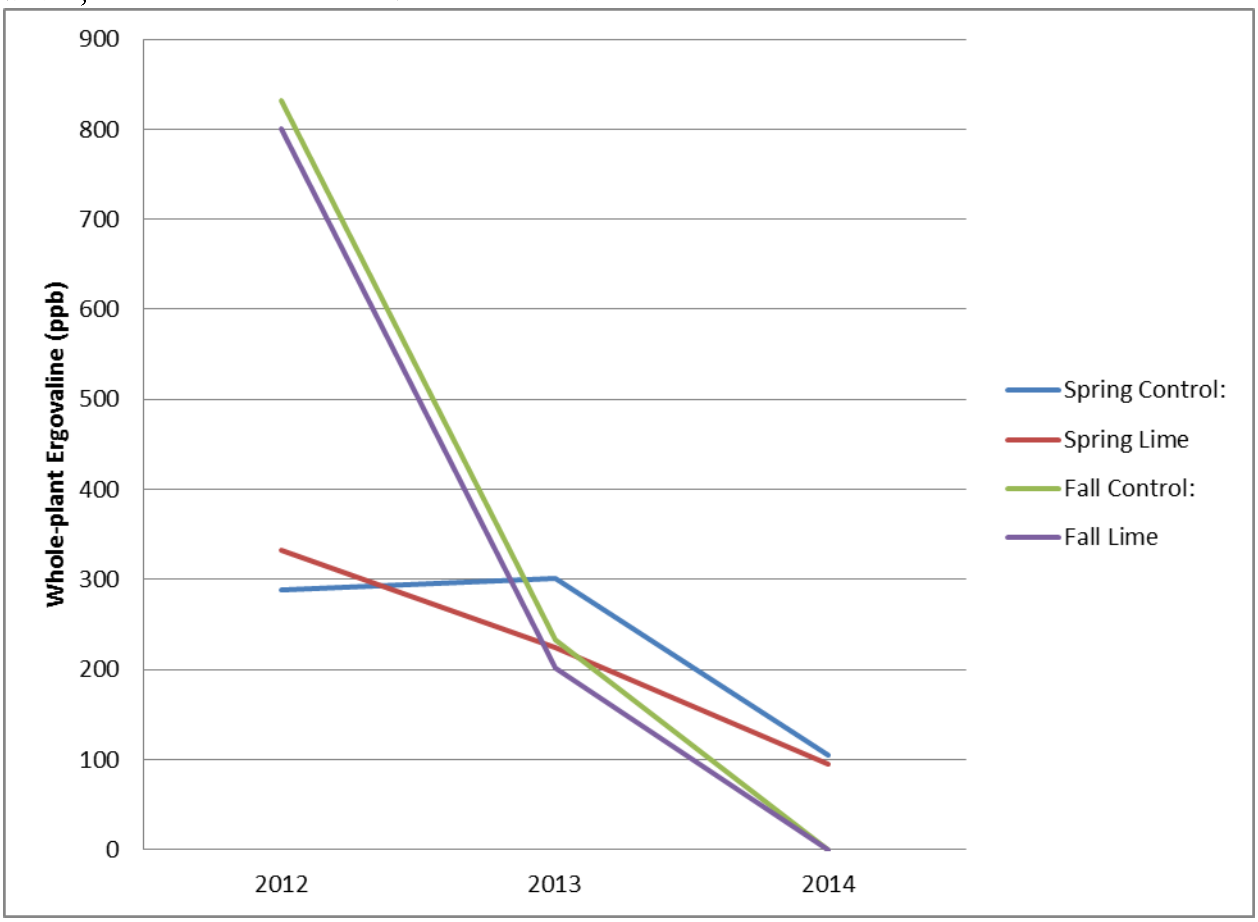

Figure 3. Ergovaline concentration of whole-plant samples subjected to treatment with limestone.

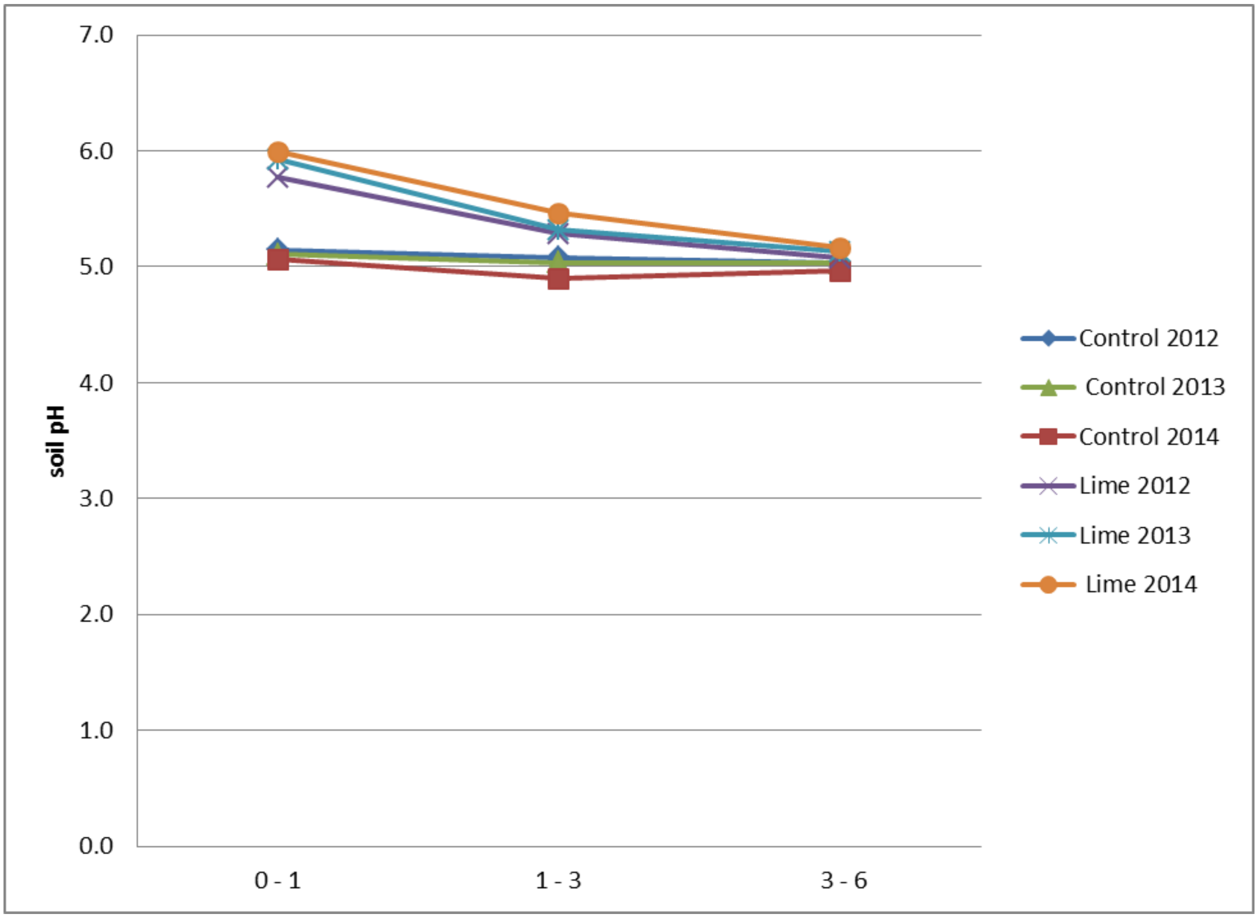

Figure 4. Changes in soil pH, soil core samples were divided into increments from the soil surface.

Ergovaline concentrations of the segmented samples were highest at the base of the plant and decreased in the upper segments sampled. At all sampling dates, the bottom 0 - 5 cm of the plant had statistically ($p<0.001$) higher concentration of ergovaline than the upper portions of the plant (Fig. 5). The fall samples had higher ergovaline concentrations when compared to the spring samples, especially the bottom 0 – 5 cm.

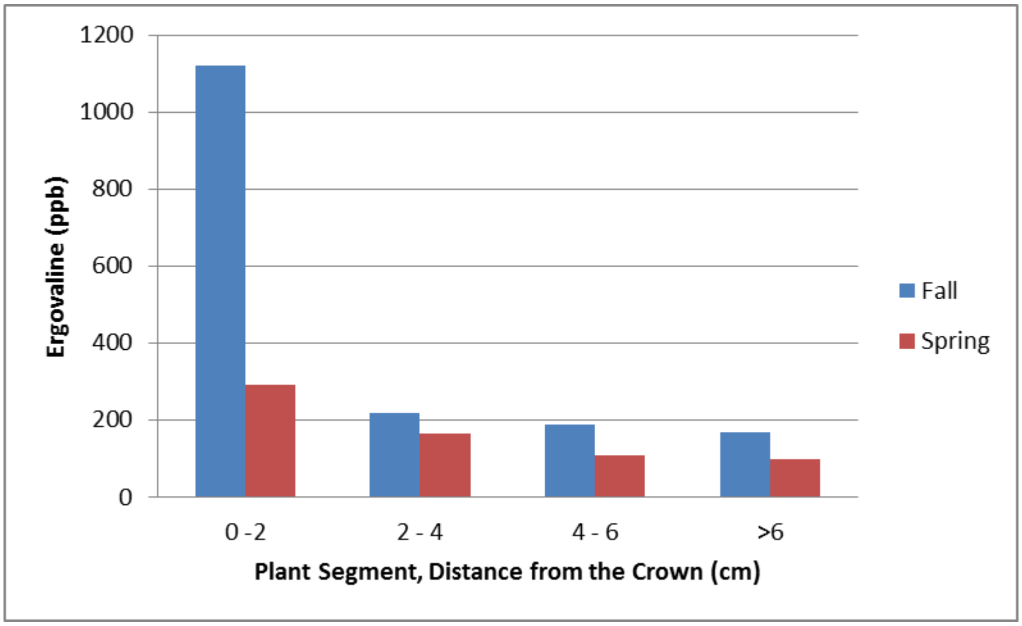

Figure 5. Ergovaline in segments of the tall fescue canopy in the spring and fall.

Conclusions

If the data for 2014 are similar to the data from the first two years, our conclusions will be that lime did not affect ergovaline concentration in toxic tall fescue during the first three years after application. This is a critical finding for both the producer, the lime and fertilizer industry, and University Extension. Had liming increased toxin concentration, as occurs with other soil nutrients, University Extension would have recommended that cattlemen exercise caution with lime application.

Currently, University Extension recommends liming pastures for a number of reasons, mainly to increase phosphorus availability and legume persistence, both of which result from a low pH environment. The data above show that there is “no penalty” for liming pastures and that producers need not be concerned with fescue toxicosis because of liming.

Additionally, future studies may show that liming actually reduces toxicity. The data above show a numerical difference in ergovaline concentration from plots treated with lime. Because the difference is not statistically different, we are not able to make any comment regarding this. But data such as this do reveal that a study conducted with less field variation may produce differences that are statistically significant, not merely numerically different. It should be remembered that statistical differences are not found when variation in responses are unrelated to the treatment; This particular site varied greatly in soil pH and in ergovaline concentration, even among commonly treated plots.

As final data are collected, they will be analyzed statistically and published in *Crop Science*.

Silicon and Lime as Amendments to Reduce Arsenic in Rice Grain

Gene Stevens, David Dunn, and Matthew Rhine

Introduction

Soil microbial and chemical processes change when fields are flooded for rice production. Iron is reduced (Fe^{+3} to Fe^{+2}) by anaerobic bacteria and soil pH slowly shifts from acid or alkaline to neutral (Fageria et al., 2011). Arsenic (As) and silicon (Si) availability to rice roots are affected by these processes. In drained fields, arsenate, As [V], and silica ions are adsorbed on oxidized iron particles. When fields are flooded for rice, the reduction of iron releases As and Si into solution where they can be taken up by rice roots (Smith et al, 1998). For this reason, tissue Si and As content are usually higher in rice than crops such as corn and wheat.

Silicon promotes rice yield while As is detrimental. Healthy rice plants contain 3.5 to 5% silicon (Korndorfer, et al., 2001). Silica is used by rice in a disease defense mechanism against blast and sheath blight and strengthens cell walls to minimize lodging. Silicon is an abundant element on earth but is mostly in the insoluble form which is available to plants. Root absorb silicon as monosilicic acid, $Si(OH)_4$. Silicon also helps plants withstand stresses such as salinity and dry soil (Matoh et al., 1985; Nolla et al., 2012). Conversely, As in rice tissue reduces yield by producing panicles without grain called straight heads. Breeders are working to identify varieties with lower As content in grain. But these varieties may have higher susceptibility to fungal diseases due to lower tissue Si. Molecules of arsenite, 4.11 angstroms, and silica, 4.38, are similar in diameter and shape. Since arsenite is slightly smaller, blocking As from passing through root membranes to the xylem also inhibits Si uptake (Ma et al., 2008).

Two proven methods to significantly reduce As in rice grain are silica fertilization and growing rice without flooding (Seyfferth and Fendorf, 2012; Li et al., 2009; Spanu et al., 2012; Norton et al., 2009). Recent research showed that As in rice grain was reduced by applying soluble silica fertilizer. Si competes with As ions for root entry points (Seyfferth and Fendorf, 2012). Liming can help depending on what species of As is present. Raising soil pH decreases arsenate adsorption by iron but increases arsenite, As[III], adsorption (Mahimairaja et al., 2005). Lime and calcium silicate from steel mill slag reduced As in radishes grown in contaminated soil (Gutierrez et al., 2010).

At the Delta Center Soil Lab, low yielding rice grown in 2012 under center pivot irrigation (not flooded) was Si deficient based on tissue testing (Korndorfer, et al., 2001). In 2013, we began a study to evaluate available Si fertilizer sources. The objective of this project is to evaluate the effect of irrigation treatments (aerobic and continuous flooding) and soil amendments of calcium silicate (CaSi) fertilizers on yield and As content of rice grain in Southeast Missouri.

Materials and Methods

Experiments were conducted at three locations: a Tiptonville silt loam (Fine-silty, mixed, superactive, thermic Oxyaquic Argiudolls) in Portageville, MO, a Dubbs silt loam (Fine-silty, mixed, active, thermic Typic Hapludalfs) at Qulin, MO, and a Sharkey clay (Very-fine, smectitic, thermic Chromic Epiaquerts) at Hayward, MO. RiceTec hybrid CLXL745 was planted at 25 lb/acre at all three locations, with two additional varieties (Jupiter and CL151) planted 90 lb/acre at Hayward, MO to determine if any variety differences could be found for As uptake.

At planting, fertilizer treatments including three rates of calcitic (white, Jonesboro, IL) lime, three rates of dolomitic (red, Piedmont, MO) lime, and five rates of pelletized calcium silicate, byproduct from steel mill, (Harsco Metals and Minerals, Sarver, PA) were applied to bare soil and incorporated. The calcium silicate material contains 12% Si and is very alkaline (pH 12 mixed with water). Three rates of foliar potassium silicate were applied as treatments at internode elongation. Nitrogen was applied at first tiller at a rate of 150 lb N/acre. Irrigation treatments varied by location. The Portageville location was sprinkler irrigated, while the Qulin location was flood irrigated at first tiller. The Hayward location had separate flood and flushed (aerobic) treatments. Three additional treatments of potassium silicate were applied at rice boot stage. Plots were harvested at the end of the season for crop yield. Grain samples were taken and hulled into brown rice for analysis of total As concentrations using ICP-MS analysis.

Results

Calcium silicate increased yields in non-flooded rice. In center pivot irrigated plots at Portageville, grain yields were increased significantly (39 bushels per acre in 2013 and 35 bushels per acre in 2014) with an application of 450 lb calcium silicate per acre compared to untreated checks (Table 1). We do not know if is from the liming effect of the calcium silicate or the Si fertilization. Soil samples will be collected and tested for pH from plots this spring (2015). Applications of calcium silicate above 450 lb/acre did not show a consistent yield response. Center pivot grain yields were significantly increased with 750 lb calcitic lime and numerically increased by 750 lb of dolomitic lime. Higher rates of agricultural lime and calcium silicate may have increased soil pH too much. Under aerobic conditions (water flushed) at Hayward, significant differences in grain yield were found from 450 lb calcium silicate in 2014 but not in 2013. Yields were highest with CLXL745 hybrid and lowest with Jupiter variety.

Under flooded conditions at Qulin and Hayward, soil amendments did not increase grain yield compared to untreated plots. Numerically, grain yields were highest with 1500 lb/ac of dolomitic lime at Hayward, Missouri followed by applications of calcium silicate. Generally, flooded systems provide enough Si through the reduction of iron under anaerobic conditions, so little yield increase was expected at flooded locations. However, Si competes with As for rice uptake, so total As was measured to see if Si amendments reduce As levels in the grain.

At Qulin in 2013 flooded rice, calcium silicate applied 900 and 1800 lb/ac significantly reduced As concentrations in brown rice grain from RiceTec CLXL745 (Table 1, $\alpha = 0.05$). However, without higher yields or a price premium for low As rice, this is not economical for farmers. We do not understand why 1350 lb/acre application did not also affect arsenic grain content. Total As concentrations in brown rice grain were consistently lower in aerobic rice (pivot or flushed) compared to flood irrigation at Hayward across all amendments (Table 2). At Portageville, under center pivot, brown rice grain from plots contained less than 20 ppb As with no significant As reduction from soil amendments.

Conclusions

In fields where rice cannot be flooded, applications of calcium silicate or agricultural lime may increase rice yield. The highest aerobic rice yields occurred with calcium silicate at 450 lb per acre and dolomitic lime at 750 - 1500 lb per acre. Applications of Si to flooded rice did not increase rice yield. Growing rice aerobically reduced As concentrations in brown rice grain, but yields tend to be lower than flooded rice. When grain As concentrations were close to 200 ppb, as seen at the Qulin location, reductions in As content were found with 900 and 1,800 lb applications of calcium silicate. While unnecessary to increase flood yields, Si applications may provide a tool for producers looking to reduced grain As content.

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Table 1. Effect of broadcast soil amendments on rice grain yield and brown rice arsenic concentrations in brown rice at Portageville and Qulin, Missouri with CLXL745 hybrid.

Soil amendment	Applied	Portageville, center pivot 2013	2014	Brown rice grain, 2013	Qulin, flooded 2013	2014	Brown rice 2013†
	lb/acre	--------bu/acre-------		arsenic, ppb	--------bu/acre-------		arsenic, ppb
None	0	127	137	16	285	131	205
Calcite lime	750	134	165		258	118	
Calcite lime	1500	140	147		270	123	
Calcite lime	2250	153	140		287	104	
Dolomite lime	750	137	146		282	118	
Dolomite Lime	1500	142	142		301	135	
Dolomite Lime	2250	141	13		286	123	
Calcium silicate	450	166	172	15	278	135	203
Calcium silicate	900	140	121	14	288	126	176
Calcium silicate	1350	147	129	14	281	146	209
Calcium silicate	1800	145	126	16	288	132	170
Calcium silicate	2250	146	143	16	297	130	191
Foliar pot silicate	0.17	129	140		285	132	
Foliar pot silicate	0.21	149	145		281	134	
Foliar pot silicate	0.25	132	137		280	127	

† Brown rice samples from 2014 are being processed for arsenic content.

Table 2. Effect of irrigation type and soil amendment on rice grain yield and total arsenic in brown rice at Hayward, Missouri averaged across CL151 and Jupiter varieties and CLXL745 hybrid.

Soil amendment	Applied	Flushed, aerobic 2013	Flushed, aerobic 2014	Brown rice grain, 2013	Flooded, anaerobic 2013	Flooded, anaerobic 2014	Brown rice grain, 2013†
		--------bu/acre-------		arsenic, ppb	--------bu/acre-------		arsenic, ppb
	lb/acre						
None	0	201	115	21	209	127	54
Calcite lime	750	197	117		201	125	
Calcite lime	1500	182	116		207	136	
Calcite lime	2250	186	122		205	119	
Dolomite Lime	750	205	112		231	120	
Dolomite Lime	1500	191	128		215	124	
Dolomite Lime	2250	210	122		213	138	
Calcium silicate	450	197	127		200	114	
Calcium silicate	900	191	120	18	203	133	56
Calcium silicate	1350	178	117		204	139	
Calcium silicate	1800	210	117	23	197	125	56
Calcium silicate	2250	211	115		203	137	
Foliar pot silicate	0.17	207	124		223	127	
Foliar pot silicate	0.21	184	121		211	123	
Foliar pot silicate	0.25	189	119		210	138	

† Brown rice samples from 2014 are being processed for arsenic content.

Final Reports
2014

Benefits of Lime Placement on Grain Yield Response and Remediation of Acid Subsoils

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Objective and Relevance:

An extensive root system is essential for crop plants to tolerate short- and long-term periods of drought that often occur during the growing season in Missouri. Acid subsoils reduce root growth and grain yield. Stratification of pH values is common in claypan soils in Missouri. In soil survey publications, surface soil samples of claypan soils may have optimum pH values; however, the subsoil from 8 to 20 in. may decrease to pH values as low as 3.6, 4.5, and 4.5 for soils such as Putnam, Mexico, and Armstrong, respectively (Ferguson, 1995). In three-paired watershed research, seventy five soil samples from the Ap, AB, and Bt1 horizons had average pH values of 6.6 ($\pm$1.7), 6.3 ($\pm$0.6), and 4.9 ($\pm$1.2), respectively (Udawatta, unpublished). Drainage research plots had subsoil (8-18 in.) pH values from 4.7 to 5.2 (Nelson, unpublished) while other research indicated average subsoil pH values from 29 claypan soils at the 0-6 in., 6-12 in., 12-24 in., and 24-36 in. depths were 6.2, 6.0, 5.0, and 5.1 (Scharf, unpublished). Over 60% of the 29 fields had pH values less than 5 at the 12-24 in. depth. The lowest pH value at any site was 4.4. Acidic subsoils (at or below the 12 in. depth) may be a greater barrier to root growth than physical restrictions in many soils in Missouri.

Research on cotton (Adcock et al., 1999) and alfalfa (Rechcigl et al., 1991) has demonstrated the benefit of deep lime placement. Methods that incorporated lime increased corn grain yields greater than conventional liming techniques using surface applications (Farina and Channon, 1988). In this research, corn grain yields increased 20 bu/a in a dry year while in a wet year grain yield increased 6 bu/a (Farina and Channon, 1988). Low soil pH, 5 to 5.5, is an agronomic and environmental concern. Macronutrient and microbial activity is restricted and phytotoxic levels of exchangeable Al and Mn are common at low soil pH values. In addition, nitrification may be limited in an acidic environment. Nitrogen applications from ammonium-based N fertilizers acidify soils and require agriculture lime applications to neutralize the impact on soil pH. Anhydrous ammonia applications are commonly used throughout the region and may contribute to a decrease in subsoil pH while the surface soil pH is acceptable. A deep lime application may also reduce the impact of low soil pH on root growth and development.

Acid-subsoil amelioration has been studied with long-term impacts on soil pH levels (Toma et al., 1999; Farina et al., 2000b). Grain and forage yields increased 29 to 50% even 16 yr. after application (Toma et al., 1999) with increased returns (Farina et al., 2000a). Deep placement of dry lime at 1500 lbs/acre over two years increased soybean grain yields over 4 bu/a and increased profitability $94/acre compared to deep tillage only (Tupper et al. 1987). Farmers have utilized no-till and conventional tillage systems to attain specific production goals. Incorporation of lime may be necessary to realize an immediate (Toma et al. 1999) increase in grain yield. Deep placement of lime utilizing conservation-type knives could accomplish an immediate increase in grain yield, provide zone-tillage, increase subsoil pH, and maintain surface residue. Concerns regarding the practicality and economics of deep incorporation have been expressed; however, numerous producers continue to subsoil claypan soils. Previous MU research has evaluated pH management in the top 6 to 8 inches of soil; however, no research has evaluated deep lime applications or the impact on subsoil properties. This research initiates a long-term evaluation of the impact of addressing subsoil pH correction in no-till and reduced tillage cropping systems. *The objective of this research was to evaluate impacts of lime placement on yield response of corn and soybean, and on changes in subsoil pH.* We will maintain the field that was established in 2012 and 2013. Corn plots will rotate into soybean while soybean will rotate into corn. A third location was established for 2014 and treatments were applied in the fall of 2013 which is more typical of a deep tillage treatment.

Materials and Methods:

Field trials were established at the University of Missouri Greenley Research Center on a Putnam silt loam in 2012, Kilwinning silt loam in 2013, and Putnam silt loam in 2014 that had been in continuous no-till production for over 13 years with acid subsoils (Table 1). A timeline for establishment was outlined in Table 2. A factorial arrangement of treatments included placement (no-till surface and conservation subsoiler deep placement), crop (corn and soybean), and lime rates (0, 1.5, and 3 tons/acre with 600 lbs effective neutralizing material/ton) to evaluate the response of corn or soybeans within a given year. Pelleted lime (Kelly's Limestone, Newark, MO) was derived from mined calcium carbonate and magnesium carbonate. A 2% lignosulfonate was utilized as the binding agent for pelletizing. The conservation subsoiler (Case IH 2500 ecolo-til) (Figure 1, left) had a custom built shank (Figure 1, right) to deliver and distribute lime to 4 different levels in the soil profile, while delivery and metering were accomplished using a commercial Montag (Figure 1, left) dry fertilizer air delivery system. The selected rates of lime were based on an average subsoil recommendation (high rate), top 6 inches of soil recommendation (low rate), and a non-treated control. A site with a low surface pH was utilized in the experiment (Table 1).

Figure 1. Deep placement applicator with Montag dry fertilizer air delivery system (left) and custom built applicator shank (right).

Precipitation is reported in Table 2 while field management and crop protection chemical applications for corn and soybean are reported in Tables 3 and 4, respectively. This research evaluated soil pH at four depths (0-5, 6-10, 11-15, and 16-20 inches) similar to other research (Farina et al. 2000a, 2000b; Tupper et al., 1987), grain yield, and crop growth characteristics. Soil samples were collected in the fall of 2012, 2013, and 2014. Soil sampling depth corresponded to the different distribution drop tubes on the applicator shank. Samples were collected from within the tilled zone, 7.5 inches, and 15 inches from the tilled zone.

Figure 2. Soil during application (left), after application (center), and an overhead overview after application (right).

The center two rows of corn were harvested for yield and converted to 15%, while the center 5 ft of the soybean plot was harvested and adjusted to 13% moisture prior to analysis. Grain samples were collected and were analyzed for protein and oil (soybean), and starch, protein, oil (corn) using near-infrared spectroscopy (Foss Infratec 1241 Grain Analyzer, Eden Prairie, MN) (data not presented). All data were subjected to ANOVA and means separated using Fisher's protected LSD at P = 0.1.

Results:

The custom built shank effectively distributed lime throughout the soil profile (Figure 2). The modified shank caused more soil disturbance than normal and tillage following application was utilized to smooth the soil surface (Tables 3 and 4) prior to planting. No tillage was used in the surface application only treatments. An extensive drought occurred in 2012. Precipitation during the 2012 growing was 7.3 inches below normal (Table 2).

Corn plants were 2 to 5 inches taller (July 5) in the deep placed treatments compared to no-till, which persisted until tasseling (August 2) in 2012 (Table 5). Plants were slightly taller for the surface applied lime at 2 ton/acre in 2013, but were shorter in the deep placed lime treatments established in 2013. In 2014, all treatments were taller than lime surface applied at 3 tons/acre at the site established in 2013. Plant height was greater than the non-treated control with deep placed lime at 3 tons/acre compared to the non-treated control, while few differences were observed among the other treatments

The site established in 2012 had plant populations that were generally greater in the no-till surface applied treatments compared to the deep ripped/placement treatments in 2012, and few differences were observed in 2013 and 2014. Deep placement had greater plant populations than surface applied lime at the site established in 2013 and 2014. There was no treatment effect on soybean height in 2012 or 2013, while slight height differences were observed in 2014. There was no treatment effect on soybean plant population in 2012 (Table 6). However, soybean plant population was 30,000 to 31,000 plants/acre greater with surface applied lime at 1.5 ton/acre compared to deep placement at both locations in 2013. In 2014, deep lime placement and tillage increased plant populations compared to the non-treated control at one location, but were lower than the non-treated control when lime was surface applied at two of the locations.

Soil test pH_s in the top 5 inches of soil for the surface applied lime increased in corn and soybean as lime rate increased at all three locations; however, there was no effect of deep placement on pH_s in the top 5 inches of soil (Table 7). At 6 to 10 inches deep, soil pH_s increased 0.5 points for deep placed lime at 1.5 tons/acre in soybean. No differences were observed 11 to 20 inches deep in the soil profile 1, 2, or 3 years after application.

In an extremely dry year (2012), deep placement treatments increased corn yields 4 to 8 bu/acre (Figure 3a). However, no differences in yield among lime treatments were detected. In 2013, grain yield was 14 bu/acre greater for the no-till, non-treated control compared to deep tillage non-treated control, and 9 bu/acre greater for the surface applied lime at 1.5 ton/acre compared to deep placement at 1.5 ton/acre (Figure 3a). Grain yields were not affected by deep placement compared to surface applied lime at the site established in 2013 (Figure 3b). In 2014, surface applied lime at 1.5 ton/acre had the highest yields for the treatments established in 2013, while deep placed lime increased yield compared to the other treatments for the site established in 2014. All treatments increased yield up to 30 bu/acre compared to the non-treated control at the site established in 2014 (Figure 3c), but the tillage component seemed to have the greatest impact on yield in a high yielding year.

Deep placement treatments in 2012 reduced soybean yield in the non-treated control and lime at 1.5 ton/acre (Figure 4a), while there was no effect of placement on soybean yield at the 3 ton/acre rate. Grain yields were 2 to 3 bu/ac greater for the no-till, non-treated control and surface applied lime compared to the equivalent deep placement treatments in 2013 (Figure 4a). Limited differences were observed among treatments at the site established in 2013 (Figure 4b). Deep placement of lime at 3 tons/acre increased yields 6 bu/acre compared to the non-treated control at the site established in 2014 (Figure 4c).

In dry years (2012 and 2013), slight differences in corn grain yields were observed when comparing no-till surface lime applications compared to deep placement. In a high yielding year, deep placement of lime at 3 tons/acre increased yield 2 years after application, while the tillage component had the greatest increase in yield 1 year after application. Deep tillage did not increase soybean yields at the site established in 2012 or 2013 over the first two dry years of this research. In 2014, only 1 of 3 sites increased yield with deep tillage.

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Table 1. Initial soil characteristics at different depths for the sites established in 2012, 2013, and 2014.

Soil characteristics	0-5 inches	6-10 inches	11-15 inches	16-20 inches
Established in 2012				
pH_s	5.6 ± 0.2	5.6 ± 0.4	4.6 ± 0.2	4.6 ± 0.2
Neutralizable acidity (meq/100 g)	3.5 ± 2	2.9 ± 1	8.5 ± 1.6	6.8 ± 1.0
Organic matter (%)	2.7 ± 0.3	2.3 ± 0.1	2.3 ± 0.3	2.2 ± 0.2
Bray 1P (lb/acre)	15.5 ± 8.7	4.5 ± 1.3	3.5 ± 1.9	13.0 ± 4.0
Ca (lb/acre)	3950 ± 310	4640 ± 590	4690 ± 630	4450 ± 600
Mg (lb/acre)	441 ± 87	615 ± 169	875 ±123	889 ± 136
K (lb/acre)	159 ± 11	155 ± 25	202 ± 30	206 ± 14
CEC (meq/100 g)	15.4 ± 2.3	17.3 ± 3.2	24.2 ± 3.2	22.0 ± 2.3
Established in 2013				
pH_s	5.0 ± 0.1	5.0 ± 0.5	4.9 ± 0.7	4.9 ± 0.8
Neutralizable acidity (meq/100 g)	5.1 ± 0.5	4.9 ± 1.9	6.9 ± 4.0	6.8 ± 3.8
Organic matter (%)	3.0 ± 0.6	1.9 ± 0.4	1.8 ± 0.3	1.4 ± 0.4
Bray 1P (lb/acre)	113.5 ± 41.2	17.0 ± 9.6	10.3 ± 3.6	27.5 ± 17.3
Ca (lb/acre)	2535 ± 273	2911 ± 616	3692 ± 1634	3697 ± 1497
Mg (lb/acre)	274 ± 81	370 ± 171	659 ± 403	757 ± 375
K (lb/acre)	530 ± 214	142 ± 42	160 ± 69	208 ± 76
CEC (meq/100 g)	13.3 ± 1.4	13.9 ± 3.3	19.1 ± 6.4	19.4 ± 4.8
Established in 2014				
pH_s	6.1 ± 0.1	6.2 ± 0.1	5.0 ± 0.2	4.6 ± 0.1
Neutralizable acidity (meq/100 g)	1.8 ± 0.5	1.9 ± 0.3	7.1 ± 1.9	12.3 ± 1.9
Organic matter (%)	2.3 ± 0.5	2.1 ± 0.2	2.3 ± 0.4	2.7 ± 0.3
Bray 1P (lb/acre)	9.3 ± 4.2	5 ± 2	1.8 ± 0.5	1 ± 0
Ca (lb/acre)	3528 ± 854	3253 ± 258	4012 ± 387	4660 ± 343
Mg (lb/acre)	355 ± 141	336 ± 52	668 ± 127	1094 ± 71
K (lb/acre)	137 ± 27	121 ± 11	196 ± 32	311 ± 25
CEC (meq/100 g)	12.2 ± 3.2	11.6 ± 0.8	20.2 ± 3.2	28.9 ± 2.7

Table 2. Monthly precipitation average (10-year) and during the 2012, 2013, and 2014 growing seasons at Novelty; and the timeline for establishment and evaluation of field sites.

Month	10-year average†	2012	2013	2014
		------------------------------	Inches	------------------------------
Apr.	3.9	---	---	4.2
May	4.4	---‡	10.3	1.0
June	4.9	2.2	3.6	8.9
July	3.7	0.7	1.9	2.0
Aug.	4.8	3.0	0	6.4
Sep.	3.4	3.6	3.1	6.9
Total	25.1	9.5	18.9	29.4
Timeline for evaluation				
Established in 2012		May 2012, Putnam¶		
Established in 2013			Fall 2012, Kilwinning¶	
Established in 2014				Fall 2013, Putnam¶

†Averaged from 2000 to 2009.
‡Planted May 30, 2012.
¶Soil series.

Table 3. Field and management information for the corn site established at Novelty in 2012.

Management information	2012	2013	2014
Plot size (ft)	15 by 80	15 by 80	15 by 80
Hybrid	DKC 63-25 VT3	DKC 63-25 VT3	P1151 AM
Planting date	30 May	14 May	16 April
Row spacing (inches)	30	30	30
Seeding rate (seeds/acre)	30,000	30,000	33,000
Harvest date	12 Oct.	19 Sep.	30 Sep.
Maintenance fertilizer	None	None	20-80-140-20S-2Zn MESZ
Nitrogen	60 lbs N/acre (Urea) and 130 lbs N/acre (PCU)	200 lbs N/acre (AA)	180 lbs N/acre (AA)
Lime	29 May	None	None
Tillage	Tilloll 2x 30 May Cultipacked 30 May in deep tilled treatments	None	None
Weed management			
Burndown	5 June, Verdict (5 oz/acre) + Roundup PowerMAX (32 oz/acre) + NIS (0.25% v/v) + UAN (1 qt/acre)	22 May, Lexar (2.5 qt/acre) + Roundup PowerMAX (32 oz/acre) + COC (1 qt/acre)	9 May, Warrant (1.5 qt/acre) 23 May, Lexar EZ (3 qt/acre) + Roundup PowerMAX (22 oz/acre) + DAS (17 lbs/100 gal)
Postemergence	22 June, Roundup PowerMAX (32 oz/acre) + DAS (17 lbs/100 gal) + COC (1 qt/acre) + Callisto (3 oz/acre) + Atrazine (1 qt/acre)	27 June, Roundup PowerMAX (32 oz/acre) + DAS (17 lbs/100 gal) + COC (1 qt/acre) + Callisto (3 oz/acre) + NIS (0.25% v/v)	18 June, Roundup PowerMAX (22 oz/acre) + DAS (17 lbs/100 gal)
Insect management	NA	NA	23 May, Warrior II 2 oz/a
Disease management	NA	NA	10 July, Quilt Xcel 12 oz/a

†Abbreviations: COC, crop oil concentrate; DAS, diammonium sulfate; NA, None applied; NIS, non-ionic surfactant; UAN, 32% urea ammonium nitrate.

Table 3 cont. Field and management information for the corn sites established at Novelty in 2013 and 2014.

	Established in 2013		Established in 2014
Management information	2013	2014	2014
Plot size (ft)	15 by 75	15 by 75	15 by 80
Hybrid	DKC 63-87	GH G09E98-3000GT	GH G09E98-3000GT
Planting date	14 May	5 May	5 May
Row spacing (inches)	30	30	30
Seeding rate (seeds/acre)	30,000	30,200	30,200
Harvest date	19 Sep.	30 Sep.	7 Oct.
Maintenance fertilizer	None	20-80-140-20S-2Zn MESZ	20-80-140-20S-2Zn MESZ
Nitrogen	120 lbs N/acre (PCU)	180 lbs N/acre (AA) + N-serve (1 qt/acre)	200 lbs N/acre (AA)
Lime	27 Nov	None	15 Nov
Tillage	Tilloll 2x 1 May	None	Tilloll 2x 23 April
Weed management			
Burndown	22 May, Lexar (2.5 qt/acre) + Roundup PowerMAX (32 oz/acre) + COC (1 qt/acre)	9 May, Sharpen (1 oz/acre) + Warrant (1.5 qt/acre) + MSO (1% v/v) + UAN (1 qt/acre) 23 May, Lexar EZ (3 qt/acre) + Roundup PowerMAX (22 oz/acre) + DAS (17 lbs/100 gal)	9 May, Sharpen (1 oz/acre) + Warrant (1.5 qt/acre) + MSO (1% v/v) + UAN (1 qt/acre) 23 May, Lexar EZ (3 qt/acre) + Roundup PowerMAX (22 oz/acre) + DAS (17 lbs/100 gal)
Postemergence	27 June, Roundup PowerMAX (32 oz/acre) + DAS (17 lbs/100 gal) + COC (1 qt/acre) + Callisto (3 oz/acre) + NIS (0.25% v/v)	18 June, Roundup PowerMAX (22 oz/acre) + DAS (17 lbs/100 gal)	18 June, Roundup PowerMAX (22 oz/acre) + DAS (17 lbs/100 gal)
Insect management	NA	23 May, Warrior II 2 oz/a	23 May, Warrior II 2 oz/a
Disease management	NA	10 July, Quilt Xcel 12 oz/a	10 July, Quilt Xcel 12 oz/a

†Abbreviations: COC, crop oil concentrate; DAS, diammonium sulfate; NA, None applied; NIS, non-ionic surfactant; UAN, 32% urea ammonium nitrate.

Table 4. Field and management information for the soybean site established at Novelty in 2012.

Management information	2012	2013	2014
Plot size (ft)	15 by 80	15 by 80	15 by 80
Cultivar	AG3730 RR2	AG3730 RR2	P93Y92
Planting date	30 May	8 May	8 May
Row spacing (inches)	7.5	7.5	7.5
Seeding rate (seeds/acre)	200,000	200,000	180,000
Harvest date	4 Oct.	9 Sep.	20 Oct.
Maintenance fertilizer	None	None	20-80-140-20S-2Zn MESZ
Lime	29 May	None	None
Tillage	Tilloll 2x 30 May Cultipacked 30 May in deep tilled treatments	None	None
Weed management			
Burndown	5 June, Verdict (5 oz/acre) + Roundup PowerMAX (32 oz/acre) + NIS (0.25% v/v) + UAN (1 qt/acre)	22 May, Prefix (2.25 qt/acre) + Roundup PowerMAX (32 oz/acre) + COC (1 qt/acre) + UAN (1 qt/acre)	9 May, Warrant (1.5 qt/acre) 23 May, Prefix (2.3 pt/acre) + DAS (17 lbs/100 gal) + NIS (0.25% v/v)
Postemergence	22 June, Reflex (1.25 pt/acre) + Roundup PowerMAX (22 oz/acre) + DAS (17 lbs/100 gal) + NIS (0.25% v/v)	NA	18 June, Roundup PowerMAX (22 oz/acre) + DAS (17 lbs/100 gal)
Insect management	NA	NA	NA
Disease management	NA	NA	10 July, Quilt Xcel 12 oz/a

†Abbreviations: COC, crop oil concentrate; DAS, diammonium sulfate; NA, None applied; NIS, non-ionic surfactant; UAN, 32% urea ammonium nitrate.

Table 4 cont. Field and management information for the soybean sites established at Novelty in 2013 and 2014.

	Established in 2013		Established in 2014
Management information	2013	2014	2014
Plot size (ft)	15 by 75	15 by 75	15 by 80
Cultivar	AG3731 RR2	AG3932	P93Y92
Planting date	16 May	8 May	8 May
Row spacing (inches)	7.5	15	7.5
Seeding rate (seeds/acre)	200,000	130,200	180,000
Harvest date	9 Sep.	19 Oct.	20 Oct.
Maintenance fertilizer	None	20-80-140-20S-2Zn MESZ	20-80-140-20S-2Zn MESZ
Lime	27 Nov	None	15 Nov
Tillage	Tilloll 2x 1 May	None	Tilloll 2x 23 April
Weed management			
Burndown	22 May, Prefix (2.25 qt/acre) + Roundup PowerMAX (32 oz/acre) + COC (1 qt/acre) + UAN (1 qt/acre)	9 May, Sharpen (1 oz/acre) + Warrant (1.5 qt/acre) + MSO (1% v/v) + UAN (1 qt/acre) 23 May, Prefix (2.3 pt/acre) + DAS (17 lbs/100 gal) + NIS (0.25% v/v)	9 May, Sharpen (1 oz/acre) + Warrant (1.5 qt/acre) + MSO (1% v/v) + UAN (1 qt/acre) 23 May, Prefix (2.3 pt/acre) + DAS (17 lbs/100 gal) + NIS (0.25% v/v)
Postemergence	NA	18 June, Roundup PowerMAX (22 oz/acre) + DAS (17 lbs/100 gal)	18 June, Roundup PowerMAX (22 oz/acre) + DAS (17 lbs/100 gal)
Insect management	NA	NA	NA
Disease management	NA	10 July, Quilt Xcel 12 oz/a	10 July, Quilt Xcel 12 oz/a

†Abbreviations: COC, crop oil concentrate; DAS, diammonium sulfate; NA, None applied; NIS, non-ionic surfactant; UAN, 32% urea ammonium nitrate.

Table 5. Corn heights and plant population at harvest as affected by no-till surface or deep placed lime (non-treated = 0 ton/acre, low = 1.5 ton/acre, and high 3.0 ton/acre) for sites established in 2012, 2013, and 2014.

	2012			2013		2014	
	Height			Height		Height	
Lime placement	July 5	August 2	Population	October 4	Population	July 3	Population
	---- Inches ----		No./acre	Inches	No./acre	Inches	No./acre
Established in 2012							
Surface non-treated	36	65	30,100	80	26,700	88	28,400
Surface 1.5 ton/acre	37	64	30,000	81	27,100	91	28,500
Surface 3 ton/acre	34	63	29,200	82	27,400	95	27,700
Deep placement non-treated	39	67	26,000	80	26,900	94	27,400
Deep placement 1.5 ton/acre	38	68	28,000	80	27,700	92	27,600
Deep placement 3 ton/acre	39	67	27,900	79	28,400	97	27,100
LSD (P = 0.1)	2	2	2,200	2	NS	9	800
Established in 2013							
Surface non-treated	---[†]	---	---	103	27,000	108	26,500
Surface 1.5 ton/acre	---	---	---	100	24,000	111	25,600
Surface 3 ton/acre	---	---	---	101	26,000	110	26,400
Deep placement non-treated	---	---	---	102	28,800	112	25,200
Deep placement 1.5 ton/acre	---	---	---	99	28,200	109	26,100
Deep placement 3 ton/acre	---	---	---	97	28,800	110	26,100
LSD (P = 0.1)				4	1,700	2	NS

Established in 2014							
Surface non-treated	---	---	---	---	---	100	22,500
Surface 1.5 ton/acre	---	---	---	---	---	101	22,200
Surface 3 ton/acre	---	---	---	---	---	93	22,300
Deep placement non-treated	---	---	---	---	---	101	27,100
Deep placement 1.5 ton/acre	---	---	---	---	---	102	26,400
Deep placement 3 ton/acre	---	---	---	---	---	103	25,300
LSD (*P* = 0.1)						4	2,600

[†]Site wasn't established at this point in time. No data were collected.

Table 6. Soybean heights and plant population at harvest as affected by no-till surface or deep placed lime (non-treated = 0 ton/acre, low = 1.5 ton/acre, and high 3.0 ton/acre) for sites established in 2012, 2013, and 2014.

	2012		2013		2014	
Lime placement	Height	Population	Height	Population	Height	Population
	Inches	No./acre	Inches	No./acre	Inches	No./acre
Established in 2012						
Surface non-treated	22	187,000	28	153,000	39	91,000
Surface 1.5 ton/acre	22	205,000	28	157,000	41	105,000
Surface 3 ton/acre	22	161,000	26	166,000	41	109,000
Deep placement non-treated	22	196,000	27	145,000	39	96,000
Deep placement 1.5 ton/acre	21	183,000	26	127,000	39	118,000
Deep placement 3 ton/acre	22	203,000	26	148,000	43	113,000
LSD (P = 0.1)	NS	NS	NS	21,000	1	1,000
Established in 2013						
Surface non-treated	---†	---	31	170,000	40	87,000
Surface 1.5 ton/acre	---	---	31	170,000	38	81,000
Surface 3 ton/acre	---	---	31	148,000	38	74,000
Deep placement non-treated	---	---	28	152,000	37	76,000
Deep placement 1.5 ton/acre	---	---	31	139,000	39	72,000
Deep placement 3 ton/acre	---	---	31	148,000	38	81,000
LSD (P = 0.1)			NS	25,000	1	5,900

Established in 2014						
Surface non-treated	---	---	---	---	40	118,000
Surface 1.5 ton/acre	---	---	---	---	39	109,000
Surface 3 ton/acre	---	---	---	---	41	96,000
Deep placement non-treated	---	---	---	---	38	100,000
Deep placement 1.5 ton/acre	---	---	---	---	40	109,000
Deep placement 3 ton/acre	---	---	---	---	40	100,000
LSD (P = 0.1)					2	6,900

†Site wasn't established at this point in time. No data were collected.

Table 7. Soil test pH_s values at 0 to 5, 6 to 10, 11 to15, and 16 to 20 inch depths after corn and soybean harvest for the experimental site established in 2012. Interactions between factors were presented when appropriate.

Lime placement	2012		2013	2014	
Depth 0-5 in.	Corn	Soybean			
Surface non-treated	5.4	5.8	5.8	5.5	
Surface 1.5 ton/acre	5.9	6.6	6.3	6.3	
Surface 3 ton/acre	6.2	6.4	6.5	6.6	
Deep placement non-treated	5.7	5.7	5.8	5.9	
Deep placement 1.5 ton/acre	5.7	5.8	6.0	5.8	
Deep placement 3 ton/acre	5.4	5.8	6.0	5.9	
LSD (*P* = 0.1)	---- 0.3 ----		0.2	0.1	
Depth 6-10 in.	Corn	Soybean			
Surface non-treated	4.9	4.7	5.9	5.9	
Surface 1.5 ton/acre	4.7	4.7	6.0	6.0	
Surface 3 ton/acre	4.8	4.7	5.8	6.1	
Deep placement non-treated	4.8	4.7	5.8	5.9	
Deep placement 1.5 ton/acre	5.0	5.2	6.2	6.3	
Deep placement 3 ton/acre	4.8	4.7	6.4	6.5	
LSD (*P* = 0.1)	---- 0.4 ----		NS	NS	
Depth 11-15 in.					
Surface non-treated	4.8		4.7	4.8	
Surface 1.5 ton/acre	4.7		4.7	4.7	
Surface 3 ton/acre	4.7		4.7	4.9	
Deep placement non-treated	4.7		4.9	4.7	
Deep placement 1.5 ton/acre	5.1		4.7	5.2	
Deep placement 3 ton/acre	4.6		4.8	4.9	
LSD (*P* = 0.1)	NS		NS	NS	
Depth 16-20 in.				Corn	Soybean
Surface non-treated	4.5		4.6	4.4	4.4
Surface 1.5 ton/acre	4.5		4.6	4.4	4.4
Surface 3 ton/acre	4.5		4.5	4.4	4.4
Deep placement non-treated	4.5		4.5	4.4	4.5
Deep placement 1.5 ton/acre	4.5		4.6	4.6	4.4
Deep placement 3 ton/acre	4.4		4.5	4.5	4.4
LSD (*P* = 0.1)	NS		NS	----0.2----	

Table 8. Soil test pH_s values at 0 to 5, 6 to 10, 11 to15, and 16 to 20 inch depths after corn and soybean harvest for the experimental site established in 2013 and 2014. Interactions between factors were presented when appropriate.

	Established 2013		Established 2014
Lime placement	2013	2014	2014
Depth 0-5 in.			
Surface non-treated	4.7	4.6	5.6
Surface 1.5 ton/acre	5.2	5.2	6.0
Surface 3 ton/acre	5.3	5.5	6.4
Deep placement non-treated	4.8	4.6	5.7
Deep placement 1.5 ton/acre	4.7	4.6	5.7
Deep placement 3 ton/acre	4.8	4.6	5.7
LSD (*P* = 0.1)	0.2	0.2	0.4
Depth 6-10 in.			
Surface non-treated	5.0	4.9	5.9
Surface 1.5 ton/acre	4.7	4.9	6.1
Surface 3 ton/acre	4.9	5.0	6.1
Deep placement non-treated	4.9	4.7	6.2
Deep placement 1.5 ton/acre	5.2	5.0	6.5
Deep placement 3 ton/acre	5.0	5.2	6.6
LSD (*P* = 0.1)	NS	NS	NS
Depth 11-15 in.			
Surface non-treated	4.8	4.7	5.0
Surface 1.5 ton/acre	4.6	4.6	5.1
Surface 3 ton/acre	4.6	4.7	5.1
Deep placement non-treated	4.7	4.7	5.0
Deep placement 1.5 ton/acre	4.6	4.9	5.4
Deep placement 3 ton/acre	5.1	4.7	6.0
LSD (*P* = 0.1)	NS	NS	NS
Depth 16-20 in.			
Surface non-treated	4.6	4.6	4.5
Surface 1.5 ton/acre	4.6	4.6	4.7
Surface 3 ton/acre	4.6	4.7	4.8
Deep placement non-treated	4.6	4.6	4.6
Deep placement 1.5 ton/acre	4.6	4.6	4.6
Deep placement 3 ton/acre	4.7	4.6	4.7
LSD (*P* = 0.1)	NS	NS	NS

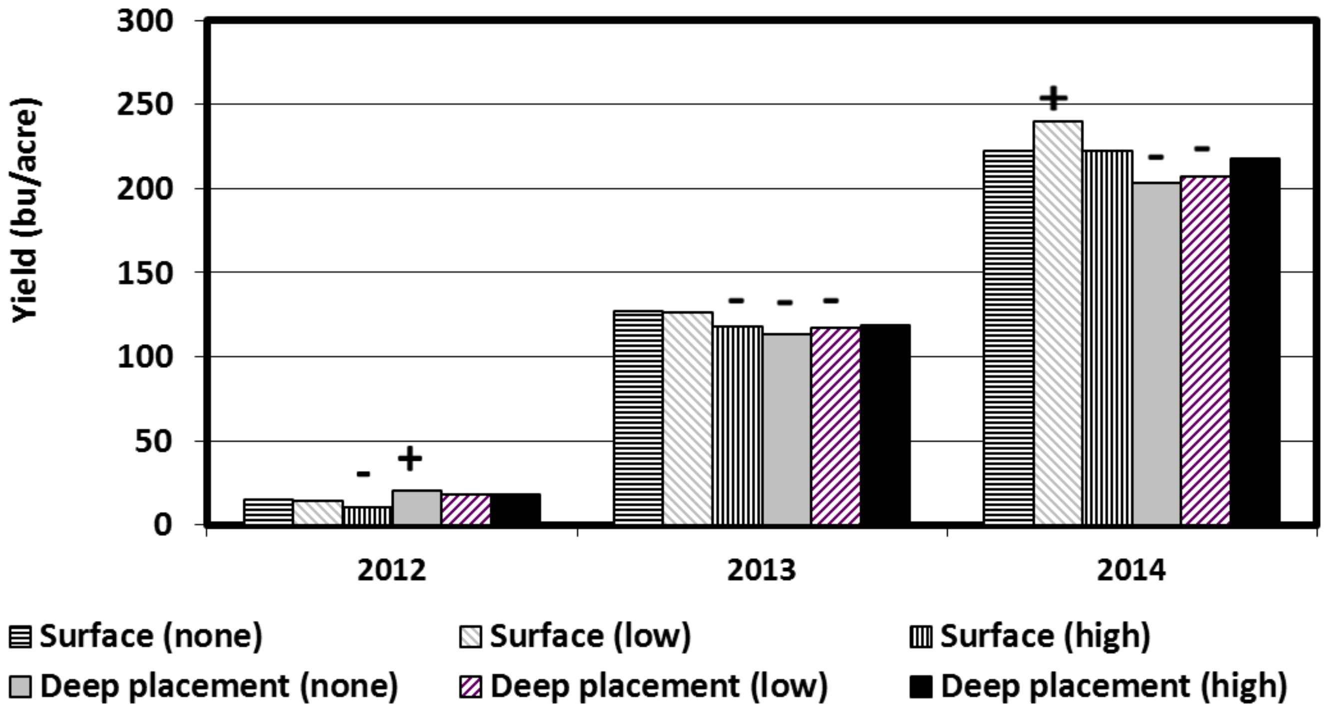

Figure 3a. Corn grain yield response to no-till surface or deep placed lime (none = 0 ton/acre, low = 1.5 ton/acre, and high 3.0 ton/acre) established in 2012. LSD (P = 0.1) was 4, 9, and 8 bu/acre in 2012, 2013, and 2014, respectively. Labels above bars indicate a significant increase (+) or decrease (-) in yield compared to the no-till, non-treated control.

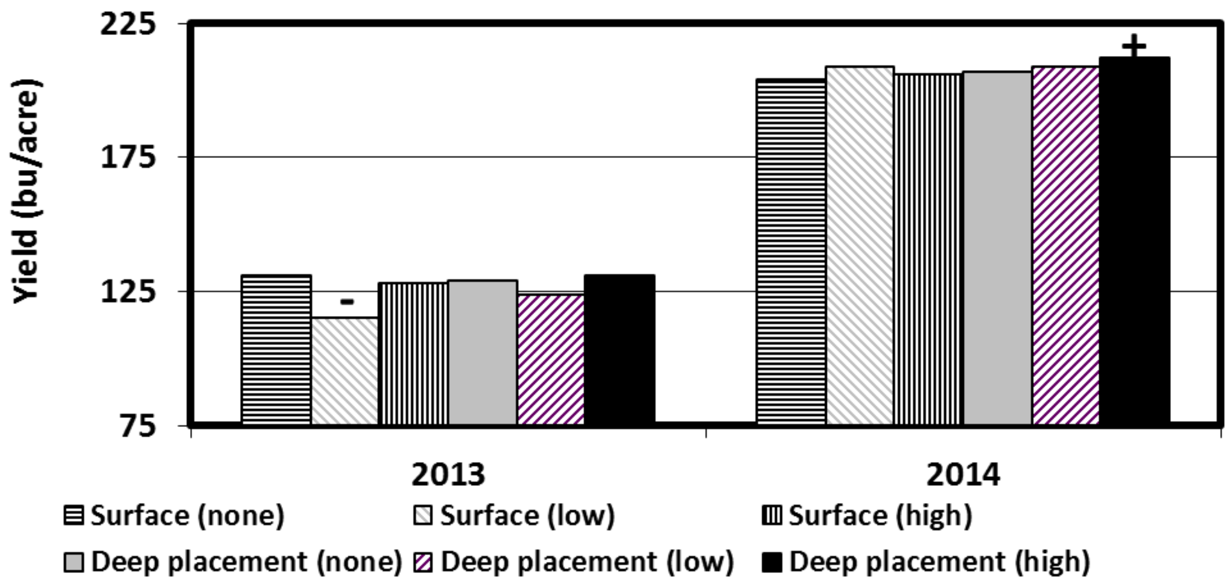

Figure 3b. Corn grain yield response to no-till surface or deep placed lime (none = 0 ton/acre, low = 1.5 ton/acre, and high 3.0 ton/acre) established in 2013. LSD (P = 0.1) was 12 and 6 bu/acre in 2013 and 2014, respectively. Labels above bars indicate a significant increase (+) or decrease (-) in yield compared to the no-till, non-treated control.

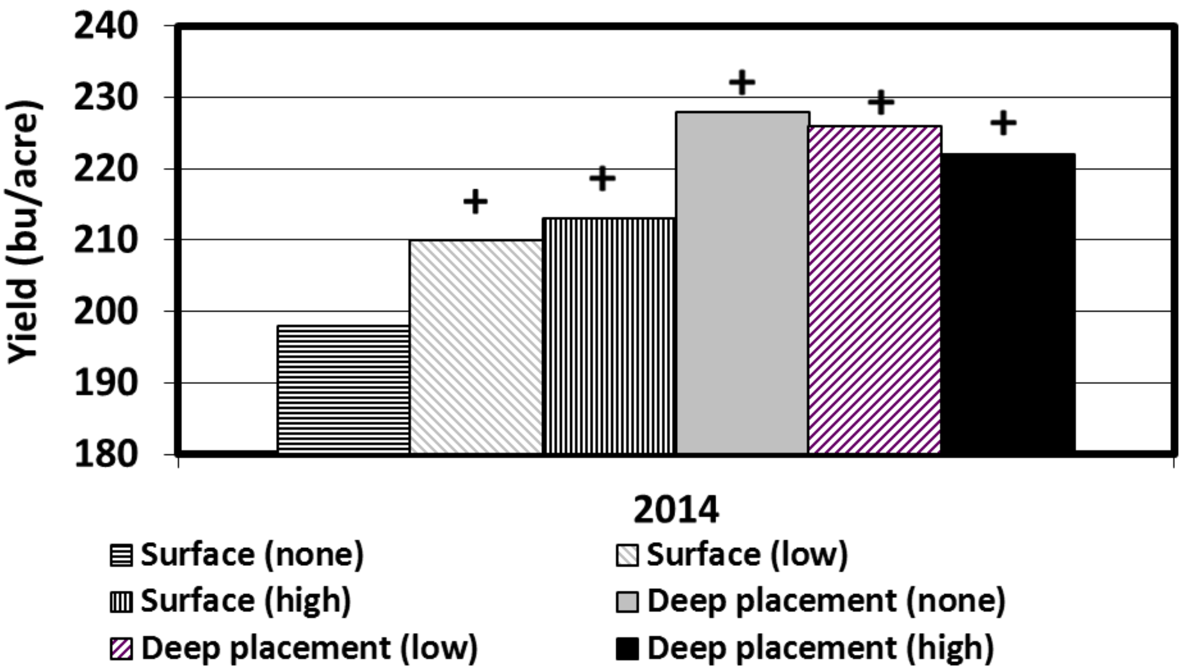

Figure 3c. Corn grain yield response to no-till surface or deep placed lime (none = 0 ton/acre, low = 1.5 ton/acre, and high 3.0 ton/acre) established in 2014. LSD (P = 0.1) was 11 bu/acre in 2014. Labels above bars indicate a significant increase (+) or decrease (-) in yield compared to the no-till, non-treated control.

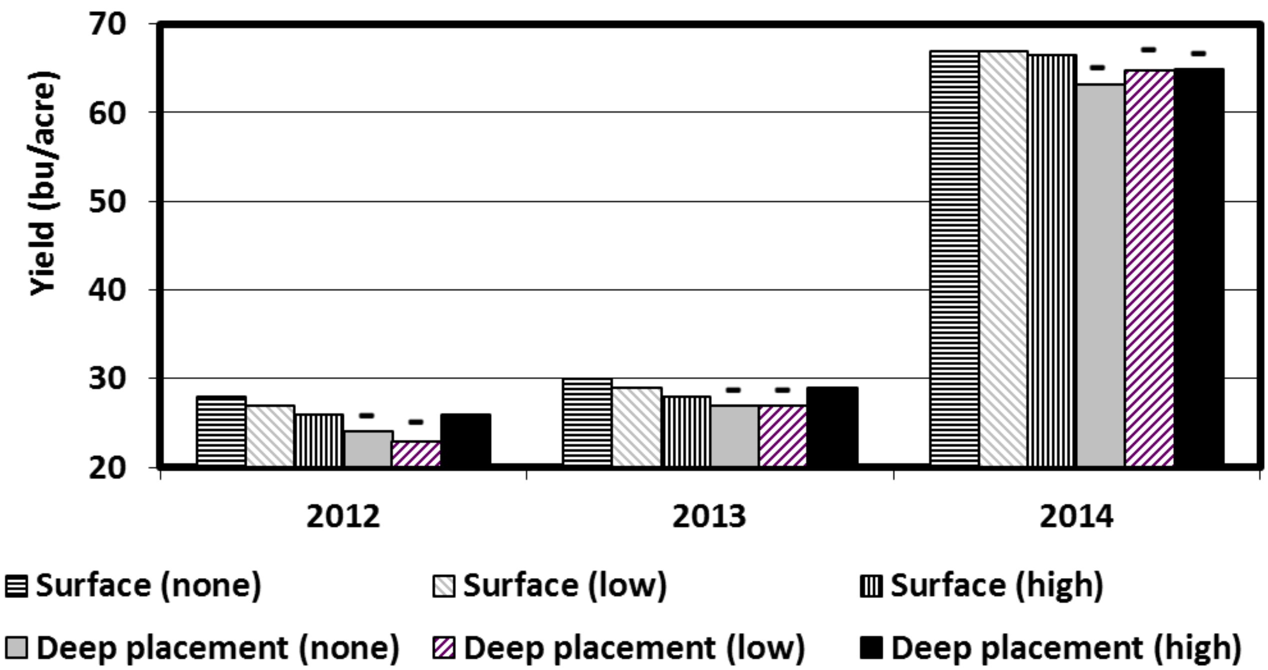

Figure 4a. Soybean grain yield response to no-till surface or deep placed lime (none = 0 ton/acre, low = 1.5 ton/acre, and high 3.0 ton/acre) established in 2012. LSD (P = 0.1) was 2, 2, and 2 bu/acre in 2012, 2013, and 2014, respectively. Labels above bars indicate a significant increase (+) or decrease (-) in yield compared to the no-till, non-treated control.

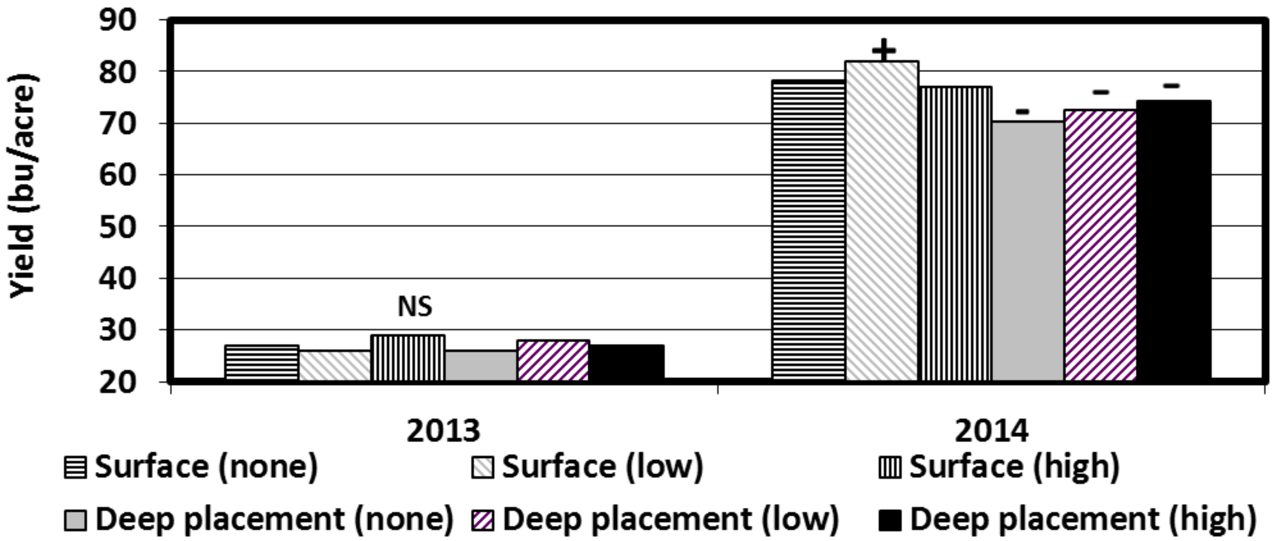

Figure 4b. Soybean grain yield response to no-till surface or deep placed lime (none = 0 ton/acre, low = 1.5 ton/acre, and high 3.0 ton/acre) established in 2013. LSD (*P* = 0.1) was non-significant (NS) and 3 bu/acre in 2013 and 2014, respectively. Labels above bars indicate a significant increase (+) or decrease (-) in yield compared to the no-till, non-treated control.

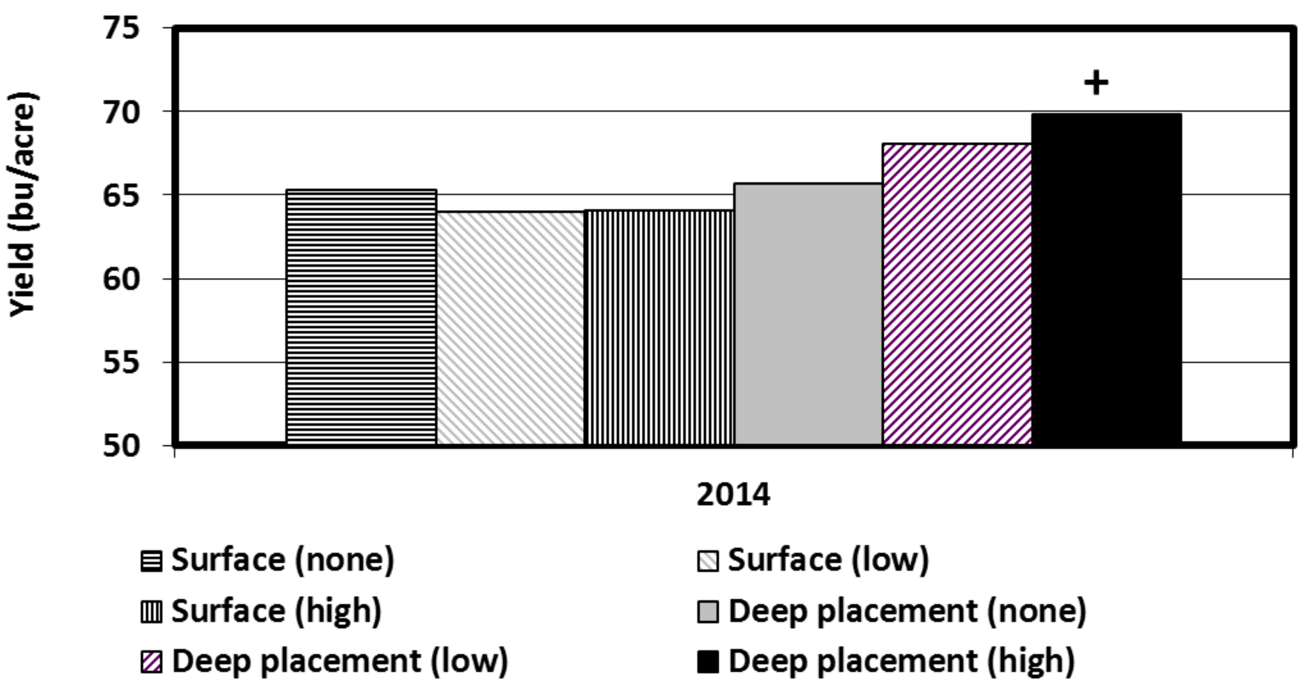

Figure 4c. Soybean grain yield response to no-till surface or deep placed lime (none = 0 ton/acre, low = 1.5 ton/acre, and high 3.0 ton/acre) established in 2014. LSD (*P* = 0.1) was 3 bu/acre in 2014. Labels above bars indicate a significant increase (+) or decrease (-) in yield compared to the no-till, non-treated control.

Nitrogen Management

Progress Reports

2012

(Report received after publication of last Fertility Update)

Sensor-based variable rate N: Long-term performance in corn and cotton

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Objective:

The objective of this project is to evaluate long-term performance of sensor-based variable N rate recommendations for corn and cotton. Sensor-based N management is compared with typical producer N management and with other N rate decision systems.

Accomplishments for 2012:

- Two small-plot corn experiments were conducted as planned at Bradford Farm near Columbia.
- Unfortunately, the planned cotton experiment was not conducted in 2012 due to miscommunication. The corn experiment will be extended for an extra year to make up for this omission.

Sensor-based variable rate N: Long-term performance in corn

Experiment 1: Long-term impact of nitrogen rate recommendation systems

- 2012 is the 6th year of this study, with each plot getting the same N timing and N rate decision system every year.
  - Four of the treatments are fixed preplant N rates: 0, 100, 140, and 180 lb N/ac
  - The 140 lb N/acre rate is the MRTN (Maximum Return to Nitrogen) rate for Missouri and is also the Univ. of Missouri N rec for 135 bushel corn with 2.8% soil organic matter
  - A fifth preplant N treatment has the 140 lb N/acre rate as a base, with soil nitrate credits subtracted based on a 2-foot soil nitrate sample
  - Three treatments have N applied sidedress; rates are based on:
    - Sidedress soil nitrate test (Iowa State University interpretation)
    - Chlorophyll meter (University of Missouri interpretation)
    - Crop Circle 210 canopy sensor (University of Missouri interpretation)
  - All treatments are surface-applied ammonium nitrate
- This experiment is conducted in continuous no-till corn to magnify the effects of any problems related to N management.

- Extreme drought occurred in this experiment in 2012.
    - Three irrigations totaling 3.6 inches were applied with a linear-move irrigation system in July to avoid complete crop failure.
- Even so, all treatment mean yields were 82 bu/acre or less due to water limitation.
- Yield differences between treatments were minimized due to this water limitation.
- Yields for the eight N system treatments are shown in the table on the next page.

Nitrogen Recommendation System	N timing Stage[1]	2012 N Rates lbs./ac	2012 [2] Yield bu/ac	2012 [4] Yield value Minus N cost $/ac	2007-12 [3] Avg. rate lbs./ac	2007-12 [3] Avg. Yield bu/ac	2007-12 [3,4] Yield value Minus N cost $/ac
Chlorophyll meter	V7	160	79	392	169	133	730
Crop Circle sensor	V7	67, 146,168 133,162,191 **avg rate = 144**	79	403	148	129	721
Sidedress soil test	V7	116	76	404	121	120	679
High	Preplant	180	81	391	180	94	475
Yield goal/ MRTN	Preplant	140	77	393	140	84	439
Preplant soil test	Preplant	140	82	425	135	83	438
Low	Preplant	100	72	390	100	75	409
Check	Preplant	0	34	218	0	45	287

[1] Growth stage V7 is about knee high corn

[2] Yields are different from one another (90% confidence) if they are more than 5 bushels apart

[3] 2011 data was not included due to insufficent stand count and uniformity

[4] Partial profit analysis based on mid-Dec. 2012 prices. Corn - $ 6.40/bu. Nitrogen cost - $ 0.71/lb.

- Six of the N treatments yielded between 76 and 82 bushels with N rates between 116 and 180 lb N/acre. Because water availability limited yields so severely, most N timing & rate combinations appeared to deliver enough N to the crop to maximize yield within the constraint of limited water.
- Only the 0 and 100 lb N/acre rates clearly yielded less than the other treatments. Although the 100 lb N rate would seem to be enough to produce 80 bushels like the other treatments, N delivery from soil to roots is inefficient when soil is dry.
- **Treatments in the table above are ordered based on profitability for the period 2007-2012.**
- **For this period, the two systems based on crop color to guide sidedress N rate out-performed the best preplant system (180 lb N rate) by about $250/acre.**
    - They produced 35-40 bushels more corn with 10-30 lb less N than the 180 lb

N/acre preplant treatment.

  - This was mainly due to serious N loss with preplant N applications during the wet springs of 2008-2010.

- The color-based systems for choosing sidedress N rate also out-performed the soil test system for choosing sidedress N rate by $40-50/acre.
  - This was due to under-recommendation by the sidedress soil test system in 2007 and 2010, resulting in lower yields.
- **Based on results from 2007-2012, long-term performance of sensor-based variable-rate N in corn appears to be good.**

<u>Experiment 2: Effect of pre-plant nitrogen on sensor-based N rate performance</u>

- Experiment 2 is designed to complement Experiment 1 and address concerns that sidedress systems with no N applied preplant may cost yield.
  - 2012 is the second year for this experiment.
  - Three of the four treatments in Experiment 2 are shared with Experiment 1.
  - The key treatment is 50 lb N/ac applied pre-plant, followed by sidedress N at rates diagnosed by the Crop Circle sensor.
    - Results from this treatment can be compared to pre-plant N management (140 and 180 lb N rates) and sensor-based sidedress with no N pre-plant to evaluate its relative performance.
    - Any N stress experienced with the sidedress-only sensor-based treatments should be avoided.
- It is right next to Experiment 1, so soils and weather are very similar. Seed, herbicide, planting date, and application dates are identical to Experiment 1. Experiment 2 received the same supplemental irrigation (total about 3.6 inches) as Experiment 1.
- Despite irrigation, yields were strongly water-limited and treatment mean yields did not exceed 79 bushels/acre.
- One of the concerns with sidedress N management with no N applied pre-plant is that the crop development will be slowed. In years with a July drought, slower development could push reproductive stages farther into the drought, causing additional yield loss
- **Sidedress-only N management did not cause yield loss despite drought stress and the potential for slower development to push reproductive growth into a more stressful time.**
- **Over the 3 years of this study, there has been no indication that sensor-based N rate recommendations perform better with preplant N than without.**

- **Over 3 years, sensor-based N management out-yielded the best preplant N management by about 8 bushels and gave about $85/acre higher profit (see table below).** This is due to higher yields with sensor-based N management than preplant N management in 2010. Yield differences between treatments were minimal or non-existent in 2011 & 2012. Average N savings over the 3-year period were 40 and 55 lb N/acre for the two sensor-based N systems while still producing higher yield than the most profitable preplant N system.

Nitrogen rates recommended and corn yields produced by four different recommendation systems in 2012

Nitrogen System Used	Nitrogen [1] Application Timing	2010 [2] Crop Circle N Rates lbs/ac	2010 [2] Total N Rates lbs/ac	2010 Yield bu/ac	2010 [3] Gross - N cost $/ac	2011 [2] Crop Circle N Rates lbs/ac	2011 [2] Total N Rates lbs/ac	2011 Yield bu/ac	2011 [3] Gross - N cost $/ac	2012 [2] Crop Circle N Rates lbs/ac	2012 [2] Total N Rates lbs/ac	2012 Yields bu/ac lbs/ac	2012 [3] Gross - N cost $/ac	3 yr Avg. N Rates lbs/ac	3 yr Avg. Yields bu/ac	3 yr Avg. [3] Gross - N cost $/ac
Crop Circle sensor	V8	135,113 108, 84 163,167 avg. rate 128	135,113 108, 84 163,167 avg. rate 128	135	$773	145,116 137,92 158,137 avg.rate 131	145,116 137,92 158,137 avg.rate 131	83	$438	155,134 93,92 90,127 avg.rate 115	155,134 93,92 90,127 avg.rate 115	73	$386	125	97	$532
50 lbs./N + Crop Circle sensor	Pre-plant + V8	60, 74 60,157 160,96 avg. rate 101	110,124 110,207 210,146 avg. rate 151	139	$782	93,103 69,117 137,74 avg.rate 99	143,153 119,167 187,124 avg. rate 149	81	$413	78, 54 79, 53 66, 85 avg.rate 69	128, 104 129, 103 116, 135 avg. rate 119	73	$383	140	98	$526
Yield goal MRTN	Pre-plant	140	140	104	$566	140	140	78	$400	140	140	64	$310	140	82	$425
High	Pre-plant	180	180	107	$557	180	180	80	$384	180	180	79	$378	180	89	$440

[1] Growth stage V6-V7 is about knee high corn, Growth stage V8-V10 is about thigh to waist high corn

[2] A different N rate was applied in each of 6 replications for this treatment. It is feasible to use this sensor to change N rate automatically while fertilizing a field, and we felt that this ability would be most accurately reflected by diagnosing N rate for each plot separately.

[3] Gross calculated using $6.40/bu. corn price, $0.71/lb. N cost as estimates of average corn prices and N cost during these years.

Sensor-based Topdressing for Winter Wheat

Peter Scharf, Larry Mueller, David Kleinsorge, and Vicky Hubbard

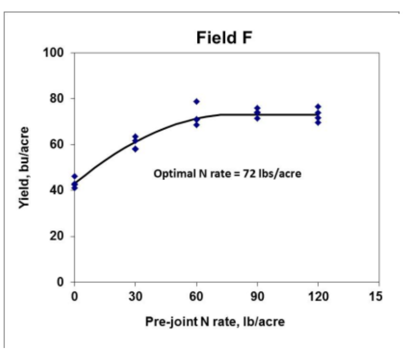
Objective:

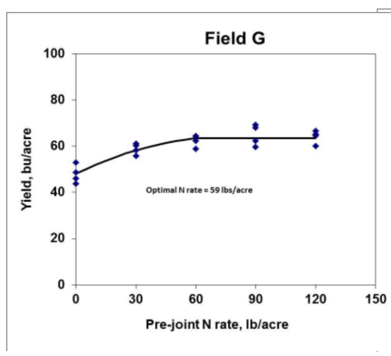
- Develop reliable sensor interpretations as a basis for on-the-go variable-rate N topdressing of winter wheat.

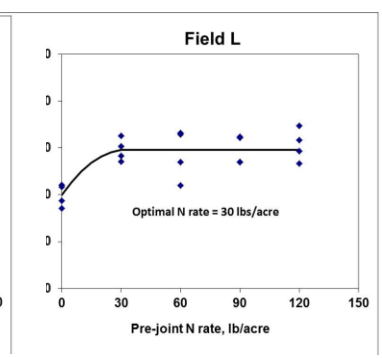
Accomplishments for 2012:

- Three nitrogen rate experiments were carried out in conjunction with sensor measurements at the pre-jointing growth stage.
- As with 2009 & 2011, **N applications just before jointing were more effective than N applications at greenup**.
  - Maximum yield with all N applied at greenup was, on average, 3 bushels/acre less than when all N was applied a month later at the pre-joint stage.
  - This compares with a 9-bushel advantage to pre-joint N in 2011 while using 20 lb N/acre less.
  - In 2009, either N timing could produce full yield, but it took an average of 120 lb N/acre applied at greenup compared to an average of just 77 lb N/acre applied pre-jointing. If the 77 lb N/acre was applied at greenup, a 5 bushel/acre yield loss was seen.
  - (No experiments were harvested in 2010 due to establishment failure.)
  - For N applications split between greenup and pre-joint, every 30 lb N/acre reduced optimal N rate applied at prejoint by 18 lb N/acre. This suggests that N applied at greenup was about 60% as effective as N applied at pre-joint.

- **Applying all N pre-joint worked fine in these experiments**
  - There was weak evidence that split spring applications may have given higher profit in 1 of the 3 experiments, but if so it wasn't much higher
  - Yield response to different N rates at the prejoint stage is shown in the graphs below





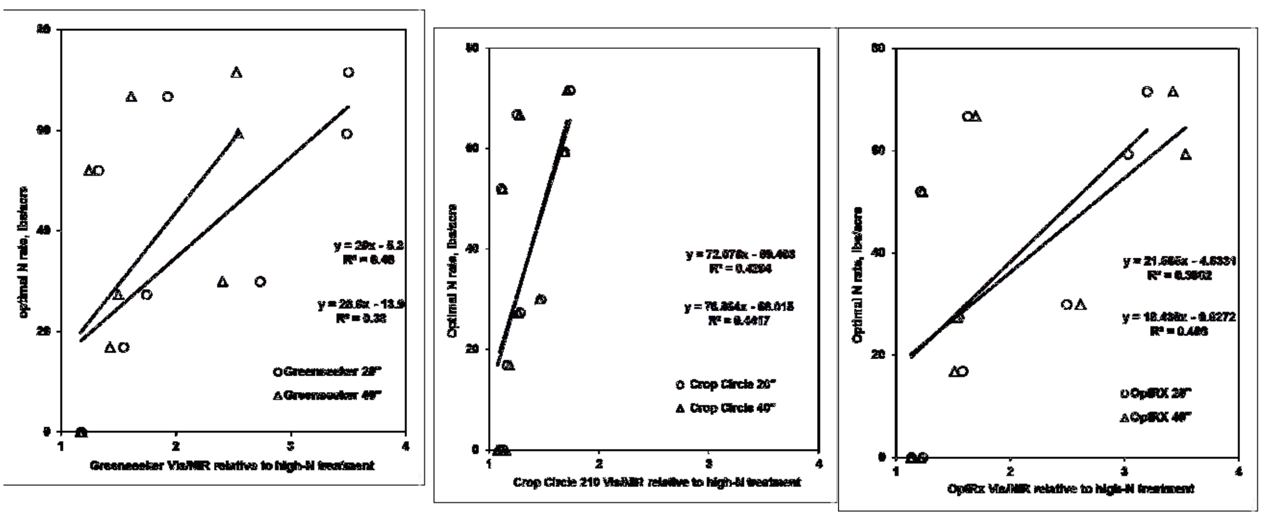


- The optimal (most profitable) N rates were lower than in most of our past research
  - Average 54 lb N/acre
  - Range from 30 to 72 lb N/acre
  - This compares to average optimal N rates of 77 lb N/ac in 2009 and 101 lb N/ac in 2011 in this project.

- A range of crop appearances and N sufficiencies at the pre-jointing stage was created by applying either 0, 30, or 60 lb N/acre at greenup. Each of these greenup N rates was followed by a complete range of N rates and by sensor measurements at the pre-jointing stage.

- Each experiment thus produces three data points of sensor value and optimal N rate:
  - One with no N applied at greenup
  - One with 30 lb N/acre applied at greenup
  - One with 60 lb N/acre applied at greenup

- The relationship between sensor readings and optimal N rate for three sensor models in 2012 experiments is shown in the graphs below.
- Sensor values are expressed relative to plots that received 120 lb N/acre at greenup: relative Visible/near-infrared = (Vis/NIR)/(Vis/NIR-120)
- Three types of sensors were used in 2012: Greenseeker, Crop Circle 210, & OptRx
- Measurements were taken with all 3 sensors at 2 heights: 20 inches and 40 inches



- All three sensors gave Relationships between relative Vis/NIR and optimal N rate that might be good enough to be useful in guiding variable-rate N applications based on real-time sensors measurements of wheat canopy properties at the pre-joint stage.
  - Equations shown above could potentially be used to translate sensor measurements to N rates during variable-rate N application.
  - The R2 values on the graphs indicate the quality or accuracy of the relationship, with a higher value being better–the highest possible value is 1.
  - The quality of N rate predictions appears to be roughly equal for all three sensors based on these results
- The relationship (equation & line) between sensor values and optimal N rates was similar for Greenseeker and OptRx. Values for the Crop Circle 210 sensor did not go up as much as the other sensors when looking at N-stressed wheat, resulting in a steeper line in the graph above, but this did not affect the quality of N rate predictions.
- The height of the sensor when taking measurements did not influence sensor values for the Crop Circle and OptRx sensors. Greenseeker measurements were more different between N-sufficient and N-deficient wheat when measured from 20 inches than when measured from 40 inches. The quality of the relationship was similar (though possibly better for 20 inches), but the equation to predict N need would depend on sensor height.

- We conducted our first on-farm demonstration of variable-rate N application based on crop sensors in 2012. OptRx sensors were mounted on the dribble UAN applicator of Mel Gerber, who farms near Versailles, MO, and the Ag Leader program for doing sensor-based N in his Integra controller was used. We found that the parameter input values for this program had to be modified to give N rates that agreed with his judgement and mine, but once we found the right combination of parameter values the variable-rate application went well. The whole field received variable-rate N, except for two strips near the west end where Mel's normal N rate (71 lb N/acre) was applied. These strips appear as solid green in the application map above.

- In the variable-rate N strips between the two green strips, and on either side of the green strips, average N rate applied was 79 lb N/acre. The sensors increased N rate in some parts of the strip and decreased N rate in others.
- The variable-rate strips out-yielded the adjacent constant-rate strips by 2.3 bushels/acre.
  - With wheat prices at around $8/bushel, this yield increase is worth about $18/acre.
  - All three strips with sensor-based N rates gave higher yields than either strip with constant-rate N.
  - The extra N applied using the sensors, at $0.75/lb N, cost about $6/acre.
  - The sensors appeared to increase profit by $12/acre. With the limited number of observations in this test, this should be considered as a preliminary result.

Timing and source of nitrogen for corn

Peter Scharf, Larry Mueller, and David Kleinsorge
University of Missouri, Plant Sciences Division

Objective:
Measure the yield impact of a range of nitrogen fertilizer application times for a range of nitrogen sources.

Accomplishments for 2012:

- Equipment acquisition, setup, and testing has been completed. We already had equipment available for the dry and liquid fertilizer applications, but needed equipment that would accurately apply anhydrous ammonia with and without N-Serve.
  - Built a 5-knife toolbar for applying anhydrous ammonia.
  - Acquired a Raven 440 controller and Raven Accuflow ammonia control system (cooler, flowmeter, control valve, shutoff valve).
  - Assembled the ammonia control system.
  - Acquired a Sidekick injection pump (for N-Serve) and mounted it on the ammonia toolbar.
  - Calibrated and tested system.

- The experimental design was developed, and the experiment was laid out at Bradford Farm near Columbia. Soybean was the previous crop.
  - This farm has claypan soils representative of the grain-producing claypan soils that are found across much of the northeast quarter of Missouri.
  - The experiment has 5 replications.
- Experimental treatments will be N timing and N source combinations as shown in the table below.
  - October anhydrous ammonia treatments have been applied, with and without N-Serve.
  - December anhydrous ammonia treatments have been applied, with and without N-Serve.
  - All aspects of this project are on track with the timeline given in the proposal.

Nitrogen timing	Nitrogen Source							
	NH_3	NH_3 *with N-Serve*	Ammonium Nitrate	Urea	Urea *with Agrotain*	UAN *Injected*	UAN dribbled	ESN *coated urea*
October	X	X						
December	X	X						
February	X	X	X	X	X	X	X	X
March	X	X	X	X	X	X	X	X
April	X	X	X	X	X	X	X	X
Knee-high	X		X	X	X	X	X	X
Waist-high				X	X			

- Nitrogen rate for all treatments will be 140 lb N/acre. This rate is usually sufficient under Missouri conditions, but not enough to mask N losses that may occur.

Budget for 2013 (as given in original proposal):

Research Specialist salary	$20,000
Benefits	5,000
Field supplies and fuel	1,000
Total year 2	**$26,000**

2013

Nitrogen Fertilizer Management of Temporarily Flooded Soils to Improve Corn Production and Reduce Environmental N Loss

Brendan Zurweller, Dept. of Soil, Environ. and Atmos. Sci, University of Missouri
Peter Motavalli, Dept. of Soil, Environ. and Atmos. Sci, University of Missouri
Kelly Nelson, Plant Sciences Division, University of Missouri, Greenley Center
Ranjith Udawatta, Dept. of Soil, Environ. and Atmos. Sci, University of Missouri

Accomplishments for Second Year:

Research was continued in 2013 with the objectives of determining the effects of flooding durations on corn (*Zea mays.* L.) growth and N use efficiency (NUE); assessing the use of different N sources including PCU, nitrification inhibitor and a post-flood rescue N fertilizer treatment; and evaluating the economic costs and benefits of using these fertilizer sources under different flooding conditions. The overall goal of this research is the development of an economically profitable N fertilizer strategy for both pre- and post-flood conditions that will increase corn production and decrease environmental N loss.

This field trial was continued in 2013 at the University of Missouri's Greenley Research Center in Northeast Missouri. The specific field chosen was adjacent to the field used in the 2012 growing season. Soil classification for the field is a Putnam silt loam (fine, smectitic, mesic Vertic Albaqualfs). Soil samples were collected in increments of 0-4, 4-8, and 8-12 inch depths before pre-plant fertilizer application and incorporation to characterize initial soil conditions (Table 1). Some differences in pre-fertilization soil characteristics compared to the 2012 growing season were lower pH_s and greater inorganic N concentrations. This could possibly be due to residual N from the exceptionally dry growing season of 2012. These inorganic N concentrations also increase with depth suggesting higher than normal N concentrations might be present below the sampling depth.

The field was separated into 15 by 100 foot plots of six 30-inch rows of DEKALB 62-97VT3 planted at 32,000 seeds/acre on 14 May. Nitrogen fertilizer treatments of a control (CO) and 150 lbs N/acre of urea (NCU), urea plus nitrapyrin nitrification inhibitor (NCU + NI) (N-Serve®, Dow AgroSciences, Indianapolis, Indiana), and polymer-coated urea (PCU) (ESN®, Agrium, Inc., Calgary, Alberta). All fertilizer N treatments were incorporated immediately after application with a cultivator. The experimental design was a randomized complete block with a split-split plot arrangement replicated three times.

Since no flooding treatment effect occurred during the 2012 growing season, an extended flooding duration treatment of 7 days was added to replace the 2 day treatment. Therefore, flooding durations imposed in 2013 were 0, 1, 3, and 7 days at the V6 corn growth stage on 18 June using temporary soil levees to surround each flooding block (Fig. 1). Levees were removed to allow ponded water to escape after the intended flooding duration had ceased. On 8 July, a rescue N fertilizer application of 75 lbs N/acre of urea plus NBPT (N-(n-butyl) thiophosphoric triamide) urease inhibitor (NCU + UI) at 1 gal/ton was applied to half of each pre-plant fertilizer treatment (Agrotain®, Koch Agronomic Services, Wichita, Kansas). Following the rescue application each 15 by 100 foot fertilizer treatment was split into two 15 by 50 foot plots, one being with the rescue application plus urease inhibitor and the other without the rescue application. The 2013 rescue application of 75 lbs N/acre was consistent to the amount applied in 2012 for an economical optimal N rate for yield response at corn growth stage V10 determined from SPAD 502 chlorophyll meter readings (Konica Minolta, Hong Kong) (Scharf et al., 2006).

Chlorophyll content was measured in all plots after the 7 day flooding treatment had ended to assess any impacts of pre-plant N treatments and flooding stress on corn plants (Fig. 2). Pre-plant fertilizer treatments of NCU+NI and PCU had significantly higher chlorophyll content than the non-fertilized pre-plant treatment of 5.5 and 4.2 SPAD units, respectively. There were no significant chlorophyll content differences among the non-fertilized and NCU treatments. Urea, NCU+NI, and PCU had significantly greater chlorophyll content compared to the non-fertilized pre-plant treatment when 3 and 7 days of flooding occurred. Chlorophyll content also generally decreased as flooding durations increased for all pre-plant N treatments. There were no statistically significant differences between pre-plant N treatments with a 7 day flooding duration. These results suggest that flooding can temporarily decrease the amount of leaf chlorophyll measured using the SPAD meter. A possible explanation for this result could be due to soil NO_3^- loss with flooding, and less corn N uptake since oxygen depleted soils can result in a decrease in plant transpiration.

Corn grain yields were determined on 23 Sept. from the total row length of the two center rows from each N treatment. There was an effect of flooding duration on the grain yield in 2013 (Fig. 3). Significant yield reductions of 15.7 and 44.6 bushels/acre occurred as a result of 3 and 7 days of flooding, respectively, when compared to the non-flooded control. An average loss of 6.6 bushels/acre occurred with each day of flooding. No effect of pre-plant or rescue N plus a urease inhibitor occurred on grain yield for the 2013 growing season. The lack of corn grain response to N fertilizer treatments could possibly be due to the combination of residual soil N in the soil profile deeper than 1 foot, and late season “flash” drought conditions during the seed-filling period (Fig. 4).

Corn silage N uptake was measured when corn plants reached physiological maturity (Fig. 5). As was observed with the decrease in grain yield with increased flooding duration, silage N uptake significantly declined with 3 and 7 days of flooding when compared to the non-flooded control. There was also significantly lower silage N uptake when comparing the 7 day flooding event to 1 and 3 days of flooding. A significant increase in silage N uptake of 17.4 pounds/acre did occur with the rescue N plus urease inhibitor application.

Pre-plant N and flooding treatments had an effect on grain quality (Fig. 6 A & B and 7). As flooding duration increased the concentration of grain protein decreased. All three pre-plant N treatments had greater protein concentration than the non-fertilized pre-plant N treatment with no-flooding and 1 day of flooding. After 3 days of flooding, PCU had 0.25 % more protein content than the non-fertilized pre-plant treatment. In contrast to the protein content, extractable starch and oil content generally increased as flooding durations increased.

Soil samples were collected from the 0-4, 4-8, and 8-12 inch depths from pre-plant N fertilizer treatments before (18 June) and after the temporary flooding events (1 July) and analyzed for soil inorganic N (ammonium-N and nitrate-N) (Fig. 8 A & B, 9, and 10). Prior to flooding, PCU and NCU+NI had 3.6 and 2.8 more pounds of NH_4^+-N per acre, respectively, than the NCU pre-plant N treatment at a depth of 8-12 inches (Fig 8A). After flooding, PCU maintained significantly greater NH_4^+-N than all other pre-plant N treatments at a depth of 0-12 inches (Fig. 9). Nitrate content prior to flooding was significantly greater for all pre-plant N treatments in comparison to the non-fertilized N control (Fig 8B). Soil samples collected after the temporary flooding durations and analyzed for NO_3^- -N showed that when no flooding occurred the PCU and NCU+NI treatments had 51.3 and 47.1 more pounds/acre of NO_3^--N, respectively, than NCU (Fig. 10). Significant losses of soil NO_3^- -N occurred even after 1 day of flooding especially with the PCU and NCU+NI-treated soils which had initially higher soil NO_3^- N concentrations compared to the control and NCU treatments when no flooding occurred (Fig. 10).

Soil samples were also collected from pre-plant N fertilizer treatments with and without rescue N plus urease inhibitor treatments following corn grain harvest and analyzed for NH_4^+-N and NO_3^--N (Fig. 11 A & B). Polymer-coated urea maintained the highest soil NH_4^+-N and NO_3^- -N content of the pre-plant N fertilizer applications that received the rescue N application plus urease inhibitor. Both the PCU and NCU+NI treatments had greater NO_3^--N content than the NCU treatment when comparing the pre-plant N treatments without the rescue N application.

Outreach and Training:

A M.S. graduate student in soil science at the University of Missouri has been involved in working on this project as part of his thesis. The first year research results were presented as an oral presentation to growers and agricultural professionals by the M.S. student at the 2013 Greenley Center Field Day in Northeast Missouri. The first and second year results were presented in a poster by the M.S. graduate student at the American Society of Agronomy (ASA) annual meetings, and at the North Central Extension-Industry Soil Fertility Conference. The student received an award for his poster presentation at the ASA Meetings and was honored at the North Central Extension Conference as the outstanding soil fertility graduate student from the state of Missouri.

Objectives for Year 3:

The objectives for the third year of this research will be similar to the second year. These objectives are:

1. To collect information to assess changes in inorganic soil N and corn grain yield response due to different soil saturation durations among enhanced efficiency products with urea fertilizer.

2. To evaluate the ability of a rescue N application of urea plus NBPT to increase grain yields following soil saturation durations at late corn growth stage of V10.

3. To calculate the cost-effectiveness over three site years of using enhanced efficiency products of polymer coated urea and the nitrification inhibitor nitrapyrin with urea under different durations of soil saturation.

The field study will be repeated for a third year to assess variation in climate on corn response to enhanced efficiency N fertilizers and rescue N application following soil saturation periods of 0, 1, 3, and 7 days. An economic analysis will be included using fluctuations in fertilizer and enhanced efficiency prices between the three years to determine whether use of enhanced efficiency products and a rescue application of N are cost effective after 0, 1, 3, and 7 days of soil saturations.

Table 1. Soil test collected prior to pre-plant fertilization for the 2013 field study site at the Greenley Research Center averaged over three replications by soil depth.

Depth	**pH_s**	**NA**	**OM**	**Bray 1 P**	**Exch. Ca**	**Exch. Mg**	**Exch. K**	**CEC**	**B.D.**	**NO_3^- -N**	**NH_4^+ -N**
inches		meq/100 g	- % -	--------------- lbs/acre			----------------	meq/100 g	g/cm^3	-- lbs N/acre --	
0-4	5.4	3.7	2.8	74.3	3302	343	391	13.9	1.11	11.3	3.7
4-8	5.9	2.5	2.0	24.0	3885	380	197	14.0	1.30	13.9	3.9
8-12	5.2	4.7	1.8	13.0	3793	490	210	16.5	1.26	18.1	4.3

†Abbreviations: NA, Neutralizable Acidity; OM, Organic Matter; P, Bray-1 Phosphorus; Exch. Ca, Exchangeable Calcium; Exch Mg, Exchangeable Magnesium; Exch. K, Exchangeable Potassium; CEC, Cation Exchange Capacity; B.D, Bulk Density; NO_3^--N, Nitrate Nitrogen; NH_4^+-N, Ammonium Nitrogen.

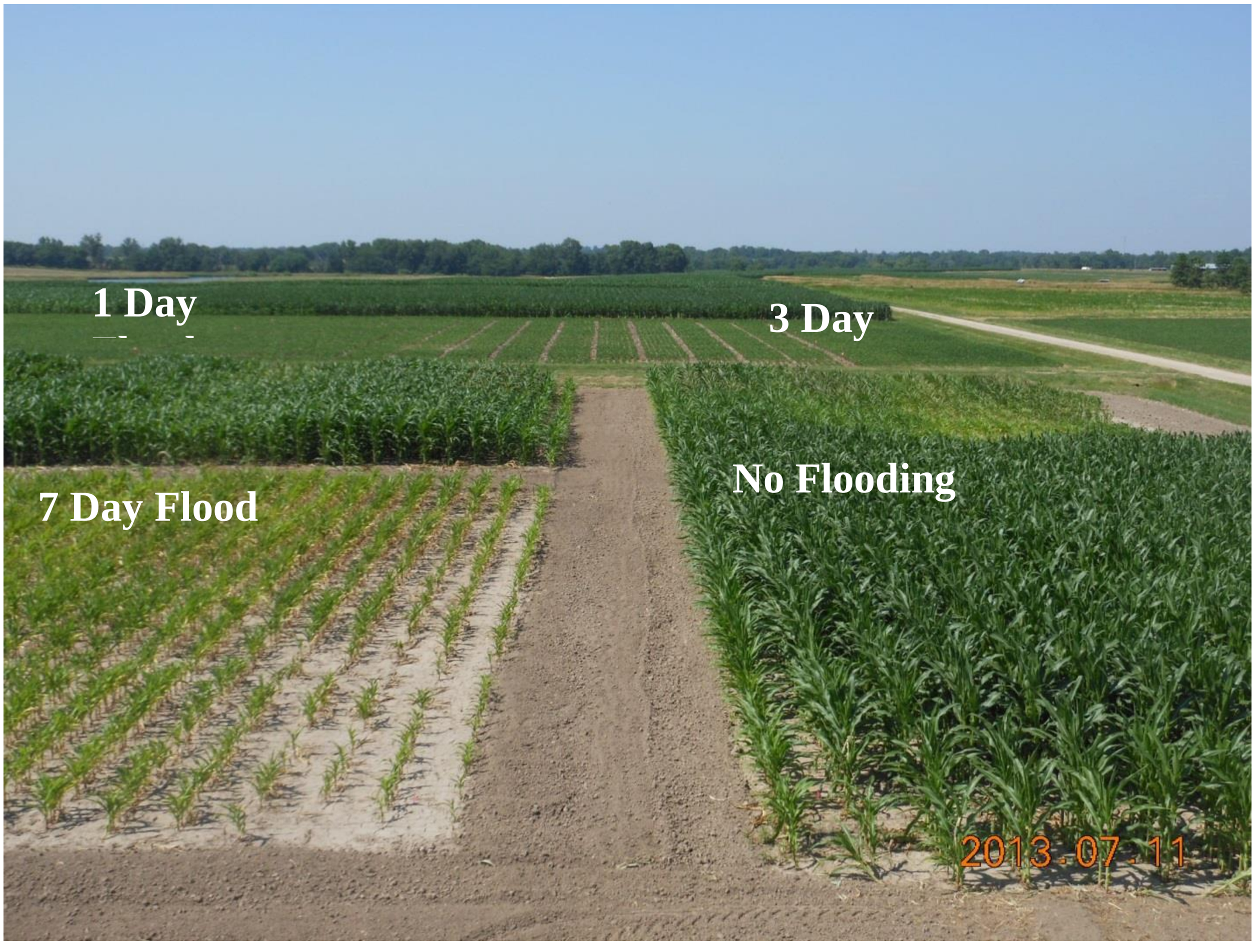


Figure 1. Flooding treatments on 11 July, 2013 which was 16 days after the 7-day flooding treatment was drained.

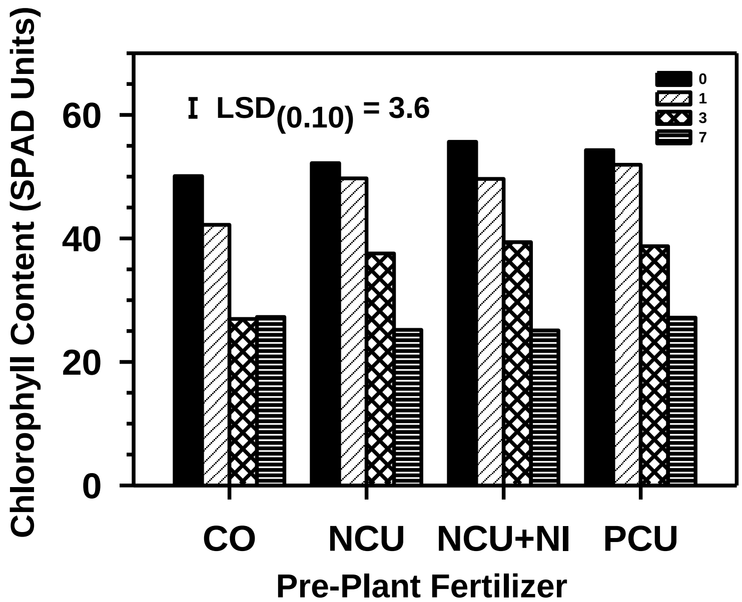


Figure 2. SPAD chlorophyll readings on 28 June, 2013 after all flooding treatments were drained to determine effects of flooding duration and pre-plant N fertilizer on chlorophyll content. (Abbreviations: CO, Control; NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea; 0, No-flooding; 1, 1 day of flooding; 3, 3 days of flooding; 7, 7 days of flooding; LSD, least significant difference at *P* < 0.10).

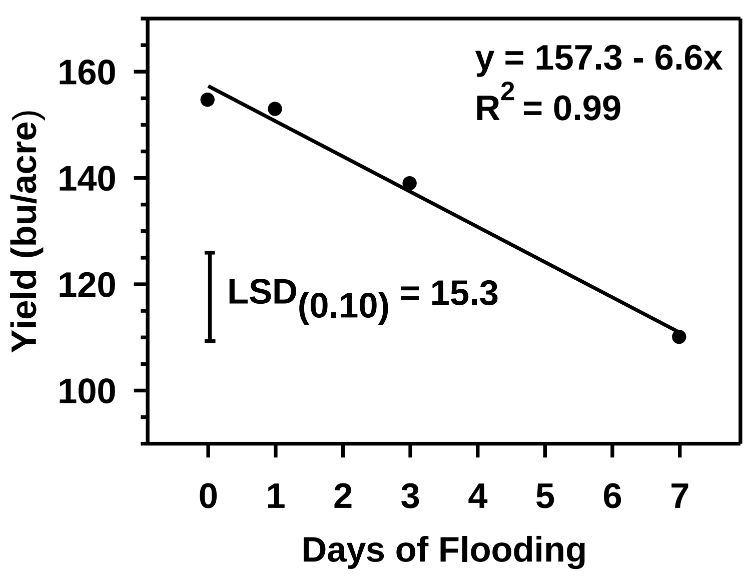


Figure 3. Average corn grain yield decline per day of flooding for all pre-plant N treatments. (Abbreviations: LSD, least significant difference at $P < 0.10$ between grain yield means of different flooding durations).

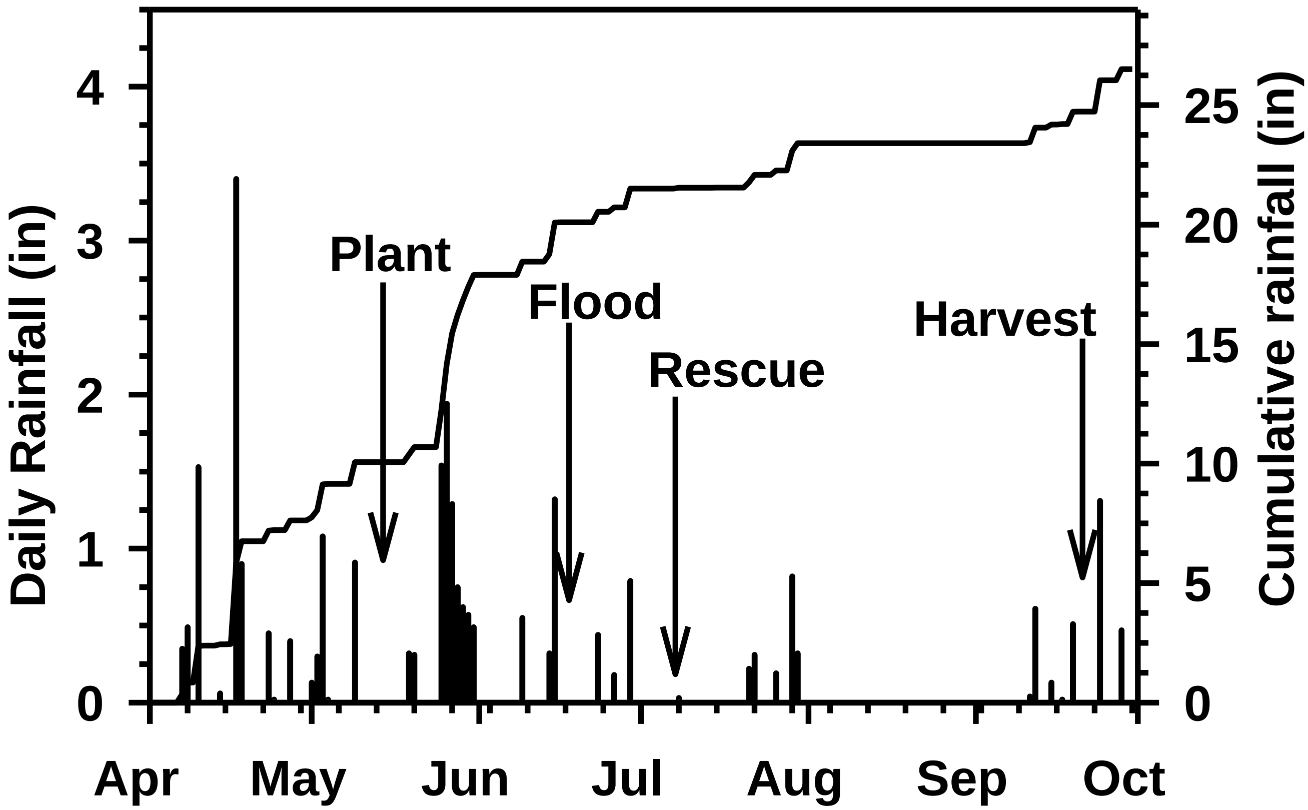


Figure 4. Daily and cumulative precipitation with from 1 April – 1 October, 2013 at the Greenley Research Center. The ten-year average from 2002 to 2011 at the Greenley Research Center was 38.8 inches for this time period.

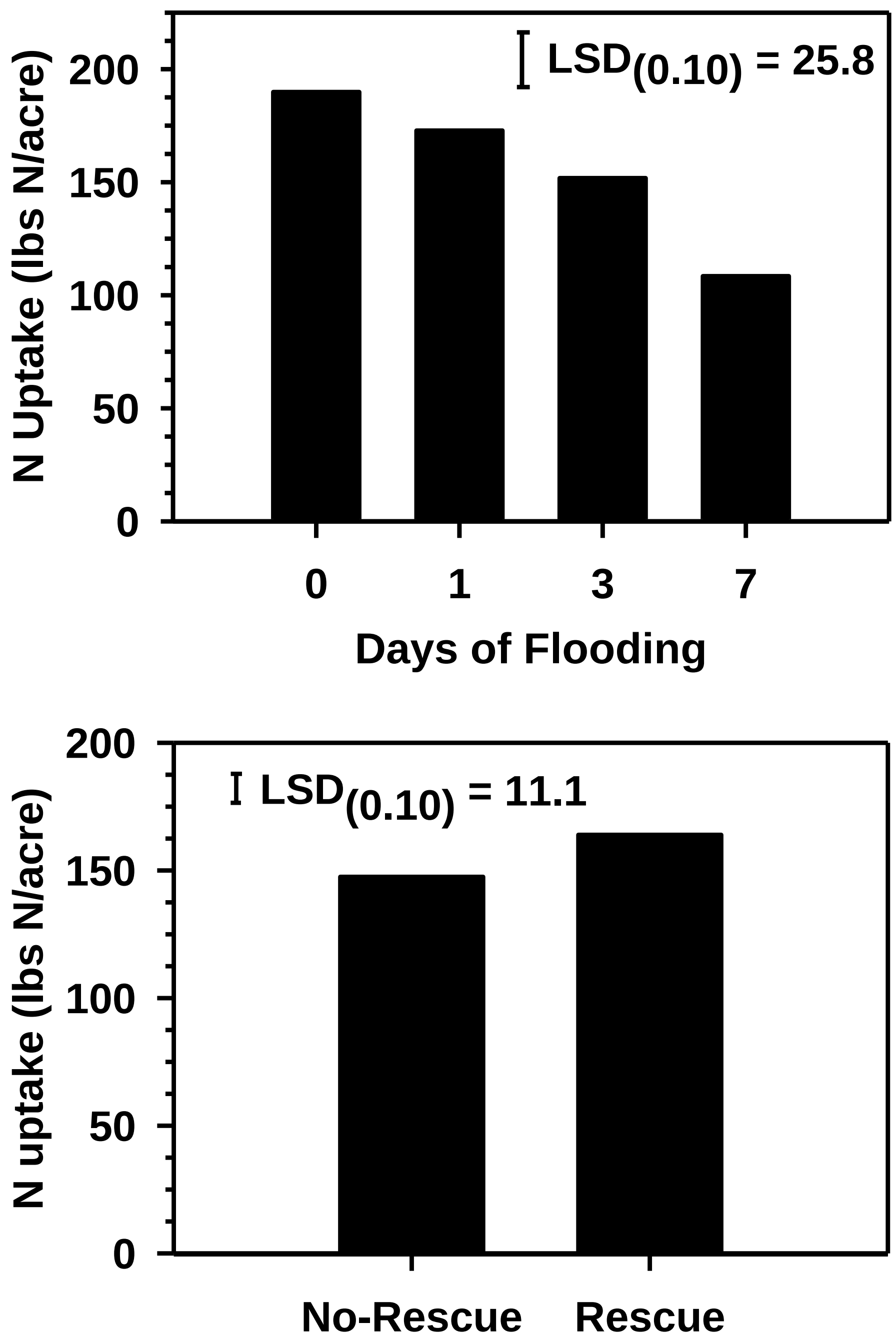


Figure 5 A&B. Average plant N uptake at physiological maturity comparing plants that experienced different flooding durations, and with and without rescue N application plus urease inhibitor. Rescue N application was applied at growth stage V10 on 8 July, 2013. (Abbreviations: LSD, least significant difference at $P < 0.10$ between N uptake and different flooding durations, and without and with rescue N application plus urease inhibitor).

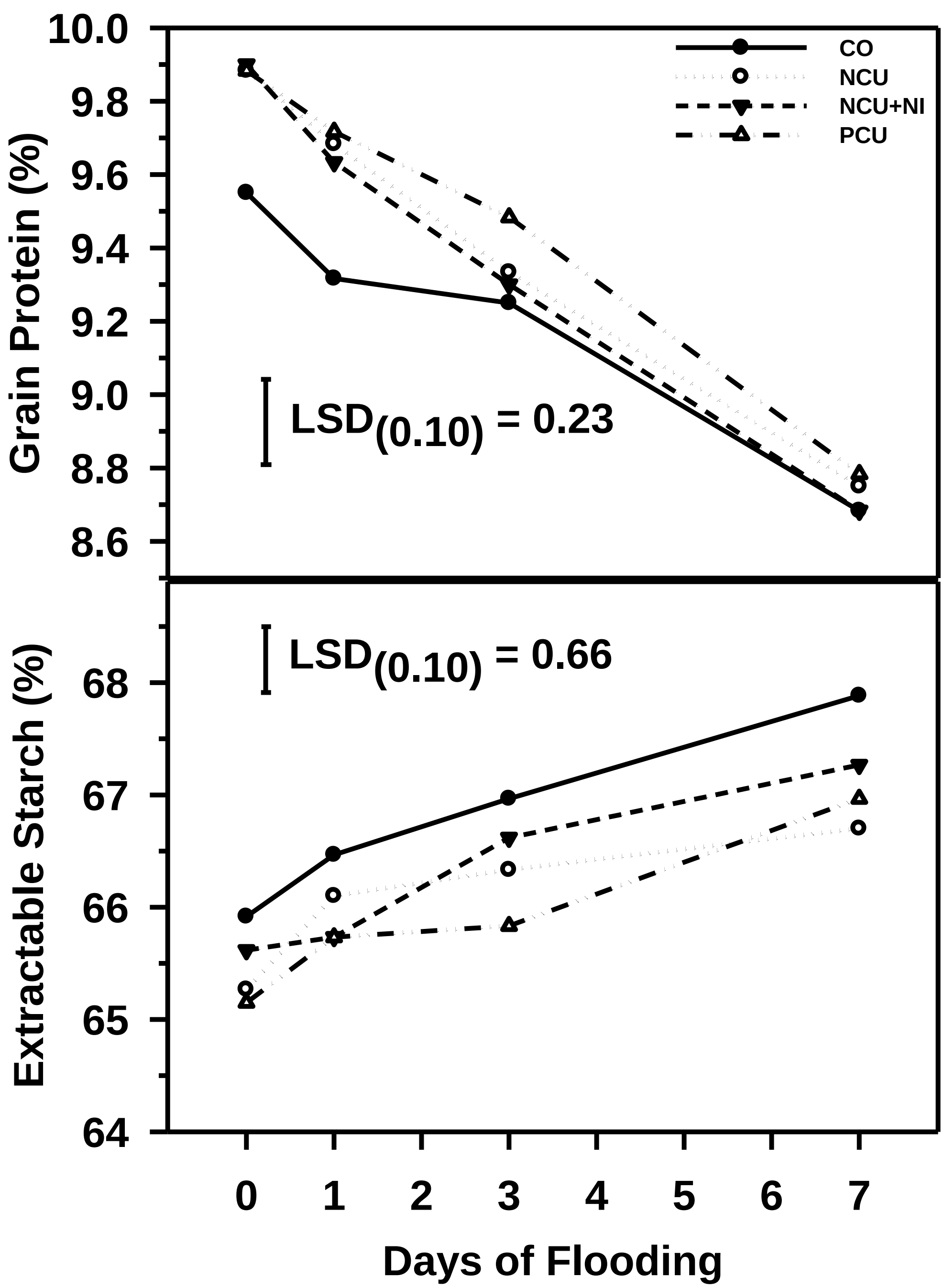


Figure 6 A & B. Average grain protein and extractable starch by pre-plant fertilizer treatments and flooding durations. (†Abbreviations: CO, Control; NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea; LSD, least significant difference at *P*< 0.10).

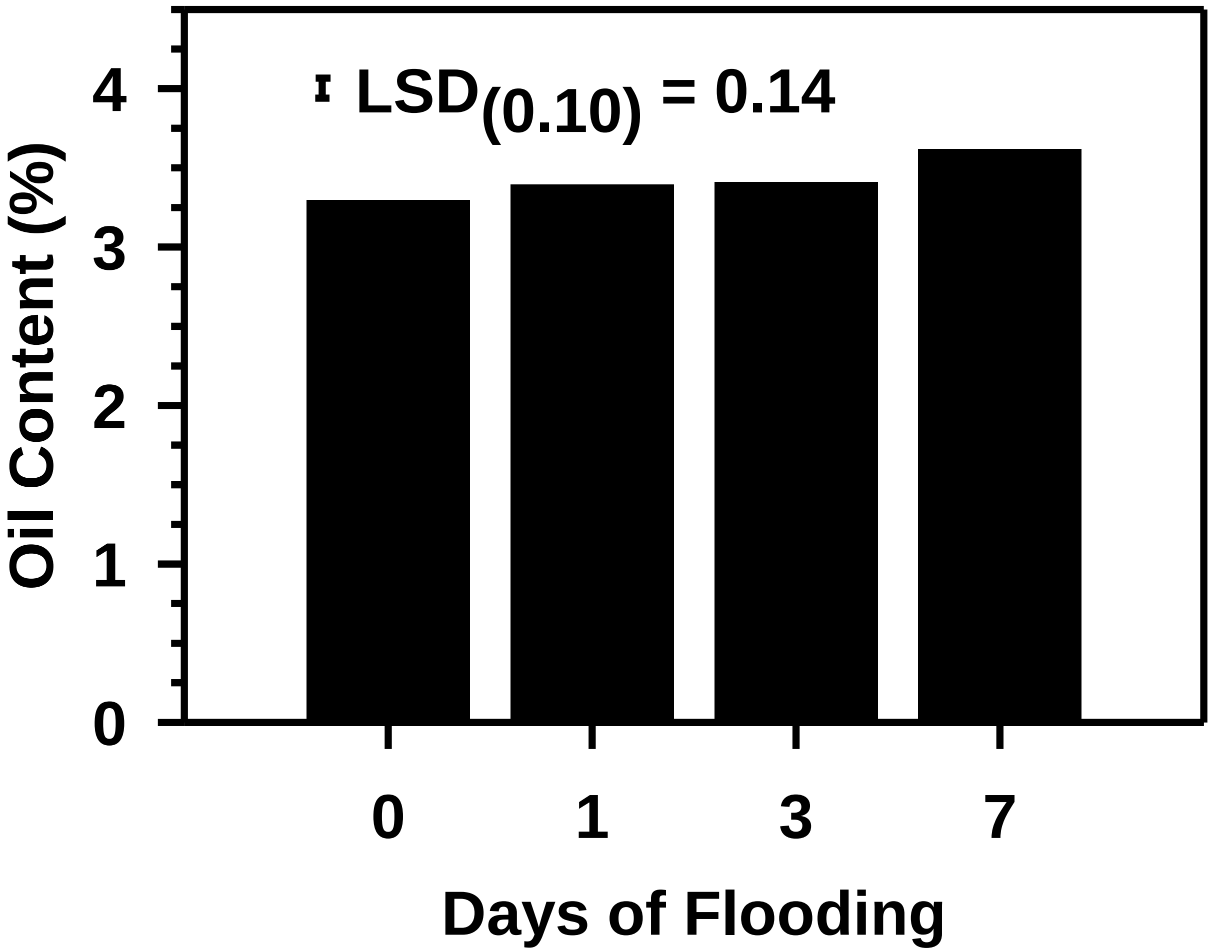


Figure 7. Average grain oil with increasing time of flooding durations. (†Abbreviations: CO, Control; NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea; LSD, least significant difference at $P < 0.10$).

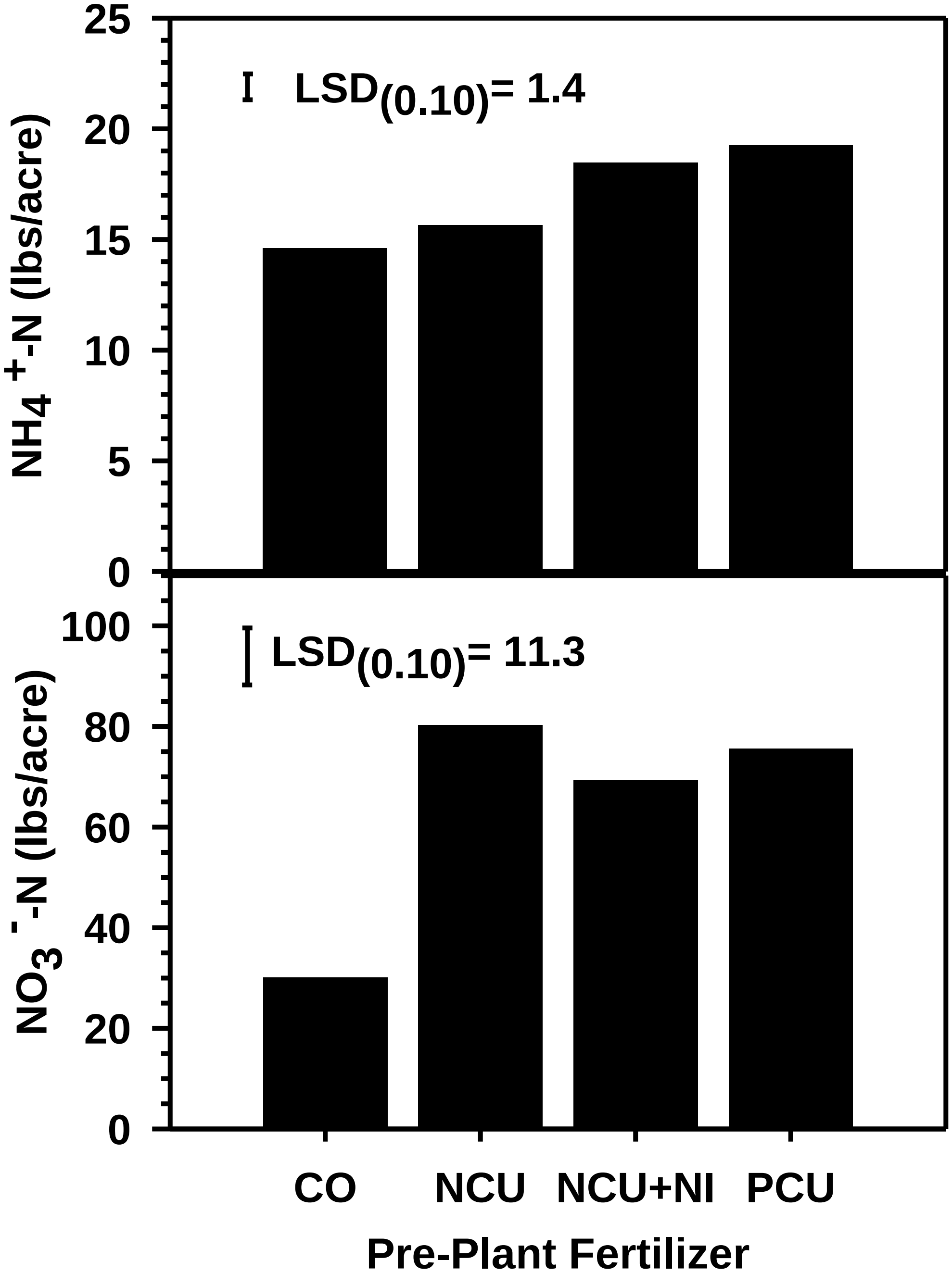


Figure 8 A & B. Average (A) NH_4^+-N (A) and (B) NO_3^-N to a depth of 12 inches with different pre-plant fertilizer applications. Sampling occurred prior to flooding on 17 June, 2013. (Abbreviations: CO, Control; NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea; LSD, least significant difference at $P < 0.10$).

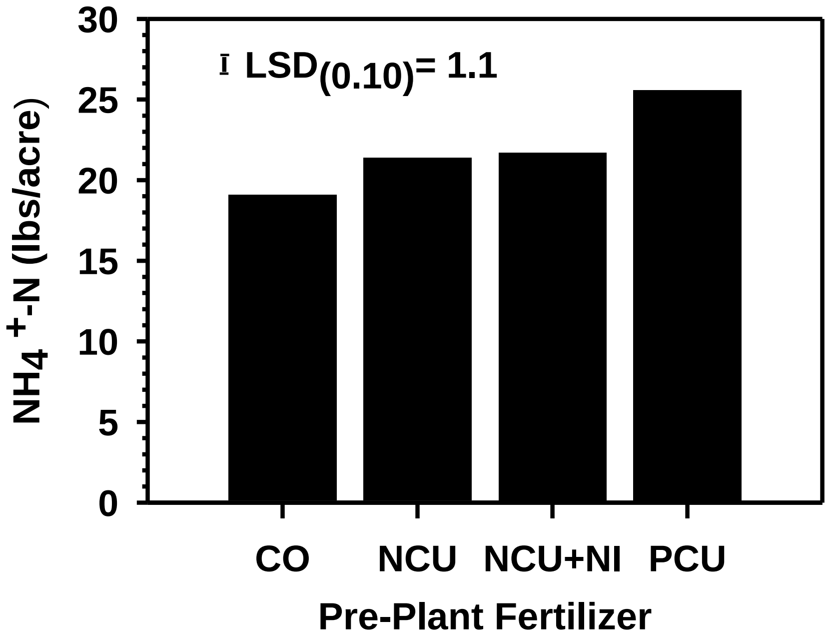


Figure 9. Average NH_4^+-N to a depth of 12 inches with different pre-plant fertilizer applications. Sampling occurred after the flooding durations on 1 July, 2013. (Abbreviations: CO, Control; NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea; LSD, least significant difference at $P < 0.10$).

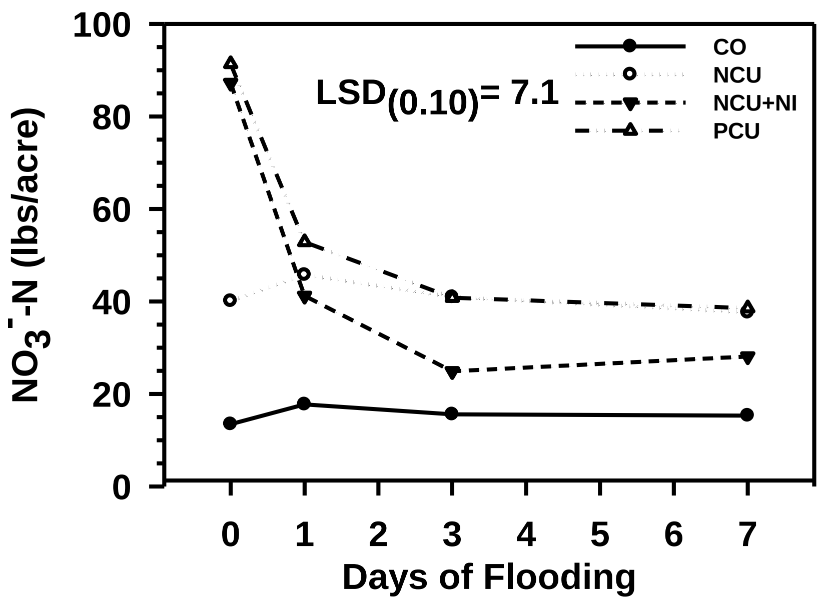


Figure 10. Average NO_3^-N to a depth of 12 inches with different pre-plant fertilizer applications and flooding durations. Sampling occurred after the flooding durations on 1 July, 2013. (Abbreviations: CO, Control; NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea; LSD, least significant difference at $P< 0.10$).

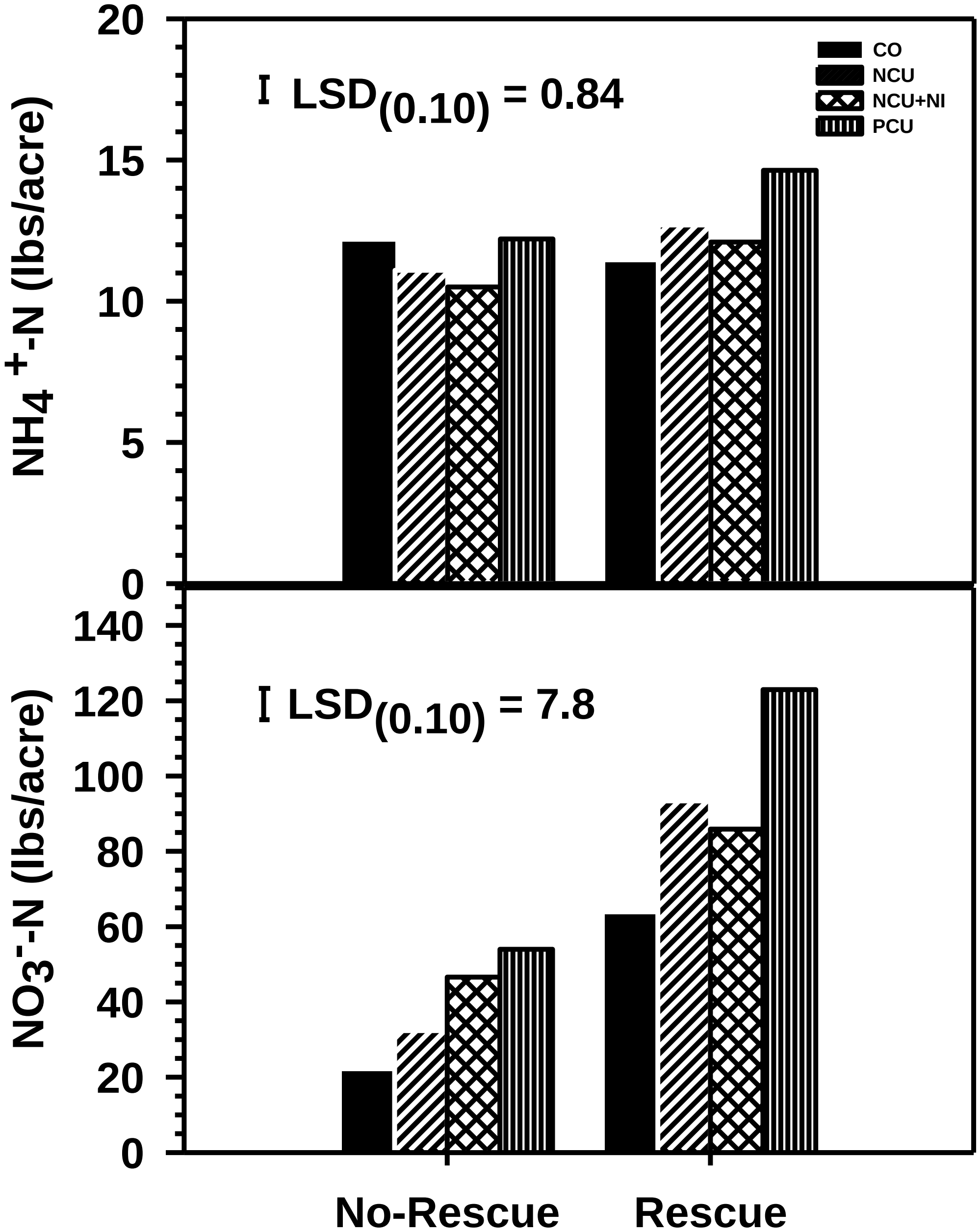


Figure 11 A&B. Average (A) NH_4^+-N and (B) NO_3^--N to a depth of 12 inches designated by pre-plant fertilizer applications with and without rescue N application plus urease inhibitor. Sampling date occurred after harvest on 10 October, 2013. (Abbreviations: CO, Control; NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea; LSD, least significant difference at $P< 0.10$).

<u>Proposed Budget for Year Three</u>:

CATEGORIES	YEAR THREE
A. Salaries M.S. Research Assistant (50%)	$17,745
B. Fringe Benefits Fringe for graduate student	$2,548
TOTAL SALARIES AND FRINGE BENEFITS	$20,293
C. Travel Travel to field site Travel to professional meeting	 $672 $1,000
TOTAL TRAVEL COSTS	$1,672
D. Equipment	$0
TOTAL EQUIPMENT COSTS	$0
E. Other Direct Costs Laboratory reagents and supplies Field supplies Soil analysis Publications/Documentation	 $2,000 $2,000 $500 $500
TOTAL OTHER DIRECT COSTS	$5,000
TOTAL REQUEST	$26,965

<u>Justification:</u>
Salaries and Fringe Benefits: Funds are requested for support of a graduate research assistant (50% time) based on set rates at the University of Missouri. Fringe benefits for the graduate student cover the cost of health insurance.

Travel: Covers cost of travel to Greenley Farm and to farm site at a rate of 48 ¢/mile. In the second year, $1,000 and in the third year $1,000 are requested to cover cost of travel and board for one researcher to attend a professional conference for presentation of results.

Laboratory Reagents and Supplies: Covers cost of laboratory reagents, sample containers, and other materials used in soil and plant tissue analyses.

Field Supplies: Cost of fertilizer, seed, plot preparation, planting, weed control and harvesting, soil samplers, flags, pots and other field supplies and operations.

Soil Analysis: Covers cost of drying, grinding and analysis of soil samples at the University of Missouri Soil and Plant Testing Laboratory.

Publications/Documentation: Defrays cost of publication and documentation of results and conclusions.

<u>Sensor-based variable rate N: Long-term performance in corn and cotton</u>

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Objective:

The objective of this project is to evaluate long-term performance of sensor-based variable N rate recommendations for corn and cotton. Sensor-based N management is compared with typical producer N management and with other N rate decision systems.

Accomplishments for 2013:

- Although this project was to be completed in 2012, we continued it into 2013 due to the accidental omission of the cotton experiment in 2012.
- We had committed to running the corn experiment for an additional year to make up for the missing 2012 cotton experiment, but ended up running both the corn and cotton experiments again in 2013.
- Two small-plot corn experiments were conducted as planned at Bradford Farm near Columbia.
- One small-plot cotton experiment was conducted as planned at the University of Missouri Delta Center near Portageville.
- Both the corn and cotton experiments were located on the same area for the duration of the experiment, with the same treatments applied to the same plots each year (except for 2012 cotton which was managed uniformly over the experimental area).

<u>Sensor-based variable rate N: Long-term performance in corn</u>

<u>Experiment 1: Long-term impact of nitrogen rate recommendation systems</u>

- 2013 is the 7th year of this study, with each plot getting the same N timing and N rate decision system every year.
    - Four of the treatments are fixed preplant N rates: 0, 100, 140, and 180 lb N/ac
    - The 140 lb N/acre rate is the MRTN (Maximum Return to Nitrogen) rate for Missouri and is also the Univ. of Missouri N rec for 135 bushel corn with 2.8% soil organic matter
    - A fifth preplant N treatment has the 140 lb N/acre rate as a base, with soil nitrate credits subtracted based on a 2-foot soil nitrate sample
    - Three treatments have N applied sidedress; rates are based on:
        - Sidedress soil nitrate test (Iowa State University interpretation)
        - Chlorophyll meter (University of Missouri interpretation)
        - Crop Circle 210 canopy sensor (University of Missouri interpretation)
    - All treatments are surface-applied ammonium nitrate

- This experiment is conducted in continuous no-till corn to magnify the effects of any problems related to N management.
- This experiment received high rainfall from March through May, but then June through September were fairly dry.
- The experiment was planted on May 15, which was the first date on which suitable planting conditions occurred.
- Four irrigations totaling about 4 inches were applied with a linear-move irrigation system from July 26 to August 30 to compensate for low rainfall and depleted soil moisture during this period.
- Due to late planting and a cool summer, grain fill remained very active into late August.

Nitrogen Recommendation System	N timing Stage[1]	2013 N Rates lb/ac	2013 Yield bu/ac	2013[3] Yield value Minus N cost $/ac	2007-13[2] Avg. rate lb/ac	2007-13[2] Avg. Yield bu/ac	2007-13[2,3] Ave. Yield value Minus N cost $/ac
Chlorophyll meter	V7	167	213	775	168	146	516
Crop Circle sensor	V7	193, 164, 175, 156, 180, 178 **avg rate = 174**	207	745	153	142	509
Sidedress soil test	V7	132	196	724	123	132	486
High	Preplant	180	126	408	180	100	322
Yield goal/ MRTN	Preplant	140	101	331	140	87	294
Preplant soil test	Preplant	140	94	303	136	85	290
Low	Preplant	100	72	235	100	74	265
Check	Preplant	0	51	210	0	46	198
Least significant difference (95% confidence)		5	12.5	52	1.3	6	24

[1] Growth stage V7 is about knee high corn
[2] 2011 data was not included due to insufficient stand count and uniformity and hail damage
[3] Partial profit analysis based on mid-Dec. 2013 prices. Corn - $ 4.10/bu. Nitrogen cost - $ 0.60/lb.

- Yields were very high in all three treatments receiving a single application of N when corn was knee-high, with treatment average yields ranging from 196 to 213 bushels/acre.
- The sidedress soil nitrate test, interpreted according to Iowa State University guidelines, gave lower N rate recommendations than the color-based (chlorophyll meter and Crop Circle sensor) systems, resulting in significantly lower yield in 2013 (99% confidence by linear contrast).
- The best preplant N treatment, 180 lb N/acre, produced a yield that was 79

bushels/acre below the average yield for the three sidedress N treatments. Clearly a great deal of preplant-applied N was lost in this experiment in 2013.

- Lower preplant N rates produced significantly lower yields and partial profits than the 180 lb N/acre preplant rate.
- **Treatments in the table above are ordered based on profitability for the period 2007-2013.**
  - This order is the same for 2013 as for the entire period.
- **For this period, the two systems based on crop color to guide sidedress N rate out-performed the best preplant system (180 lb N rate) by nearly $200/acre/year.**
  - They produced 42-46 bushels more corn with 10-30 lb less N than the 180 lb N/acre preplant treatment.
  - This was mainly due to serious N loss with preplant N applications during the wet springs of 2008-2010 and 2013.
  - The difference was considerably larger than this when calculated with the higher corn prices seen in recent years (for the values in the table, we used $4.10/bushel as a current price and applied that value to all years).
- The color-based systems for choosing sidedress N rate also out-performed the soil test system for choosing sidedress N rate by $23-30/acre.
  - This was due to under-recommendation by the sidedress soil test system in 2007, 2010, and 2013, resulting in lower yields.
- **Based on results from 2007-2013, long-term performance of sensor-based variable-rate N in corn appears to be good.**
- Our motivation for starting this experiment was the concern that using diagnostic systems to apply just enough N each year might, over a period of years, deplete the soil's productive capacity. This has clearly not happened.

Experiment 2: Effect of pre-plant nitrogen on sensor-based N rate performance

- Experiment 2 is designed to complement Experiment 1 and address concerns that sidedress systems with no N applied preplant may cost yield.
  - 2013 is the fourth year for this experiment.
  - Three of the four treatments in Experiment 2 are shared with Experiment 1.
  - The key treatment is 50 lb N/ac applied pre-plant, followed by sidedress N at rates diagnosed by the Crop Circle sensor.
    - Results from this treatment can be compared to pre-plant N management (140 and 180 lb N rates) and sensor-based sidedress with no N pre-plant to evaluate its relative performance.
    - Any serious N stress experienced with the sidedress-only sensor-based treatments should be avoided.

- It is right next to Experiment 1, so soils and weather are very similar. Seed, herbicide, planting date, and application dates are identical to Experiment 1. Experiment 2 received the same supplemental irrigation (total about 4 inches) in 2013 as Experiment 1.
- Yields with in-season N were excellent, topping 200 bushels/acre.
- **Lack of N applied at planting did not reduce yield in the treatment with all N applied sidedress based on Crop Circle sensor measurements.**
- **This is despite extreme wetness before and after planting that led to N loss and poor yields in the preplant N treatments. Soil N supply was likely very limited during early growth, but this did not result in reduced yield.**
- Both in 2013 and over the 4 years of the study, total N rates based on the Crop Circle sensor and University of Missouri equations were similar regardless of whether preplant N rate was 0 or 50.
    - This indicates that the sensors were able to sense the effect of the 50 lb preplant N rate on crop color and adjust sidedress rates downward in compensation.
- **Over the 4 years of this study, there has been no indication that sensor-based N rate recommendations perform better with preplant N than without.**
- **Over 4 years, sensor-based N management out-yielded the best preplant N management by about 18 bushels/acre/year and gave about $74/acre/year higher profit (see table below).**
    - This is due to higher yields with sensor-based N management than preplant N management in both 2010 and 2013.
    - Yield differences between treatments were minimal or non-existent in 2011 & 2012.
    - Average N savings over the 3-year period were about 30 lb N/acre for the two sensor-based N systems while still producing 18 bushels higher yield than the most profitable preplant N system.
- Yields with preplant N were far below those with in-season N, but were 20 to 35 bushels/acre higher than the same treatments in experiment 1. This may be due to the N loss that occurred in these treatments in experiment 1 in 2008 and 2009, leading to low yields and possibly depletion of soil organic N and C pools. Experiment 2 did not begin until 2010 and was cropped to soybean in both 2008 and 2009.

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Nitrogen Recommendation System	N timing Stage[1]	2013 N Rates lb/ac	2013 Yield bu/ac	2013[3] Yield value Minus N cost $/ac	2010-13[2] Avg. rate lb/ac	2010-13[2] Avg. Yield bu/ac	2010-13[2,3] Ave. Yield value Minus N cost $/ac
Crop Circle sensor 0 N preplant	V7	197	203	714	143	123	480
Crop Circle sensor 50 N preplant	V7	201	204	718	155	124	478
High	Preplant	180	160	548	180	106	405
Yield goal/ MRTN	Preplant	140	122	416	140	92	357
Least significant difference (95% confidence)		18	13	57	16	9	40

[1] Growth stage V7 is about knee high corn.

[2] 2011 data was not included due to insufficient stand count and uniformity and hail damage.

[3] Partial profit analysis based on mid-Dec. 2013 prices. Corn - $ 4.10/bu. Nitrogen cost - $ 0.60/lb.

Sensor-based variable rate N: Long-term performance in cotton

- Yields in 2013 were a little below yields from previous years, but were still quite good, with an average of 1152 lb lint/acre.
- Yield in the zero-N (check) treatment was higher-yielding numerically than any other treatment in 2013.
- Little yield response to N fertilizer was seen over the 3-year study. This silt loam soil appears to be high in N-supplying ability.
  - Average yield for all treatments receiving N was only about 50 lb lint/acre above the unfertilized check.
  - Thus **little N fertilizer was needed to optimize yield.**
  - Any of the N treatments should have been able to supply enough N to the crop to produce a response of this size.
- **The crop sensors did a good job of diagnosing that soil N supply was high and N fertilizer need was low.**
  - Average N rate recommended by crop sensors was only 24 lb N/acre when zero N was applied preplant, and 22 lb N/acre when 30 lb N was applied preplant.
- The two sensor-based N decision systems ended up near the top of the profitability (cotton yield value minus nitrogen cost) list because they produced equal yields with less N.
  - **Both sensor-based N rate systems were significantly more profitable than the high N rate.**
  - The 60-20 split recommended by the University of Missouri also was significantly

more profitable than the high N rate.

- With the low yield response to N observed in this test, the performance of different recommendation systems in correctly diagnosing high N need was not tested.
- When soil is supplying a lot of N, and little fertilizer N is needed, there is potential for N applications to hurt yields, quality, or harvestability. However, **we did not see any evidence that N over-application caused problems with yield or quality in any year.** Significant differences in quality parameters were rare.

[1]PP=pre-plant ES=early square stage MS= mid-square stage (about 10 days after early square stage)

Table 3. Nitrogen rates recommended and cotton yields produced by different recommendation systems in 2010, 2011, & 2013.

Nitrogen Recommendation System	2013 Nitrogen Rate lbs. N/ac @ Each timing			2013 Total Nitrogen Rates	2013 Yield[2]	2013 Yield value minus N Cost[3,4]	3 yr. Avg. N rate	3 yr Avg. Yield[2]	3 yr Avg. Yield value minus N Cost[3,4]
	PP[1]	ES[1]	MS[1]	lb/ac	lb/ac	$/ac	lb/ac	lb/ac	$/ac
Soil Test	60	20	0	80	1200	1027 AB	80	1285	1108 A
Sensor[5]	0	0	20, 34, 27 22, 22, 10 Avg. rate = 23	23	1136	1014 B	24	1238	1100 A
Sensor with Pre-plant N[5]	30	0	21, 24, 19 34, 28, 8 Avg. rate = 22	52	1200	1045 AB	52	1243	1088 A
Petiole nitrate test	50	0	0	50	1173	1032 AB	51	1224	1071 AB
Check	0	0	0	0	1202	1095 A	0	1187	1068 AB
Standard	50	50	0	100	1060	914 C	100	1249	1064 AB
Low	20	50	0	70	1127	989 B	70	1223	1059 AB
High	50	80	0	130	1081	872 C	130	1214	1015 B

[2] Analysis of variance did not show a significant yield difference due to N treatment either in 2013 or over the three years combined.

[3]Values within a column that are followed by a shared letter are not statistically different from one another with 90% confidence.

[4] Yield value calculated using $0.90/lb cotton lint; N cost calculated using $5.00/ac cost for 2nd N application and $0.60/lb N.

[5]A different N rate was applied in each of 6 replications for this treatment. It is feasible to use this sensor to change N rate. automatically while fertilizing a field, and we felt that this ability would be most accurately reflected by diagnosing N rate for each plot separately.

<u>Timing and source of nitrogen for corn</u>

Peter Scharf, University of Missouri, Plant Sciences Division

Objective:

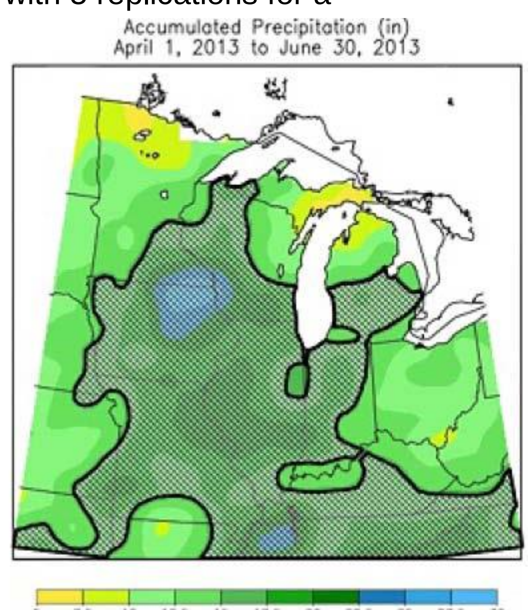
Measure the yield impact of a range of nitrogen fertilizer application times for a range of nitrogen sources.

Accomplishments for 2013:

- Nitrogen fertilizer treatments were applied according to plan starting with anhydrous ammonia (with and without N-Serve) in October 2012 and concluding with broadcast urea (with and without Agrotain) in July 2013 (see table).

Nitrogen timing	Nitrogen Source							
	NH_3	NH_3 *with N-Serve*	Ammonium Nitrate	Urea	Urea *with Agrotain*	UAN *Injected*	UAN dribbled	ESN *coated urea*
October	X	X						
December	X	X						
February	X	X	X	X	X	X	X	X
March	X	X	X	X	X	X	X	X
April	X	X	X	X	X	X	X	X
Knee-high	X		X	X	X	X	X	X
Waist-high				X	X			

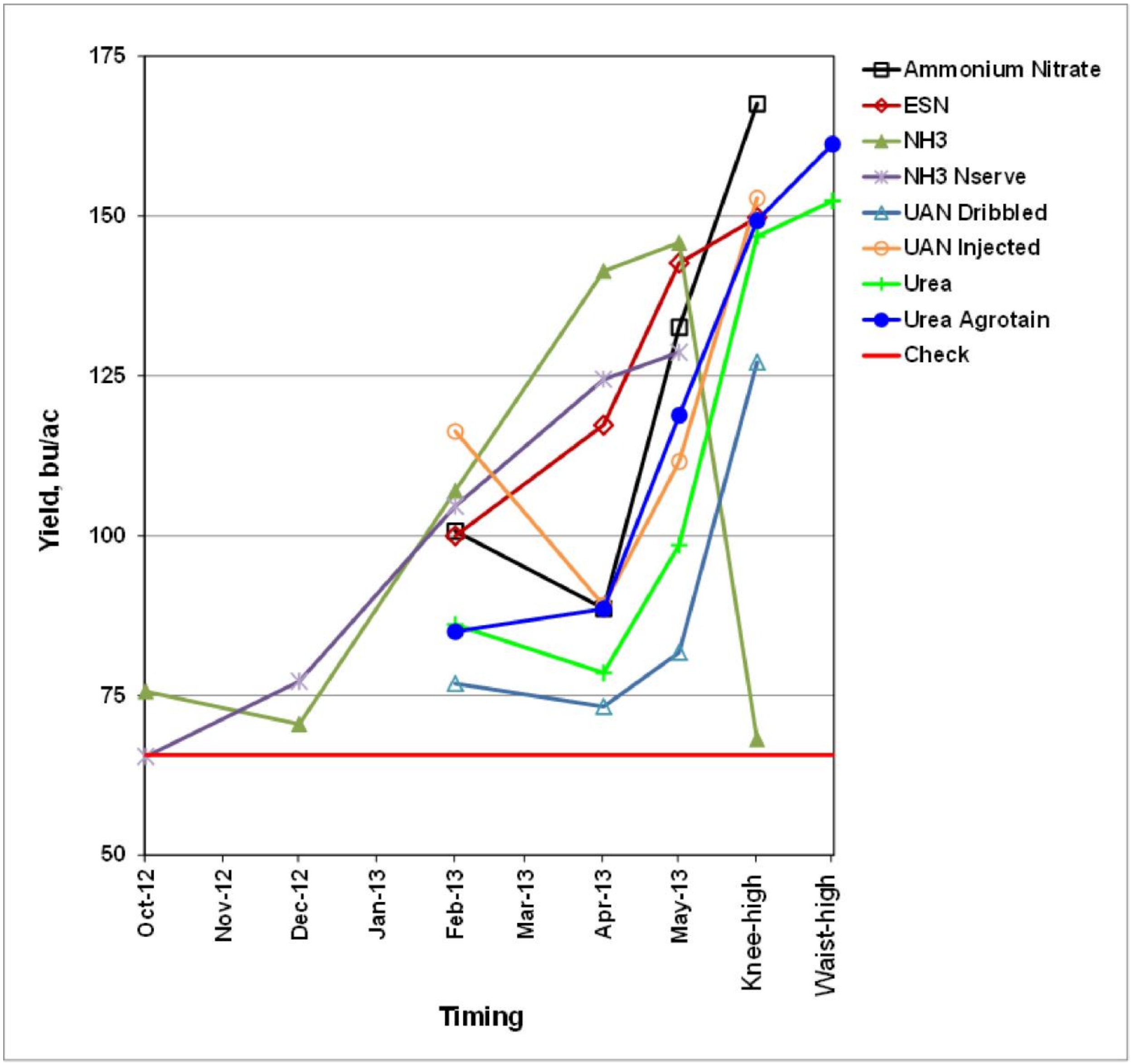
- A total of 38 N timing & source treatments (the 37 shown above, plus a treatment that received no N fertilizer) were applied, with 5 replications for a total of 190 plots.



- Nitrogen rate for all treatments is 140 lb N/acre made in a single application. This rate is usually sufficient under Missouri conditions, but not enough to mask N losses that may occur.
- Although conditions were extremely dry in fall 2012, with thoughts that carryover N from soil and fertilizer might contribute to the 2013 corn crop, heavy snowfall and rainfall from mid-February through May resulted in wet soils and N loss conditions. These conditions were widespread across the corn belt (crosshatched areas in map).
- Conditions conducive to N loss meant that N source and especially N timing had a

huge effect on corn yield in this
experiment.

- Water availability limited yields despite early-season wetness. Rainfall from June 16 to the end of July was 2.36 inches.
- Yield effects of N timing and source are shown in this graph:



- Statistically, N timing, N source, and the interaction of timing and source all affected yield with 99.99% confidence.
- Treatments planned for March were delayed to early April, and those planned for April were delayed to mid-May due to excessively wet soils.

- **In general, the later N was applied, the more the corn yielded.**
- **Anhydrous ammonia produced 63 bushels higher average yield applied in April or May compared to October or December (which yielded barely higher than the check receiving no N fertilizer).**

- **All dry and liquid N sources except ESN produced yields 30 to 48 bushels higher when applied to knee-high corn than when applied in mid-May just before planting. These N sources experienced massive loss between planting and uptake.**

- **The two urea treatments (with and without Agrotain) applied to waist-high corn on July 11 yielded on average 10 bushels more than the same N sources applied when the corn was knee-high (and 50 bushels more than the same N sources applied in May).**
    - This is despite that fact that the soil surface was relatively dry when N was applied (0.77 inches of rain in the 2 weeks before application) and little rain was received after application (0.26 inches in 2 weeks).
    - This suggests that loss of urea N occurred before uptake in June & July even when applied to knee-high corn.

- The main exception to the rule that later N produced higher yields is for anhydrous ammonia applied to knee-high corn. Soil conditions were wet at the time of application, resulting in poor slot sealing, leakage of ammonia from the slot, and leaf burn in the plots (see photos). Yields with sidedress anhydrous ammonia were similar to yields with October or December applications of anhydrous ammonia, and to the check yield with no N applied.

Wet soil conditions led to poor slot sealing with sidedress anhydrous ammonia applications.

Poor slot sealing with sidedress anhydrous ammonia applications led to leakage, leaf burn, and low yields.

- The other case where later applications were associated with lower yields was for

. February vs early April applications of dry and liquid N (excepting ESN). The early April applications received 2.6 inches of rain in the first 5 days after application, and 4.1 inches in the first 10 days. These heavy rains shortly after application may have served to carry N away in surface runoff or into soil macropores where it leached below rooting depth. ESN and anhydrous ammonia would be resistant to both of these loss processes, and yields went up with these N sources going from a February to an April application.

- **Anhydrous ammonia and ESN were generally the highest-yielding N sources for preplant N applications**, whether in February, April, or May. Both of these sources are more resistant to N loss during wet weather (as we had in 2013) than the other N sources.
- Although anhydrous ammonia and ESN are the N sources most resistant to loss in wet weather, and gave the highest yields of any source with pre-plant application, **they did not perform as well as in-season applications of N.**
  - The highest-yielding preplant N treatment was anhydrous ammonia applied in May
  - Most N sources applied to knee-high or waist-high corn produced higher yields than anhydrous ammonia applied just before planting in mid-May.
  - This suggests that even anhydrous ammonia and ESN applied the day before planting in mid-May were lost before the critical uptake period (which would have been July and the first half of August in 2013).
- **N-Serve did not appear to give any yield benefit when added to anhydrous ammonia at any timing**. Given the clear N losses associated with early applications of ammonia, there was an opportunity for N-Serve to reduce those losses. With the October application timing, it's likely that the effect of N-Serve does not last long enough to be effective in most years. However, the December through April application timings would seem to have provided an excellent opportunity for N-Serve to result in reduced N loss and increased yield.

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Aerial photo of the experiment taken on July 12, 2013, the day after urea treatments (with and without Agrotain) were applied to waist-high corn. Dark lines outline the experiment. Wide alleyways for turning were left between replications. The light yellowish color of many plots indicates inadequate N availability.

- **Agrotain did produce a yield benefit when added to surface-applied urea.** The only timing at which urea treated with Agrotain did not out-yield (numerically) untreated urea was the February application. Averaged over all application timings, Agrotain gave an 8 bushel yield advantage (with 93% confidence).
- **Injection greatly improved the performance of UAN in this study compared to dribble application.** Average yield was 27 bushels higher over all timings. The reason for the poor performance of dribbled UAN is not clear.
  - Ammonia volatilization losses should have been half of the loss from urea, thus a yield penalty of 4 bushels (half of the Agrotain benefit) would be a reasonable estimate.
  - Previous crop was soybean with medium-low yields, thus the amount and quality of residue on the surface would not be expected to lead to immobilization or tie-up of the dribbled UAN.
- For one N source & timing treatment (see graph) to be different than another with 95% confidence, they must be (on average) 17 bushels different.

Budget for 2014 (as given in original proposal):

Research Specialist salary	$20,000
Benefits	5,000
Field supplies and fuel	1,000
Total year 3	**$26,00**

2014

Timing and source of nitrogen for corn

Peter Scharf, University of Missouri, Plant Sciences Division

Objective:

Measure the yield impact of a range of nitrogen fertilizer application times for a range of nitrogen sources.

Accomplishments for 2014:

- Nitrogen fertilizer treatments were applied but the plan had to be altered due to the severe and long winter. Treatments where injection of N into soil was planned for December and February had to be postponed due to ground freezing to considerable depth.
  - The anhydrous ammonia (with and without N-Serve) treatments planned for December and February were instead applied on March 20 with the planned March ammonia applications. This was the first date with soil conditions that reasonably allowed injection of anhydrous ammonia.
  - Similarly, the injected UAN treatment planned for February had to be postponed, and was applied March 20 with the planned March UAN injection treatment plots.
  - Broadcast treatments were completed in February as planned.
- A total of 5 N timings & 8 N sources were used. Not all treatments were applied at all times. Total number of treatments is 38, with 5 replications giving a total of 190 plots.
- Nitrogen rate for all treatments is 140 lb N/acre made in a single application. This rate is usually sufficient under Missouri conditions, but not enough to mask N losses that may occur.
- Corn was planted on May 3 with good conditions.
- April and June were wet, with about 6.5" rainfall in each of those two months.
  - 5" of rain fell in 2 days in early April; much of this probably ran off.
  - Rainfall in June was more even, though there was a 2.6" event on June 20-21. June rainfall was probably high enough to cause numerous days with saturated soils and loss of nitrate by denitrification.
- It was an excellent cropping year and the best-yielding treatment (ammonium nitrate broadcast on knee-high corn) produced a yield of 202 bushels/acre.
- From July 14 to August 6 there was only 0.06" of rain or yields might have been even higher.
- Yield with no nitrogen applied was 98 bushels/acre.
- Statistically (99.99% certainty), both N source and N timing had strong effects on corn yield.
- Effects of N source and N timing on corn yield are shown in the graph below.

- There was little evidence (56% certainty) of any interaction between N source and N timing this year.

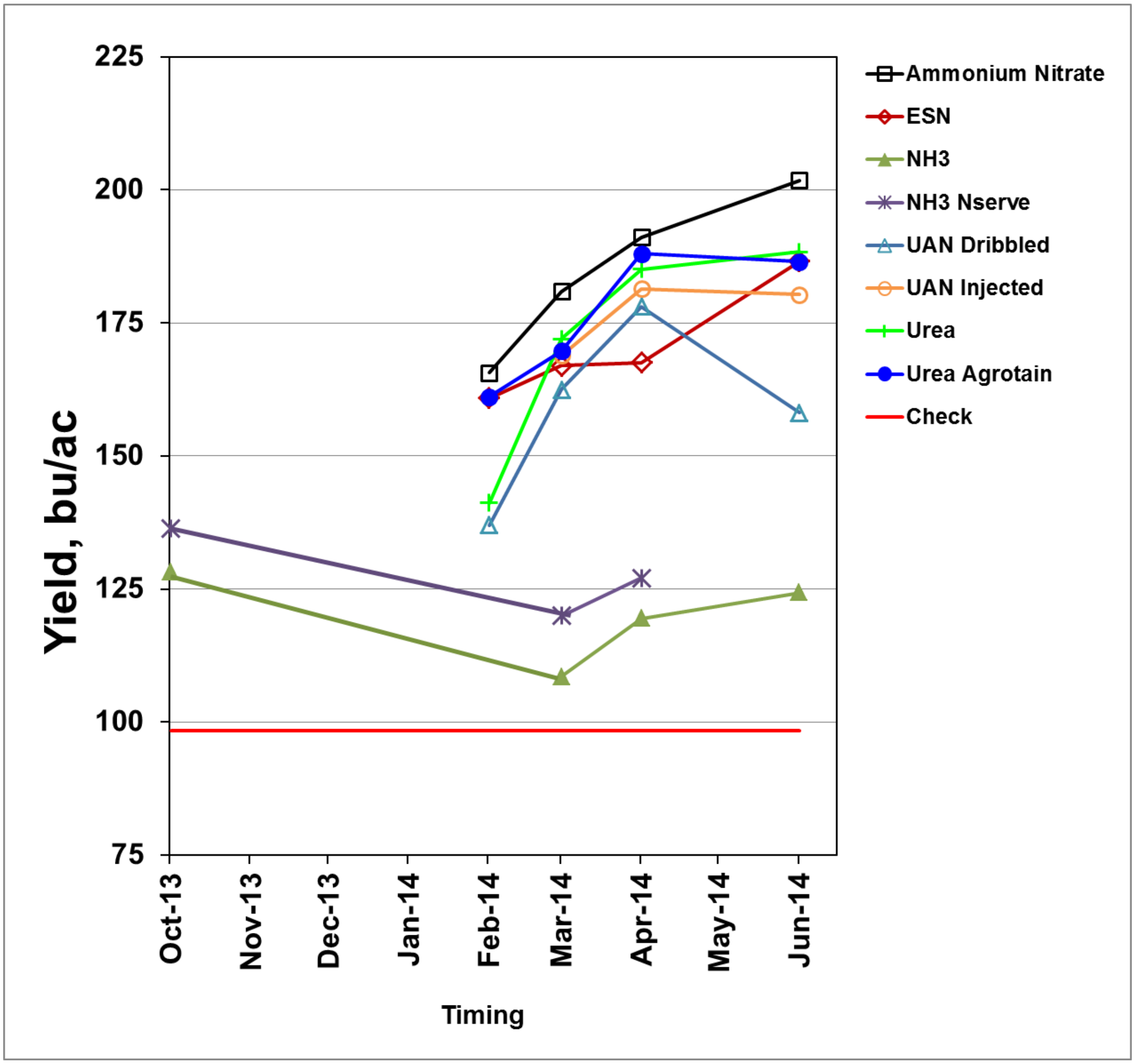

Figure 1. Corn yield with different N application timings and N fertilizer sources in 2014. Injected N (anhydrous ammonia and UAN) treatments planned for December and February had to be delayed until March 20 due to frozen ground.

- The most surprising outcome is the poor performance of anhydrous ammonia at all application times.
    - Rate of anhydrous ammonia was controlled by a metering system (flow meter and ball valve operated by a Raven controller to hit the target application rate) (Figure 2) so it's unlikely that fertilizer rate was lower than intended.
    - There is a 100 foot buffer between plots. We start anhydrous ammonia application 100 feet before entering the plot to allow the application

system to equilibrate, helping to ensure that flow rate is steady and at the intended rate.
  - Soil conditions were also good at all application times. We did not expect problems due to questionable closure of the application slot.
  - In short we do not have any explanation for the poor yields obtained with anhydrous ammonia in this experiment in 2014. In past research, anhydrous ammonia has generally produced excellent yields.

Figure 2. Cold flow unit, flow meter, and control valve used to apply anhydrous ammonia treatments.

- Unlike 2013, we got a yield response of 10 bu/acre to adding N-Serve to anhydrous ammonia. The yield response was consistent across all timings (October, March, and April). N-Serve was injected with a Sidekick injection pump (Figure 2).
- Although the spring was not exceptionally wet, it was apparently wet enough to cause substantial loss of early-applied N.
  - For all N fertilizers other than anhydrous ammonia, corn yield increased as N application timing went from February to March to April (Figure 1).
  - Average yield for dry and liquid N fertilizers was:
    - 153 bushels/acre in February
    - 170 bushels/acre in March
    - 182 bushels/acre in April
    - 184 bushels/acre in June
  - Early (February or March) application of N fertilizer came with a substantial yield penalty in 2014.
  - Delaying N application from April until June had mixed results—yield went up for ammonium nitrate and ESN, down for dribbled UAN, and did not change for urea, urea + Agrotain, and injected UAN. All June treatments were applied on June 3, and then 6.5 inches of rain fell during the rest of June—as a result there may have been N loss even from the June-applied treatments.
- Ammonium nitrate gave statistically (95% confidence) higher yields (averaged over timing) than all other nitrogen fertilizers in this experiment except for urea + Agrotain.
  - Ammonium nitrate applied in June gave a yield of 202 bushels/acre, which was higher than all other yields with 90% confidence except for ammonium nitrate applied in April (191 bu/acre).

- Agrotain as a urea treatment did not give a significant yield increase averaged over all timings.

    - Yield increase due to Agrotain was observed only in February—20 bushels/acre with 96% confidence.
- UAN dribbled gave statistically (95% confidence) lower yields (averaged over timing) than all other dry and liquid nitrogen fertilizers in this experiment.
    - The experiment was established no-till into soybean stubble. There is some chance that dribbled UAN was tied up on soybean stubble.
- 2015 experiments are well under way, with October anhydrous ammonia applications completed. December applications have been postponed due to wet soil conditions right up until the soil froze.
    - Plots are in the exact same locations as 2013.
    - No-till soybean was grown in this area in 2014.

July treatments are omitted from this report. Only broadcast urea and urea + Agrotain treatments were planned for July. The application of these treatments is recorded on the calendar as July 2, but yields from these plots were not different than the unfertilized plots. Given past excellent yields in many experiments with July N applications, good soil moisture at that time, and no observed difference in yield from the unfertilized plots, the chance that we accidentally failed to apply

Use of Nitrogen Fertilizer Sources to Enhance Tolerance and Recovery of New Corn Hybrids to Excessive Soil Moisture

Gurpreet Kaur, Dept. of Soil, Environ. and Atmos. Sci, University of Missouri
Peter Motavalli, Dept. of Soil, Environ. and Atmos. Sci, University of Missouri
Kelly Nelson, Division of Plant Sciences, University of Missouri, Greenley Center
Felix Fritschi, Division of Plant Sciences, University of Missouri

Accomplishments for Second Year:

The research was initiated in 2013 and continued for a second year in 2014 to develop a combination of N fertilizer management and hybrid selection for growers to increase corn production and reduce environmental N loss under temporary soil waterlogging and to evaluate the efficiency of rescue N application in increasing yields under flooded soil conditions.

A field experiment was continued for a second year in 2014 at the University of Missouri Greenley Research Center in Northeast Missouri. The specific field chosen was adjacent to the field location used in 2013. The experimental field was underlain by a Putnam silt loam soil (fine, smectitic, mesic Vertic Albaqualfs). Initial soil samples were collected at depths of 0-4, 4-8 and 8-12 inches before fertilizer application and planting (Table 1). The experimental design was a randomized split-split-split block with 3 replications. Each block was divided into two main plots which included flooding treatments of 0 and 7 days accomplished by setting up berms and use of supplemental flood irrigation after the V3 stage of corn. The flood was initiated on 16th May 2014 and ended on 23th May 2014. The subplots consisted of N fertilizer treatments of a control or 150 lb N/acre as pre-plant-applied urea (NCU), polymer-coated urea (PCU; ESN®, Agrium, Inc), and urea plus a nitrification inhibitor (NCU+NI) (Instinct®, Dow AgroSciences) and two corn hybrids. The two corn hybrids, Hybrid #1 and Hybrid #2 were selected based on the results of the greenhouse screening trial to provide one hybrid that showed tolerance and another that was less tolerant to flooded soil conditions. These subplots measured 10 x 80 ft and row spacing was 30 inches. There were 4 rows of corn in each subplot. After the flooding treatment, the subplots were divided into two parts of 40 ft length and one of them was treated with 75 lb N/acre of a rescue post-flood broadcast application of urea plus NBPT (N-(n-butyl) thiophosphoric triamide) urease inhibitor (1 gal/ton urea; Agrotain®, Koch Agronomic Services) while the other subplot did not receive any additional N. Corn was harvested on 29 September, 2014 for determining grain yield.

Soil conditions during the flooding were measured by determination of changes in soil redox potential (E_h), soil pH, soil temperature and bulk density at the soil surface. The soil redox potential decreased as the duration of flooding increased from 475 mV to 169 mV indicating that the soil was being depleted of oxygen. The soil redox potential was significantly different on the 1st, 3rd and 6th day during flooding (Table 2). Soil pH during flooding ranged from 5.6 to 6.1. The soil pH was significantly different on the 1st and 3rd day of flooding. Soil temperature was significantly lower in flooded versus non-flooded treatments (Table 3). The non-flooded treatments had 1.8 ^{0}F higher temperatures than the flooded treatments. The soil temperature also varied significantly with each day of flooding (Table 3). Bulk density samples were taken before and after 7 days of flooding. Significant differences were observed in bulk density among different depths, but no effect of flooding duration was detected (Table 4). It had been expected that flooding might cause dispersion of soil aggregates in the soil surface which could affect subsequent crop growth. The bulk density was highest in the 4-8 inch depth compared to that of the 0-4 and 8-12 inch depths before flooding but after flooding, the highest bulk density was in the 8- 12 inch depth (Table 4).

Soil samples were collected from all N treatments before and after flooding as well as after harvest at the end of season. These samples were taken from 0-4, 4-8 and 8-12 inch depths. These samples were analyzed for soil inorganic N (ammonium and nitrate N). Both pre-flood and post-flood nitrate and ammonium N were significantly higher at the 0-4 inch depth compared to the 4-8 inch depth (Figure 1 A and B). The pre-flood soil nitrate N was not affected by different N treatments and flooding duration. The post-flood nitrate N was significantly affected by flooding duration, fertilizer treatments and depths. The post-flood nitrate N in the NCU+NI treatment was significantly lower compared to that of the PCU and urea treatments, but similar to that of the control. The non-flooded treatments had 68% higher soil nitrate N compared to that of flooded treatments. The post-flood ammonium N was significantly affected by different N treatments and soil depth, but no effect of flooding duration was observed. The PCU treatment had higher soil ammonium N than that of the NCU+NI and control treatments.

Fertilizer packets of PCU weighing 10 g each were placed on the soil surface before fertilizer application in the different treatments to evaluate PCU dissolution due to flooding and time. They were removed at eight different times as shown in Figure 3. The urea release was significantly affected by the flooding duration and N treatments. The flooded treatments had 5% higher release of urea compared to non-flooded treatments. The urea release from PCU was greater in flooded plots compared to non-flooded treatments, with >60% release two weeks after flooding (Figure 2).

There was no significant effect of flooding duration on grain yield during the relatively wet growing season of 2014. Both hybrids did not show any significant differences in grain yield and, therefore the results that are shown are averaged over the two hybrids (Figure 3). Corn yield was significantly affected by N fertilizer treatments and rescue N application ($P \leq 0.1$). In the previous year, rescue N treatments did not show grain yield response probably due to low rainfall after application but in 2014 adequate rainfall did occur after application. The average grain yields for hybrid #1 and #2 were 208 and 215 bu/acre. The PCU treatment had 14% greater yields compared to the control and NCU treatment when no rescue N was applied. Post-flood rescue N applications of NCU+NI resulted in 14 bu/acre higher grain yield for hybrid #1. On average, grain yield was decreased with rescue N application to treatments receiving NCU+NI, whereas rescue N increased yield with other pre-plant N treatments. The high yields observed in the control treatment may be due to residual soil N from the previous year (Figure 3).

Outreach and Training:

A Ph.D. student in soil science is being trained under this project for her dissertation research. The results from the field trial were presented to growers and agricultural professionals at the 2014 Greenley Center Field Day in Northeast Missouri and at the 2014 American Society of Agronomy (ASA) National Meetings held in Long Beach, California. The Ph.D. student won a prize for her poster presentation of this research at the ASA Meetings in the S4 Soil Fertility Division. The research was also presented at the 2014 North Central Extension-Industry Soil Fertility Conference in Des Moines, Iowa.

Objectives for 2015 year:

The field study will be repeated for a third year to evaluate climate variation on corn yield in response to different flooding and N treatments. The objectives for the third year of this research will be same as of the first and second years. The objectives for the third year will be: 1) evaluate a selection of new corn hybrids for tolerance to soil waterlogging at early growth stages, 2) assess the interactive effects of corn hybrid and pre- and post-waterlogging applications of different N fertilizer sources (e.g., PCU and NI) on corn yields and NUE, 3) determine the effects of the treatments and excessive soil moisture conditions on plant available soil inorganic N during the growing season, and 4) evaluate the economic costs and benefits of using these fertilizer sources under waterlogged conditions.

Table 1. Initial selected soil properties of the study site at the Greenley Research Center in Northeast Missouri to a depth of 12 inches.

Depth	pH_s (0.01 M $CaCl_2$)	Neutralizable acidity	Organic matter	Bray-1 P	Exchangeable Ca	Exchangeable Mg	Exchangeable K	CEC†	Total N
inches		- meq/100 g -	- % -	-------------- lbs/acre --------------				meq/100 g	-% -
0-4	6.0	1.7	2.3	67.0	4322	445	228	14.6	0.12
4-8	5.7	2.7	1.6	14.3	3835	504	140	14.5	0.06
8-12	4.7	7.3	1.8	10.3	5226	1136	237	25.4	0.08

†Abbreviations: CEC, Cation Exchange Capacity

Table 2. Soil redox potential and pH during flooding.

Days after flooding started	Redox potential	Soil pH
	------------ mV ----------	
1	475	5.6
3	298	6.1
4	250	6.0
6	169	5.9
LSD $_{(0.05)}$ ‡	28	0.4

‡ LSD, Fisher's least significant difference ($P \leq 0.05$); NS, not significant.

Table 3. Soil temperature during flooding among different flood durations.

Days after flooding starts	Flooding duration (In days)		
	0	7	LSD$_{(0.05)}$ ‡
	---------------- ^{o}F ------------------		
1	57.7	62.6	0.6
2	69.3	66.2	0.6
3	63.9	59.0	0.6
4	66.7	64.4	0.6
6	70.3	69.3	0.6
LSD $_{(0.05)}$	--------------- 1.0 ------------------		

‡LSD, Fisher's least significant difference ($P \leq 0.05$); NS, not significant.

Table 4. Bulk density before and after flooding at different depth.

Depth (inch)	Bulk density		
	Pre-flood	Post-flood	LSD$_{(0.05)}$ ‡
	--------------g/cm^3 --------------		
4	1.28	1.23	NS
8	1.40	1.41	NS
12	1.31	1.42	NS
LSD $_{(0.05)}$	0.06	0.06	

‡LSD, Fisher's least significant difference ($P \leq 0.05$); NS, not significant.

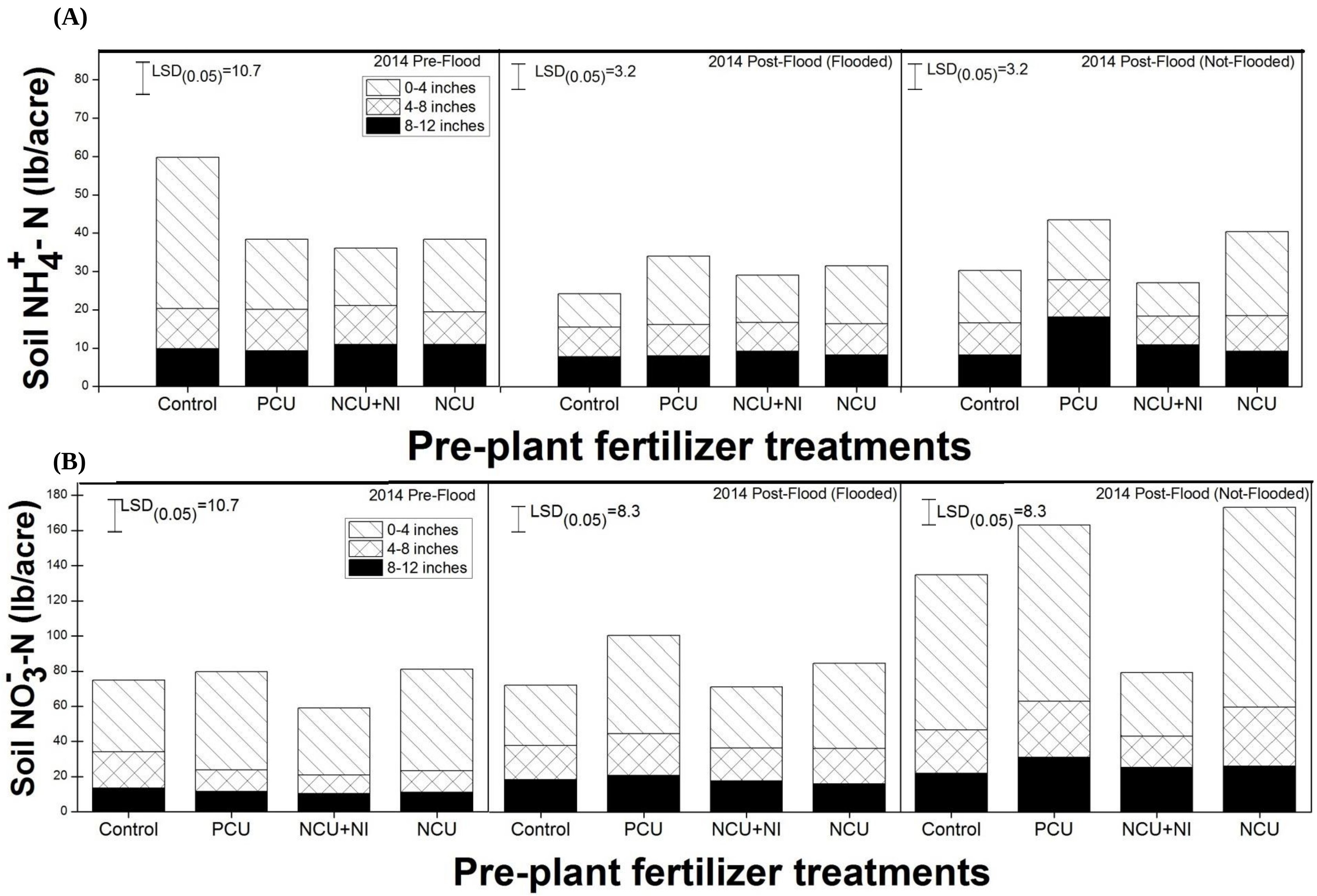

Figure 1. Average pre-flood and post flood soil ammonium (A) and nitrate N (B) by depth among different N fertilizer treatments. Data is averaged over flooding durations and two hybrids. †Abbreviations: NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea.

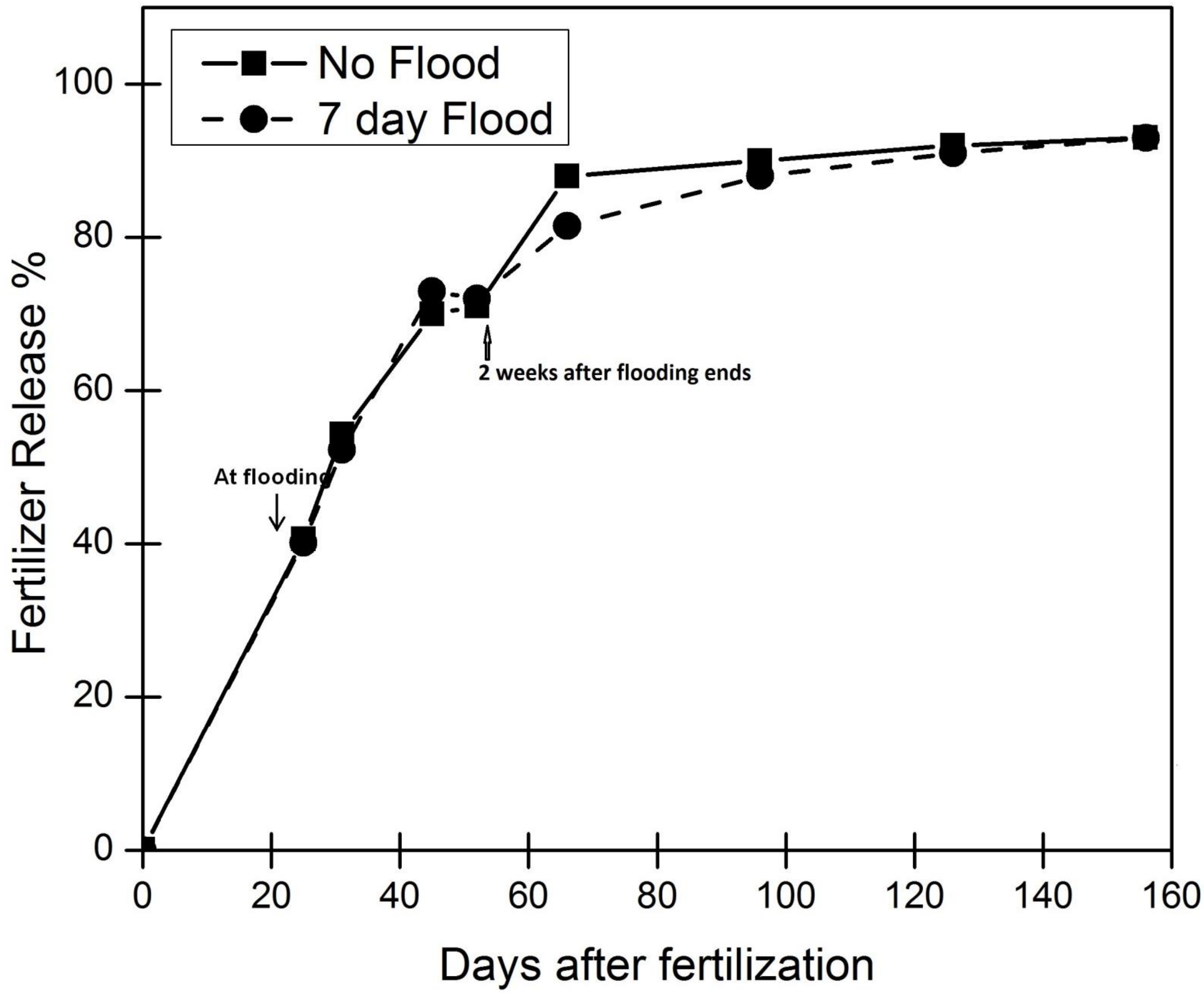

Figure 2. Release of polymer coated urea over the growing season in 2014.

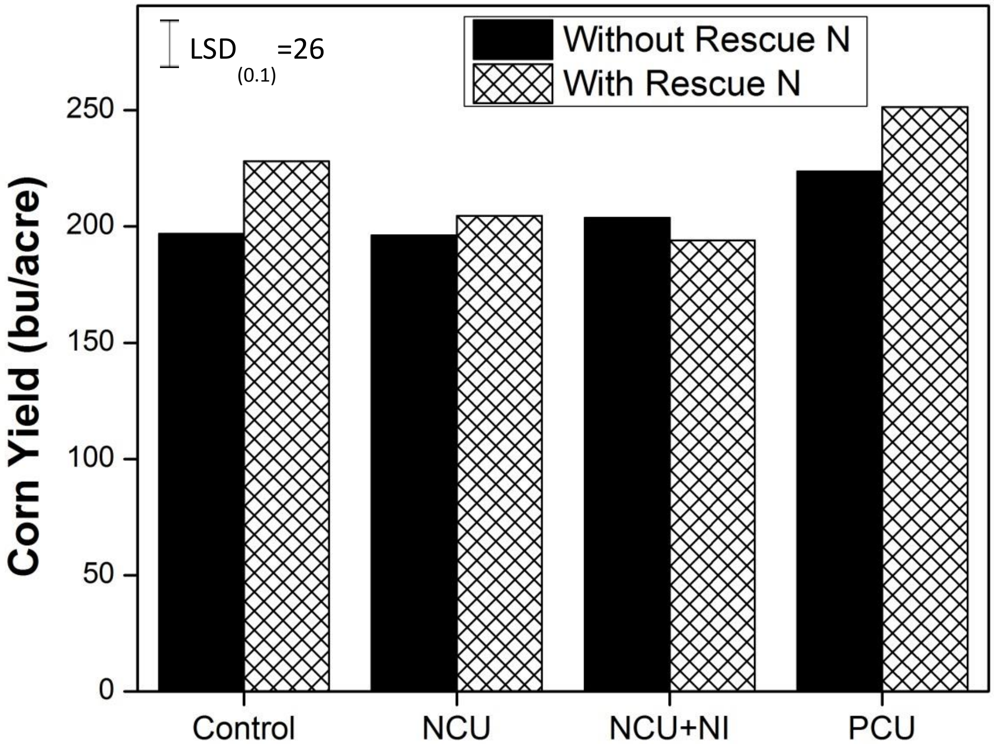

Figure 3. Corn grain yields among different N fertilizer treatments, averaged over the two hybrids and flooding duration with and without rescue N application. †Abbreviations: NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea.

Proposed Budget:

CATEGORIES	YEAR THREE
A. Salaries M.S. or Ph.D. Graduate Research Assistant (50%)	$18,277
B. Fringe Benefits Fringe for graduate student	$2,724
TOTAL SALARIES AND FRINGE BENEFITS	$21,001
C. Travel	
Travel to field site	$735
Travel to professional meeting	$1,000
TOTAL TRAVEL COSTS	$1,735
D. Equipment	$0
TOTAL EQUIPMENT COSTS	$0
E. Other Direct Costs	
Laboratory reagents and supplies	$3,000
Field supplies	$2,000
Soil analysis	$500
Publications/Documentation	$500
TOTAL OTHER DIRECT COSTS	$6,000
TOTAL REQUEST	$28,736

Justification:
Salaries and Fringe Benefits: Funds are requested for support of a graduate research assistant (50% time) based on set rates at the University of Missouri. Fringe benefits for the graduate student cover the cost of health insurance.

Travel: Covers cost of travel to Greenley Center and to farm site at a rate of 52.5 ¢/mile. In the second year, $1,000 and in the third year $1,000 are requested to cover cost of travel and board for one researcher to attend a professional conference for presentation of results.

Laboratory Reagents and Supplies: Covers cost of laboratory reagents, sample containers, and other materials used in soil and plant tissue analyses.

Field Supplies: Cost of fertilizer, seed, plot preparation, planting, weed control and harvesting, soil samplers, flags, pots and other field supplies and operations.

Soil Analysis: Covers cost of drying, grinding and analysis of soil samples at the University of Missouri Soil and Plant Testing Laboratory.
Publications/Documentation: Defrays cost of publication and documentation of results and conclusions.

Final Report
2013

Utilization of Enhanced Efficiency Nitrogen Fertilizer and Managed Drainage to Reduce Nitrate-N Loss

Investigators:
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Objective and Relevance:

Enhanced efficiency fertilizers such as polymer-coated urea (PCU) have been shown to reduce nitrate concentrations in lysimeters in claypan soils (Nelson et al., 2009). These fertilizers may further reduce NO_3-N loss through subsurface drainage systems that utilize managed drainage for corn production, but no research has been conducted to evaluate both best management practices. Agricultural drainage is not a new concept; however, utilizing managed drainage as part of an integrated water management system is a relatively new concept that has been shown to improve water quality by reducing NO_3-N load up to 75% (Drury et al., 1996; Frankenberger et al., 2006; Drury et al., 2009) and sustain agricultural viability (Belcher and D'Itri, 1995). Groundwater quality is affected by nitrate (NO_3^-) pollution that may result from excessive N fertilizer applications and other practices (Knox and Moody, 1991). Since NO_3-N is soluble in water and is not retained by soil particles, it is susceptible to be leached to groundwater prior to crop growth or following harvest. In the United States, N losses in crop production are a concern due to relatively high N fertilizer application rates and considerable amounts of NO_3-N released in drainage waters from agricultural soils (Cambardella et al., 1999). As a result, NO_3-N concentration is regulated to prevent negative health impacts and eutrophication (Shaviv and Mikkelsen, 1993; USEPA, 1995; Hunter, 2001).

Soil and water conservation systems for productivity and environmental protection are key components of this enhanced efficiency N fertilizer and managed drainage project. In order for rural communities to remain competitive in a rapidly changing agricultural environment, technology that integrates current best management practices must also maintain a highly productive, safe, and efficient food supply. Water conservation, reduced fertilizer loss, increased nutrient use efficiency, and reduced sediment loss while improving crop production combined with managed drainage that is based on solid research is a win-win situation for farmers, consumers, and the environment. It is expected that there will be a reduction in NO_3-N loading of up to 75% (Zucker and Brown, 1998; Frankenberger et al., 2006; Drury et al., 2009) and an additive effect of the enhanced efficiency fertilizer on reducing N loss in the crop production system and increasing corn grain yield. The hypothesis of this research is that managed drainage and enhanced efficiency fertilizer (polymer-coated urea) will synergistically increase corn yields and reduce NO_3-N loss.

The objective of this research is to determine the effects of managed drainage systems (MSD) and enhanced efficiency nitrogen fertilizer (PCU) on corn production, gaseous emissions of N, and nitrogen loss through the subsurface drainage system.

Results:

Research was initiated in July 2010 in a Putnam silt loam (Greenley site) and Wabash silty-clay (Bee Ridge site). Water samples and flow were collected and monitored from the drainage systems at both sites year-round using automated collection systems and flow monitoring equipment. Water samples were analyzed for nitrate-N, ortho-phosphate, and sediment concentration. Water flowing out of subsurface drainage systems was typically restricted over the period of Oct. through Apr. with MSD, while conventional subsurface drainage systems (CSD) had unrestricted water flow over the same period of time.

Supplemental data including ammonia volatilization, nitrous oxide gas loss, and soil nitrogen concentration were also collected at the Greenley site which allows us to better understand how subsurface drainage systems and enhanced efficiency nitrogen fertilizer impacted corn production, nitrogen loss, and fertilizer use efficiency. However, some of this supplemental data is currently being analyzed at this time and were not presented in this report.

Putnam silt loam (Greenley site)

Corn grain yields averaged over the 2010-13 season at the Greenley site (Putnam silt loam) were generally low (<91 bu/acre) for all treatment combinations, which was primarily a function of a wet springs followed by dry summer conditions (Table 1). In the absence of subsurface drainage (NSD), PCU averaged 15 bu/acre greater yields (20%) compared to non-coated urea (NCU). When NCU was applied, the addition of CSD or MSD increased yields (18%) by an average of 13 bu/acre compared to NSD. When PCU was applied, grain yields were similar among drainage systems (CSD, MSD, and NSD). Over 2010-2013, increased corn yields with MSD compared to CSD was limited.

Totaled over four growing seasons, N loss via ammonia volatilization from the NCU/CSD treatment was 48.7 lbs-N/acre which was significantly ($P \leq 0.1$) greater than all other treatments that included PCU application (Table 1). Non-coated urea with NSD had the second largest ammonia volatilization loss (37.1 lbs-N/acre), while PCU/MSD treatment had the least (22.5 lbs-N/acre). When totaled over 2010-2013 and averaged over drainage systems, PCU (25 lbs-N/acre) reduced ammonia volatilization loss 37% compared to NCU (40 lbs-N/acre). Annual N loss through denitrification as nitrous oxide gas when averaged over the four year study was not significantly ($P \leq 0.1$) impacted by the presence of subsurface drainage (data not presented). However, soil nitrous oxide emissions were reduced by 47% with PCU compared to NCU when averaged over 2010-2013 (data not presented).

Water drained from tile drains collected from July 2010 through December 2013 was significantly ($P \leq 0.1$) reduced 62% with MSD compared to CSD (Table 1). Managed drainage reduced total nitrate (NO_3) and ortho-phosphate loss 72 and 80% compared to CSD, respectively. However, differences in the average flow weighted mean of nitrate-N over this period among treatments were not different. Large reductions in water drained as well as nitrate and ortho-phosphate loss over the four year study was likely due to drought conditions experienced during three of the four growing seasons.

Wabash silty-clay (Bee Ridge site)

The corn crop at the Bee Ridge site (Wabash silty-clay) was lost in 2010 due to a severe flooding event which occurred in July. This may have contributed carryover N into 2011 that resulted in no significant differences ($P \leq 0.1$) in yields among drainage and N fertilizer treatments (Table 2). In 2012 and 2013, a drought occurred throughout the summer months and was the primary factor that lowered overall yields. Averaged over 2012 and 2013, N fertilizer source had a limited effect on yields with drainage treatments; however, yields increased (9%) with subsurface drainage (123 bu/acre) compared to NSD (113 bu/acre).

Analysis of subsurface drainage water data collected from July 2010 through Oct. 2012 found that MSD significantly ($P \leq 0.1$) reduced the total amount of water drained by 46% compared to CSD (Table 2). MSD had a 20 and 61% reduction in the total nitrate (NO_3) and ortho-phosphate loss, respectively, compared to CSD. Additionally, the average N flow weighted mean in drainage water was typically greater with MSD compared to CSD.

Conclusions:

Nitrogen fertilizer's effect on corn grain yield among PCU and NCU was present in the Putnam soil site, but not the Wabash soil site. Averaged over 2010-2013 at the Putnam soil site, PCU increased corn yield (20%) compared to NCU in the absence of drainage. When NCU was applied in the presence of subsurface drainage (CSD or MSD), corn grain yields increased 18% compared to NSD. Overall, the presence of subsurface drainage increased yield by 8 and 10% compared to NSD at the Putnam (2010-2013) and Wabash (2012-2013) soil sites, respectively. Corn yields were generally similar with MSD compared to CSD over the four year studies at both sites.

Managed subsurface drainage on average reduced the amount of water drained 46 to 62% compared to CSD for the Wabash (2010-2012) and Putnam soil sites (2010-2013), respectively. Annual nitrate-N loss in the drainage water was reduced by an average of 20% (Wabash soil site) and 73% (Putnam soil site) with MSD compared to CSD. Annual ortho-phosphorus loss in the drainage water was reduced by an average of 61% (Wabash soil site) and 80% (Putnam soil site) with MSD compared to CSD. Annual reductions in nitrate and ortho-phosphorus loss in drainage water with MSD were derived primarily from reducing the water drained during the non-cropping period. Additionally, wet conditions during the non-cropping period in combination with dry conditions in the summer months probably magnified the environmental benefits of MSD compared to CSD. Polymer-coated urea effectively reduced ammonia volatilization (36%) and soil nitrous oxide emissions (47%) compared to NCU. Slow release properties of PCU likely limited early season gaseous emissions of N compared to NCU.

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Table 1. Yield, subsurface drainage, and gaseous N loss data from 2010-13 on a Putnam silt loam soil in continuous corn production.

				Subsurface drainage				Gaseous N loss
Year(s)[†]	**Drainage**[‡]	**N fertilizer**	**Yield**[§] **(Bu/acre)**	**Water drained (1000 L/acre)**	**NO_3 loss (Lbs-N/acre)**	**N flow weighted mean (ppm)**	**Ortho-P loss (Lbs-P/acre)**	**NH_3 (Lbs-N/acre)**
2010	NSD	NTC	41b	NA	NA	NA	NA	2.8d
2010	NSD	NCU	102a	NA	NA	NA	NA	15.0b
2010	NSD	PCU	107a	NA	NA	NA	NA	8.7bcd
2010	CSD	NCU	110a	640a	7.4a	5.5a	0.18a	26.3a
2010	CSD	PCU	103a	600a	6.4a	4.9a	0.13ab	4.6bcd
2010	MSD	NCU	113a	380a	4.9a	6.1a	0.06bc	14.2bc
2010	MSD	PCU	106a	370a	4.9a	6.3a	0.03c	3.7cd
2011	NSD	NTC	14c	NA	NA	NA	NA	4.2a
2011	NSD	NCU	44b	NA	NA	NA	NA	4.5a
2011	NSD	PCU	81a	NA	NA	NA	NA	4.0a
2011	CSD	NCU	61ab	710a	20.3a	12.2ab	0.23a	5.8a
2011	CSD	PCU	67a	630a	25.2a	16.9a	0.19ab	4.6a
2011	MSD	NCU	61ab	180b	3.8a	11.3bc	0.02b	4.6a
2011	MSD	PCU	63ab	180b	2.9a	7.2c	0.02b	4.2a
2012	NSD	NTC	12d	NA	NA	NA	NA	10.1a
2012	NSD	NCU	45c	NA	NA	NA	NA	8.0bc
2012	NSD	PCU	51b	NA	NA	NA	NA	9.0ab
2012	CSD	NCU	50b	470a	25.7a	25.0a	0.12b	8.2bc
2012	CSD	PCU	51b	560a	29.0a	23.7a	0.40a	8.6bc
2012	MSD	NCU	55a	110b	6.9b	29.1a	0.06b	7.6c
2012	MSD	PCU	55a	140b	5.0b	16.8a	0.07b	7.9bc
2013	NSD	NTC	42b	NA	NA	NA	NA	6.0c
2013	NSD	NCU	113a	NA	NA	NA	NA	9.5a
2013	NSD	PCU	124a	NA	NA	NA	NA	6.3bc
2013	CSD	NCU	135a	150a	8.8a	25.4bc	0.01a	8.4ab
2013	CSD	PCU	138a	80ab	4.0ab	23.4c	0.03a	8.0abc
2013	MSD	NCU	131a	20b	1.7b	31.5a	0.00a	7.8abc
2013	MSD	PCU	141a	70ab	4.1ab	28.5ab	0.01a	6.6bc
			Average	Total	Total	Average	Total	Total
2010-13	NSD	NTC	27b	NA	NA	NA	NA	23.1b
2010-13	NSD	NCU	76a	NA	NA	NA	NA	37.1ab
2010-13	NSD	PCU	91a	NA	NA	NA	NA	28.0b
2010-13	CSD	NCU	89a	1960a	62.2a	12.2a	0.55a	48.7a
2010-13	CSD	PCU	90a	1860a	64.5a	12.5a	0.74a	25.8b
2010-13	MSD	NCU	90a	690b	17.2b	14.9a	0.14b	34.2ab
2010-13	MSD	PCU	91a	750b	16.9b	10.8a	0.12b	22.5b

[†] Study years represent the period of time from N fertilization up until the next years' N fertilization.

[‡] Abbreviations: CSD = conventional subsurface drainage; MSD = managed subsurface drainage; NA = not applicable; NCU = non-coated urea; NH_3 = ammonia; NSD = no subsurface drainage; NTC = non-treated control; PCU = polymer-coated urea.

[§] Letters following yields, water drained, N flow weighted mean, NO_3, ortho-P, and NH_3 loss (by year) denote Fisher's Least Sign. Diff. (P = 0.1).

Table 2. Yield and subsurface drainage data from 2010-13 on a Wabash silty-clay soil in continuous corn production.

				Subsurface drainage			
Year(s)[†]	Drainage[‡]	N fertilizer	Yield[§] (Bu/acre)	Water drained (1000 L/acre)	NO_3 loss (Lbs-N/acre)	N Flow weighted mean (ppm)	Ortho-P loss (Lbs-P/acre)
2010[¶]	NSD	NCU	0	NA	NA	NA	NA
2010	NSD	PCU	0	NA	NA	NA	NA
2010	CSD	NCU	0	1598a	8.1a	2.7a	0.03a
2010	CSD	PCU	0	1457a	7.1a	2.3a	0.03a
2010	MSD	NCU	0	946b	13.3a	7.4a	0.03a
2010	MSD	PCU	0	970b	9.5a	5.3a	0.03a
2011	NSD	NCU	199a	NA	NA	NA	NA
2011	NSD	PCU	196a	NA	NA	NA	NA
2011	CSD	NCU	194a	2997a	51.2a	8.1b	0.26ab
2011	CSD	PCU	201a	3011a	46.1b	7.3b	0.32a
2011	MSD	NCU	195a	1746b	35.2c	10.0ab	0.13bc
2011	MSD	PCU	195a	1727b	49.7ab	14.0a	0.12c
2012	NSD	NCU	92a	NA	NA	NA	NA
2012	NSD	PCU	92a	NA	NA	NA	NA
2012	CSD	NCU	105a	2099a	20.9a	5.8a	0.08b
2012	CSD	PCU	101a	1988a	12.8a	3.7a	0.12a
2012	MSD	NCU	104a	895b	4.3a	3.6a	0.03c
2012	MSD	PCU	105a	850b	5.4a	3.5a	0.03c
2013	NSD	NCU	133a	--------[††]	--------	--------	--------
2013	NSD	PCU	135a	--------	--------	--------	--------
2013	CSD	NCU	146a	--------	--------	--------	--------
2013	CSD	PCU	141a	--------	--------	--------	--------
2013	MSD	NCU	138a	--------	--------	--------	--------
2013	MSD	PCU	146a	--------	--------	--------	--------
			Average[‡‡]	Total	Total	Average	Total
2010-13	NSD	NCU	112a	NA	NA	NA	NA
2010-13	NSD	PCU	114a	NA	NA	NA	NA
2010-13	CSD	NCU	126a	6693a	80.2a	5.5ab	0.34a
2010-13	CSD	PCU	121a	6456a	66.0a	4.4b	0.45a
2010-13	MSD	NCU	121a	3586b	64.6a	7.0ab	0.16b
2010-13	MSD	PCU	125a	3548b	52.8a	7.6a	0.15b

† Study years represent the period of time from N fertilization up until the following years' N fertilization.

‡ Abbreviations: NO_3 = nitrate; CSD = conventional subsurface drainage; MSD = managed subsurface drainage; NA = not applicable; NCU = non-coated urea; NSD = no subsurface drainage; P = phosphorus; PCU = polymer-coated urea.

§ Letters following yields, water drained, NO_3 loss, N flow weighted mean, ortho-P loss (by year) denote Fisher's Least Significant Difference (P = 0.1).

¶ Corn crop in 2010 was lost due to severe flooding event.

†† Environmental nutrient loss data from 2013 is currently being analyzed.

‡‡ Corn yields were only averaged over the 2012 and 2013 season.

2014

Nitrogen Fertilizer Management of Temporarily Flooded Soils to Improve Corn Production and Reduce Environmental N Loss

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Summary:

Research was conducted for three years from 2012 to 2014 at the University of Missouri's Greenley Research Center in Northeast Missouri to determine the effects of flooding durations on corn (*Zea mays*. L.) growth and nitrogen (N) use efficiency (NUE); assessing the use of different N sources including PCU, nitrification inhibitor and a post-flood rescue N fertilizer treatment; and evaluating the economic costs and benefits of using these fertilizer sources under different flooding conditions. The overall goal of this research is the development of an economically profitable N fertilizer strategy for both pre- and post-flood conditions that will increase corn production and decrease environmental N loss.

- Corn grain yields were significantly reduced due to flooding durations of 3 and 7 days that were imposed at the V6 corn growth stage in 2013 and 2014. An average loss of 6.6 bushels/acre and 11.4 bu/acre occurred with each day of flooding in 2013and 2014, respectively. No yield reductions occurred in 2012 due to flooding possibly because of relatively dry climatic conditions experienced during that cropping season.

- Rescue N fertilizer applications increased corn grain yields in two (2012, 2014) out of three years. The three years of research results suggest that grain yield response to rescue N fertilizer depended on the amount of rainfall received after the rescue N application and the severity of the crop stress caused by increasing duration of soil waterlogging.

- Application of different pre-plant N fertilizers generally resulted in increased grain yields compared to the control but no consistent differences in response were observed among the fertilizer sources tested in this research.

- Corn silage yield and N uptake provided in this report for the 2012 cropping season were significantly affected by flooding duration and rescue N application, but further analysis for the 2013 and 2014 seasons have not been completed. In 2012, increasing flooding duration decreased N uptake and N uptake was higher in treatments receiving rescue N application.

- Chlorophyll content of corn leaves was decreased by flooding duration in 2013, but not in 2012. Chlorophyll results for 2014 are being analyzed. Lower chlorophyll content resulted from lower N absorption due to loss of N during flooding.

- Soil nitrate and ammonium N were significantly affected by the flooding duration and N fertilizer sources in 2012 and 2013. The 2014 data is being analyzed. In general, PCU had higher soil N content compared to other treatments in 2012.

- Soil surface nitrous oxide gaseous emissions measured in 2012 and 2013 were affected by the flooding duration and fertilizer sources. PCU in 2012 and NCU in 2013 had the highest cumulative higher effluxes compared to other N treatments during 72 hour flooding duration events. The proportion of N fertilizer lost as N_2O-N averaged over all pre-plant N treatments during the 2012 and 2013 sampling periods in the non-waterlogged soils was 0.04% and 0.03%, and 1.1% and 2.6% in the waterlogged soils, respectively. These results indicate that a high proportion of the N fertilizer that is lost as nitrous oxide gas occurs during short-terms events when soils are waterlogged.

Materials and Methods:

A field experiment was conducted for three years from 2012 to 2014 at the University of Missouri's Greenley Research Center in Northeast Missouri. Adjacent fields were used each year for conducting the experiment. Soil classification for the field areas is a Putnam silt loam (fine, smectitic, mesic Vertic Albaqualfs). Soil samples were collected in increments of 0-4, 4-8, and 8-12 inch depths before pre-plant fertilizer application and incorporation to characterize initial soil conditions (Table 1). Pre-fertilization soil characteristics were different in all years. Soil pH was lower in 2013 than that of the other two years in the 0-8 inch depth.

The field was separated into 15 by 100 foot plots of six 30-inch rows of DEKALB 62-97VT3 in 2012 and 2013. In 2014, only four rows were planted in each plot. Nitrogen fertilizer treatments of a control (CO) and 150 lbs N/acre of urea (NCU), urea plus nitrapyrin nitrification inhibitor (NCU + NI) (N-Serve®, Dow AgroSciences, Indianapolis, Indiana), and polymer-coated urea (PCU) (ESN®, Agrium, Inc., Calgary, Alberta) were included in this study. All pre-plant fertilizer N applied was incorporated immediately after application using a cultivator. The experimental design was a randomized complete block with a split-split plot arrangement with three replications. A rescue N fertilizer application of 75 lbs N/acre of urea plus NBPT (N-(n-butyl) thiophosphoric triamide) urease inhibitor (NCU + UI) at 1 gal/ton was applied to half of each original fertilizer treatment plot (Agrotain®, Koch Agronomic Services, Wichita, Kansas). Following rescue application, each 15 by 100 foot fertilizer treatment was split into two 15 by 50 foot plots, one being with the rescue application and the other without the rescue application. A rescue application of 75 lbs N/acre was applied as an estimate of an economical optimal N rate for yield response at corn growth stage V10 determined from SPAD 502 chlorophyll meter readings (Konica Minolta, Hong Kong) taken after flooding in 2012. Rescue N was applied at the same rate during 2013 and 2014 as in 2012.

In 2012, ponding of water occurred for durations of 0 (no flood), 24 (1 day), 48 (2 days), and 72 hours (3 days) at the V6 corn growth stage on June 1st using temporary soil levees to surround each flooding block. Levees were knocked down to allow ponded water to escape after intended flooding duration had ceased. An extended flooding duration treatment of 7 days was added in 2013 to replace the 2 day treatment, since no flooding treatment effect occurred during the 2012 growing season. Therefore, flooding durations used in 2013 and 2014 were 0, 1, 3, and 7 days at the V6 corn growth stage using temporary soil levees to surround each flooding block (Fig. 1).

Soil samples were collected from N fertilizer treatments before and after temporary flooding events from 0-4, 4-8, and 8-12 inch depths and analyzed for soil inorganic N (ammonium and nitrate-N).

Corn grain yields were harvested from the total row length of the two center rows from each N treatment. Corn silage was collected from 20 foot of one row when corn plants reached physiological maturity and total biomass dry weight, tissue N and N uptake were determined. Chlorophyll content was measured on corn leaves using a SPAD chlorophyll meter in all plots after the 7 day flooding treatment had ended.

Soil surface effluxes of nitrous oxide and carbon dioxide gases were measured in 2012 and 2013 prior, during, and after soil saturation events to determine changes in gas loss from the soil under different flooding durations and enhanced efficiency N treatments. Gases were collected using small sealed chambers fitted with rubber septa for sample extraction using a syringe and placed into sealed vials. These gases were analyzed using gas chromatography and an automated sampler.

Results:

The total precipitation during three years of experiment trial was highly variable. The total precipitation during the 2012 growing season was relatively low compared to that of 2013 and 2014 (Table 2). The total monthly precipitation during the 2012 crop growing period from March to October was 10 and 12 inches lower compared to that of 2013 and 2014. There was 7% higher precipitation during the growing season from March to October in 2014 compared to 2013, which made 2014 a relatively wetter year for crop growth. In addition in 2014, approximately 9 inches of rainfall occurred during the month of June when the flooding treatment was imposed.

No significant effects of flooding were found on corn grain yields in 2012 most probably due to the drought conditions affecting crop response. In 2013, significant yield reductions of 16 and 45 bu/acre occurred as a result of 3 and 7 days of flooding, respectively, when compared to the non-flooded control. An average grain yield loss of 6.6 bu/acre and 11.4 bu/acre occurred with each day of flooding in 2013 and 2014, respectively (Fig. 2). There were significant yield increases of 12 and 10 bu/acre among PCU and NCU + NI, respectively, versus the control for the 72 hour flooded plots in 2012 (Fig. 3). Overall grain yield increases occurred with all applications of fertilizer treatments compared to the control in 2014 (data not shown).

Significant increases in corn yield were observed due to rescue N application of urea+UI in 2012 and 2014, but not in 2013. Yield increases of 11 bu/acre occurred as a result of the rescue application with NCU fertilizer plots of 48 and 72 hour flooding durations in 2012 (Fig. 3). An increased yield of 10 bu/acre also occurred with rescue N application in the NCU + NI treated plots at a 72 hour flooding duration. In 2013, no effect of rescue N application was observed probably due to low rainfall after its application. In 2014, rescue N application resulted in an average 6% higher yield compared to treatments not receiving rescue N up to three days of flooding but the effect was dependent on the time of flooding (Fig. 4). The results for the three years of research with rescue N fertilizer suggest that both adequate rainfall after rescue N fertilizer application and the duration the crop was previously stressed by soil waterlogging may influence the grain yield response to the rescue N fertilizer application.

No effect of flooding duration on plant chlorophyll content was observed during 2012. In 2013, chlorophyll content was decreased with an increase in flooding durations (Fig. 5). No significant differences were found between different N treatments with a 7 day flooding duration. These results suggest that flooding can temporarily decrease the amount of leaf chlorophyll measured using the SPAD meter. A possible reason for this result could be higher loss of nitrate with flooding and less uptake of N by corn roots due to reduction in plant transpiration and root conductivity for nutrient absorption. A significant effect of fertilizer sources was found with chlorophyll content in 2012 and 2013. Chlorophyll content was increased with N fertilizer application compared to the control and PCU had a higher chlorophyll content compared to urea after 24 and 72 hour of flooding in 2012 (Table 3). In 2013, pre-plant fertilizer treatments of NCU+NI and PCU had significantly higher chlorophyll content compared to the non-fertilized control treatment of 5.5 and 4.2 SPAD units, respectively (Fig. 5). Chlorophyll content in NCU treatments was not significant different than the non-fertilized control. Urea, NCU+NI, and PCU had significantly greater chlorophyll content compared to the non-fertilized pre-plant treatment when 3 and 7 days of flooding occurred (Fig. 5).

In 2012, silage yield increases occurred with PCU versus the control for 0, 24, and 72 hour flooding durations where no rescue N application was applied (Table 4). There were no significant increases with the PCU and the control where no N was applied in these flooding duration plots with the rescue application as a result of decreases in biomass. Plants in the 24 and 48 hour flooding had more N uptake with PCU and NCU + NI compared to control plots (Table 5). There were no significant differences between the amounts of N uptake with NCU in comparison with control plots. In 2013, N uptake was significantly decreased the longer the duration of flooding from 1 to 3 or 7 days compared to the non-flooded control (Figure 6A). The rescue N application significantly increased silage N uptake by 17.4 lbs/acre compared to the treatments not receiving rescue N (Fig. 6B).

The PCU treatment generally maintained higher soil NO_3^--N and NH_4^+-N concentrations among all the N treatments (Fig. 7). There was a significant decrease in soil NO_3^--N concentration from all plots treated with enhanced efficiency N fertilizers from 0 to 24 hours of soil saturation at a depth from 0-4 inches (Fig. 7). The PCU treatment was the only N fertilizer treatment to have significantly decreasing soil NO_3^--N concentration between 24 to 48 hours of soil saturation at a depth from 0-4 inches. No decrease in NH_4^+-N concentration occurred as a result of saturated soils.

In 2013, PCU and NCU+NI had 3.6 and 2.8 more pounds of pre-flood NH_4^+-N per acre, respectively, compared to NCU treatment at a depth of 8-12 inches (Fig 8A). Significantly greater NH_4^+-N concentration was maintained at a depth of 0-12 inches in PCU treatment than all other pre-plant N treatments (Fig. 9A). All pre-plant fertilizer N treatments had higher pre-flood NO_3^- -N concentration compared to control plots (Fig 8B). PCU and NCU+NI treatments had 51.3 and 47.1 more pounds/acre of NO_3^--N, respectively, than NCU in plots receiving no flooding compared to plots received 1 to 7 days of flooding. At the end of 7 days of flooding, NO_3^--N concentration was significantly higher among NCU and PCU treatments compared to control and NCU+UI (Fig. 9B). Higher NH_4^+-N and NO_3^- was maintained in PCU treatments at end of growing season that received rescue N application. Only NO_3^- -N content was higher with PCU and NCU+NI treatments compared to NCU when no rescue N was applied.

Fertilizer packets of PCU weighing 10 g each were placed on the soil surface before fertilizer application in the different treatments to evaluate release of urea from PCU due to flooding and time. They were removed at different times as shown in Figure 10. The urea release was significantly different between 0 and 1 day flooding duration. Urea release was significantly different at different timing up to 2 months after flooding.

Waterlogged soil conditions caused by the flooding treatments resulted in higher gaseous emissions of soil nitrous oxide compared to when soils were not saturated in 2012 and 2013(Fig. 11 A & B). In 2012 with the 3 day flooding period, PCU had higher efflux of soil nitrous oxide compared to NCU and NCU + NI possibly due to the higher initial pre-flood soil nitrate-N in the PCU-treated plots compared to the other N fertilizer treatments (Fig. 11B). In 2013, the NCU treatment had the highest cumulative nitrous oxide emissions among the fertilizer sources. The proportion of N fertilizer lost as N_2O-N averaged over all pre-plant N treatments during the 2012 and 2013 sampling periods in the non-waterlogged soils was 0.04% and 0.03%, and 1.1% and 2.6% in the waterlogged soils, respectively.

Outreach and Training:

A M.S. and PhD graduate student in soil science at the University of Missouri have been involved in working on this project. The first and second year research results were presented as an oral presentation to growers and agricultural professionals by the M.S. student at the 2013 and 2014 Greenley Center Field Day in Northeast Missouri. The first and second year results were presented in a poster by the M.S. graduate student at the American Society of Agronomy (ASA) annual meetings in Tampa, FL and at the North Central Extension-Industry Soil Fertility Conference. The student received an award for his poster presentation at the ASA Meetings and was honored at the North Central Extension Conference as the outstanding soil fertility graduate student from the state of Missouri. The results from the second and third years were presented by the PhD graduate student at the 2014 American Society of Agronomy (ASA) annual meetings in Long Beach, CA.

Table 1. Soil properties collected before pre-plant fertilizer application for three years from 2012 to 2014 for field study site at the Greenley Research Center. Data were averaged over three replications and reported by soil depth.

					Exchangeable			
Depth	pH_s	NA	OM	Bray 1 P	Ca	Mg	K	CEC
inches		meq/100 g	- % -	--------------- lbs/acre ----------------				meq/100 g
				2012				
0-4	6.1	1.7	2.7	58	4599	353	364	15
4-8	6.3	1.4	2.0	21	4792	340	179	15
8-12	5.5	2.8	1.7	8	4566	509	188	18
				2013				
0-4	5.4	3.7	2.8	74	3302	343	391	14
4-8	5.9	2.5	2.0	24	3885	380	197	14
8-12	5.2	4.7	1.8	13	3793	490	210	16
				2014				
0-4	6.2	1.5	2.0	58	4439	328	282	14
4-8	6.3	1.0	1.4	20	4298	296	148	13
8-12	5.0	5.2	1.3	9	4522	604	196.33	19

†Abbreviations: NA, Neutralizable Acidity; OM, Organic Matter; P, Bray-1 Phosphorus; Ca, Calcium; Mg, Magnesium; K, Potassium; CEC, Cation Exchange Capacity.

Table 2. Total monthly precipitation in 2012, 2013 and 2014 at the Greenley Research Center, Novelty, Missouri.

Month	Total monthly precipitation		
	2012	2013	2014
	---------- Inches ----------		
January	0.44	1.85	0.35
February	2.14	2.28	0.93
March	2.34	2.13	0.88
April	4.69	7.62	4.16
May	2.49	10.27	1.03
June	2.23	3.62	8.85
July	0.73	1.90	2.01
August	2.99	0.0	6.45
September	3.56	3.10	6.90
October	3.25	3.84	4.37
November	1.47	1.25	1.02
December	2.08	0.70	1.05
Total	28.41	38.56	38.00

Table 3. Average SPAD chlorophyll readings on June 12th, 2012 after flooding to determine an economically optimum N rate for rescue N application of urea plus urease inhibitor according to N treatments and temporary flooding durations.

N fertilizer treatment	Saturation duration			
	0	24	48	72
	SPAD units			
Control	42.7	41.2	40.1	37.8
Urea	47.4	45.7	47.2	45.1
Urea + NI†	48.3	48.6	46.0	45.1
PCU‡	49.0	51.8	48.7	48.6
$LSD_{(0.05)}$ ††	3.2			

†Urea + nitrification inhibitor, ‡Polymer-coated urea
††Fisher's protected least significant difference at P<0.05.

Table 4. Average corn silage yield in 2012 with corresponding N treatments and temporary flooding durations with and without rescue N plus urease inhibitor application.

N fertilizer treatment	Saturation duration			
	0	24	48	72
	tons dry matter/acre			
<u>Without Rescue N</u>				
Control	1.84	1.36	1.72	1.25
Urea	2.14	1.82	1.85	1.77
Urea + NI†	2.07	2.06	1.75	2.05
PCU‡	2.43	2.18	2.01	1.90
<u>With Rescue N</u>				
Control	1.98	1.60	1.83	1.49
Urea	1.67	1.94	1.97	2.01
Urea + NI†	1.59	1.97	1.89	1.90
PCU‡	1.81	2.02	2.52	1.84
$LSD_{(0.05)}$ ††	0.53			

†Urea + nitrification inhibitor
‡Polymer-coated urea
††Fisher's protected least significant difference at P<0.05.

Table 5. Average plant N uptake with corresponding N treatments and temporary flooding durations without and with rescue N application in 2012.

N fertilizer treatment	Saturation duration			
	0	24	48	72
	---------------------------- lbs N uptake/acre -----------------------			
Without Rescue N				
Control	24.0	16.4	19.5	15.3
Urea	28.3	19.1	26.5	24.9
Urea + NI†	33.2	28.2	21.5	23.9
PCU‡	34.6	29.8	29.1	23.2
With Rescue N				
Control	30.4	25.7	24.8	28.4
Urea	31.6	30.6	32.4	35.7
Urea + NI†	30.0	36.2	33.3	28.8
PCU‡	36.9	38.8	42.7	30.4
$LSD_{(0.05)}$ ††	-------------------------------------- 12.2 ---------------------------			

†Urea + nitrification inhibitor, ‡Polymer-coated urea, ††Fisher's protected least significant difference at P<0.05.

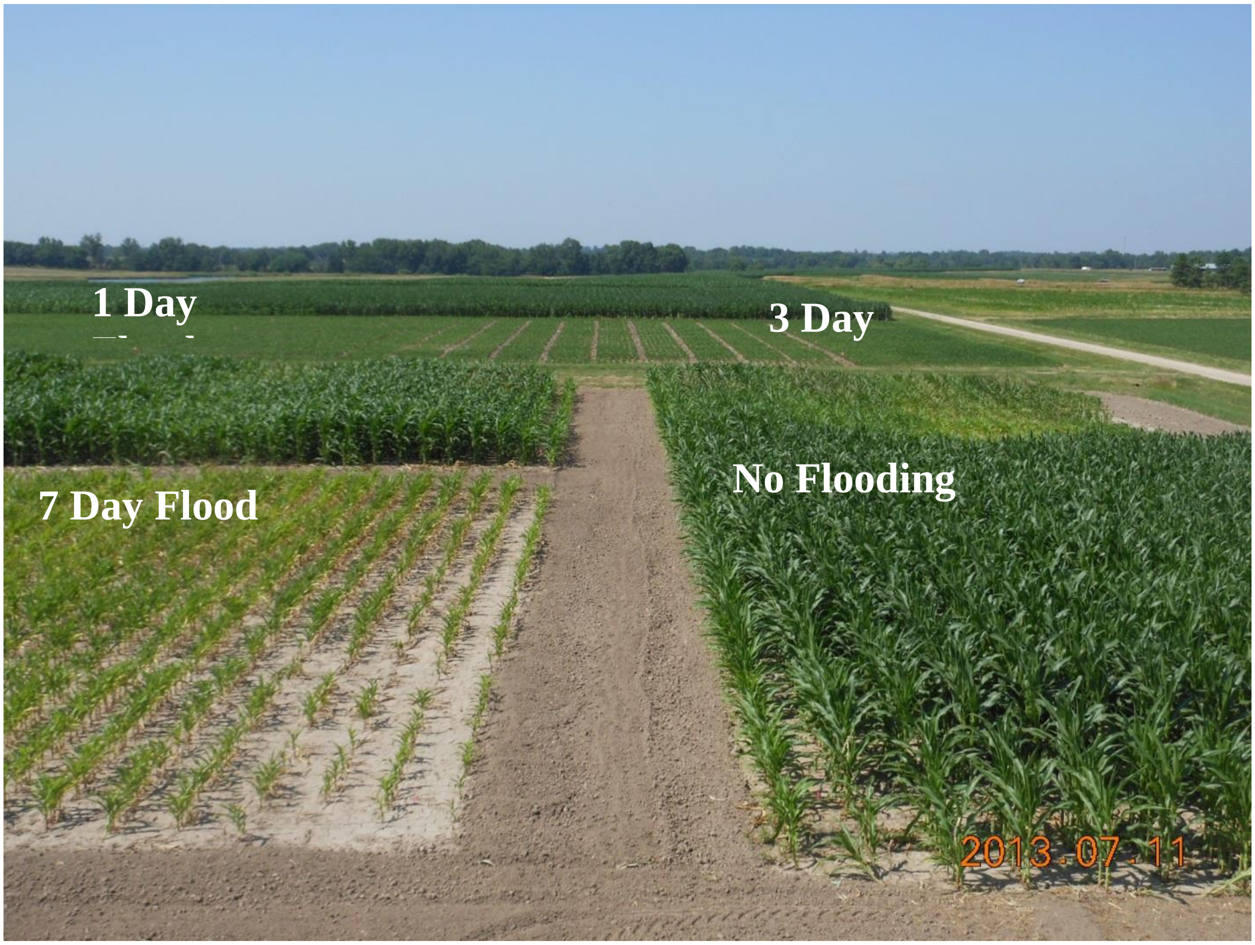

Figure 1. Flooding treatments on 11 July, 2013 which was 16 days after the 7-day flooding treatment was drained.

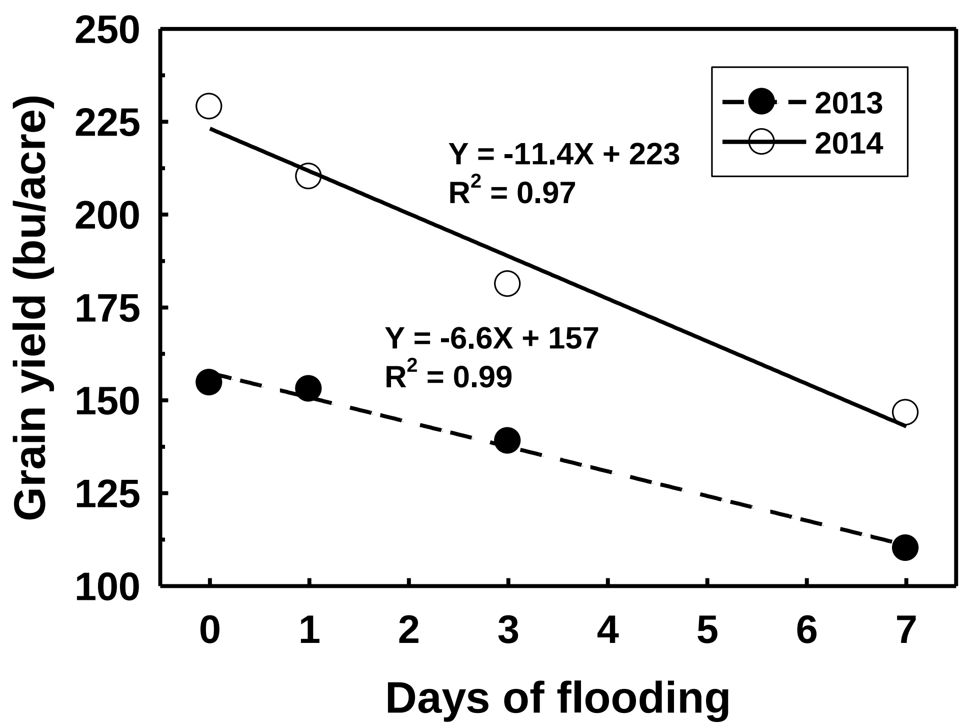

Figure 2. Average corn grain yield decline per day of flooding for all pre-plant N treatments in 2013 and 2014. Lines and equations shown are the linear regression for the grain yields.

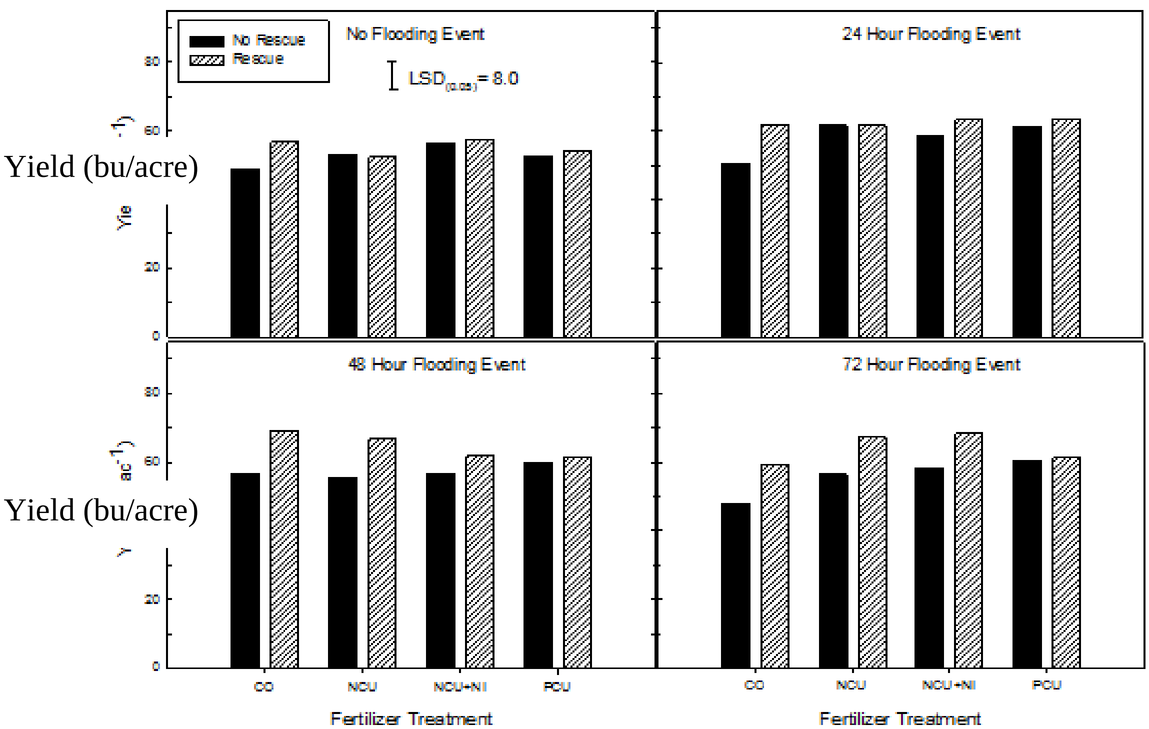

Figure 3. Average corn grain yield with and without rescue N application among different N treatments for different flooding durations in 2012.

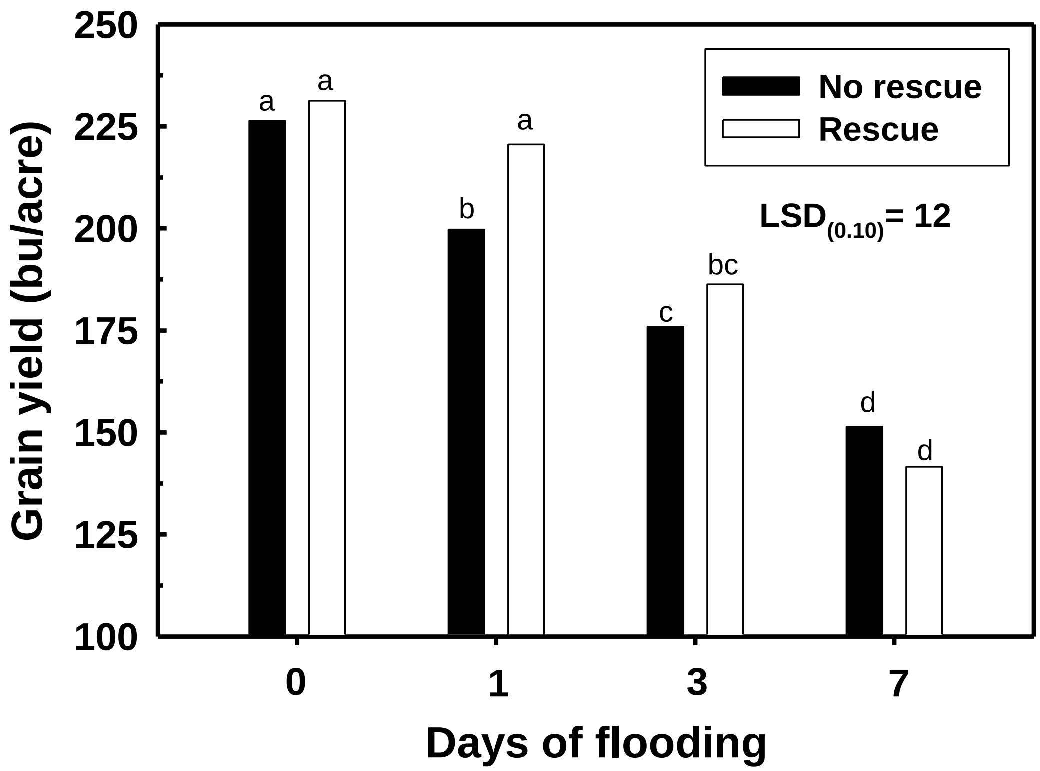

Figure 4. Effect of flooding duration and rescue N fertilizer on corn grain yields in 2014. Letters indicate statistical differences based on least significant difference test (LSD) at P < 0.10).

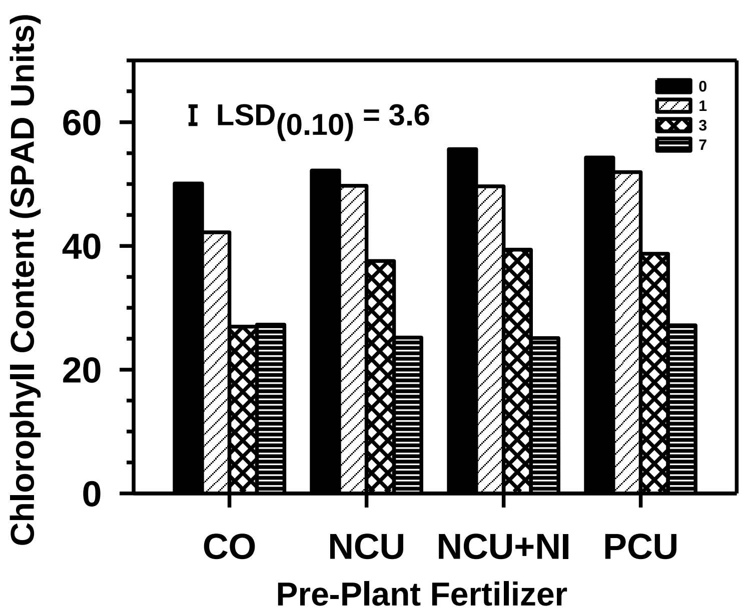

Figure 5. SPAD chlorophyll readings on 28 June, 2013 after all flooding treatments were drained to determine effects of flooding duration and pre-plant N fertilizer on chlorophyll content. (Abbreviations: CO, Control; NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea; 0, No-flooding; 1, 1 day of flooding; 3, 3 days of flooding; 7, 7 days of flooding; LSD, least significant difference at P < 0.10).

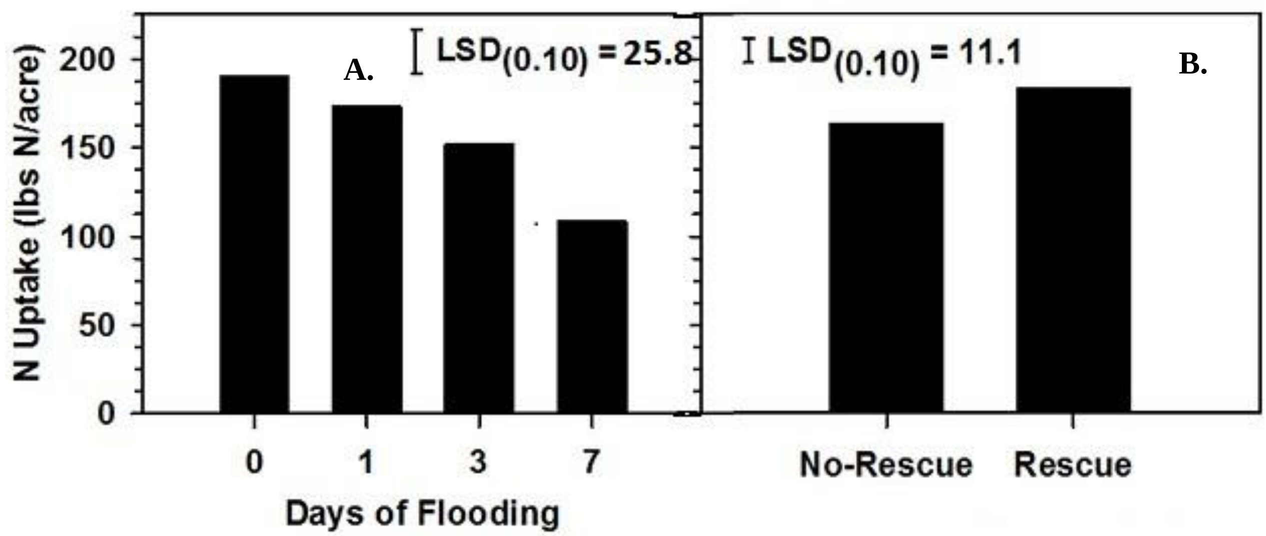

Figure 6 A&B. Average plant N uptake at physiological maturity comparing plants that experienced different flooding durations, and with and without rescue N application plus urease inhibitor in 2013. Rescue N application was applied at growth stage V10 on 8 July, 2013. (Abbreviations: LSD, least significant difference at P< 0.10 between N uptake and different flooding durations, and without and with rescue N application plus urease inhibitor).

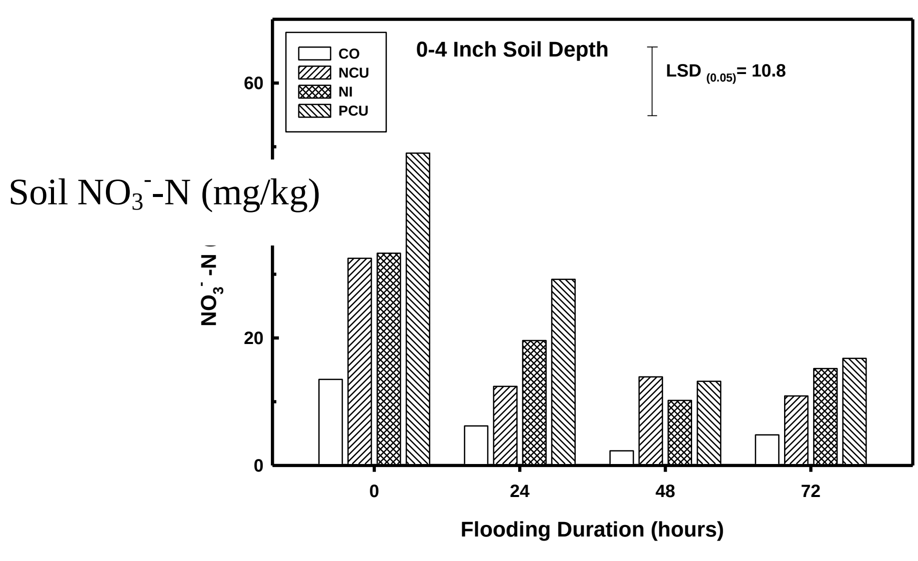

Figure 7. Average post-flood soil NO_3^--N concentrations at a depth from 0-4 inches with respect to its N treatment and flooding duration in 2012. (†Abbreviations: CO, Control; NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer-coated urea; LSD, least significant difference at P< 0.05)

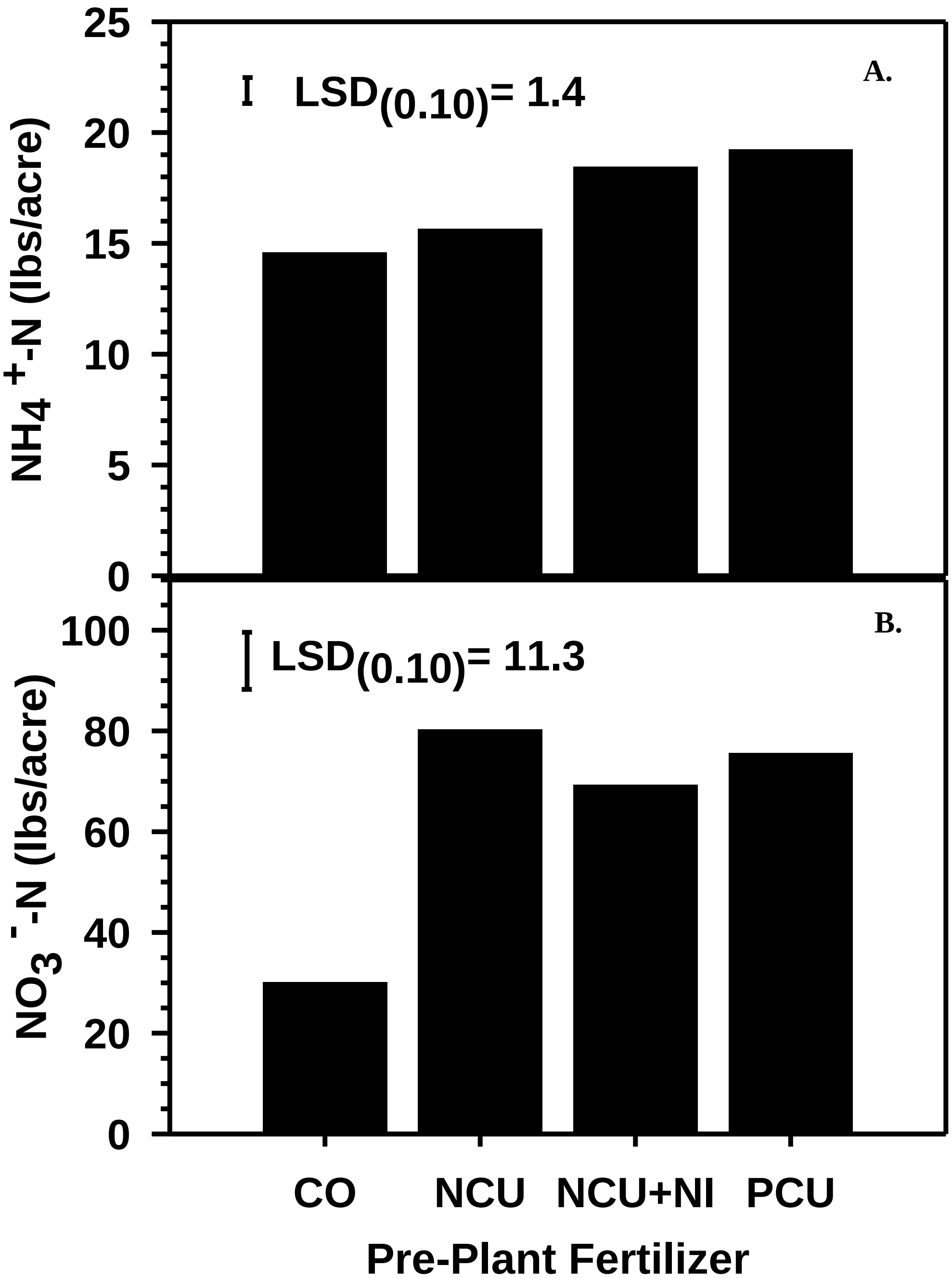

Figure 8 A & B. Average pre-flood NH_4^+-N and NO_3^--N to a depth of 12 inches with different pre-plant fertilizer applications. Sampling occurred prior to flooding on 17 June, 2013. (Abbreviations: CO, Control; NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer-coated urea; LSD, least significant difference at $P< 0.10$).

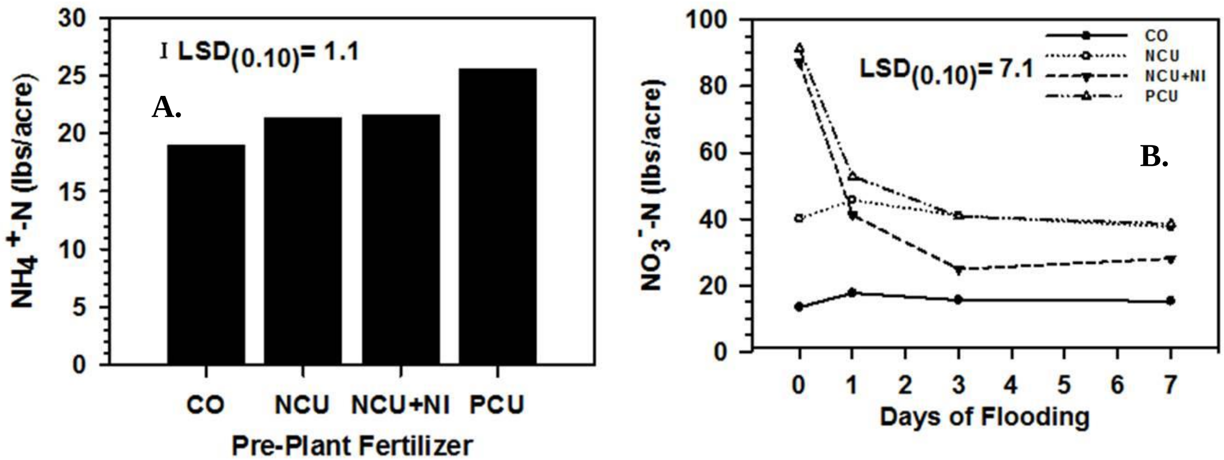

Figure 9 A & B. Average (A) NH_4^+-N and (B) NO_3^-N to a depth of 12 inches with different pre-plant fertilizer applications and flooding duration. Sampling occurred after the flooding durations on 1 July, 2013. (Abbreviations: CO, Control; NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer-coated urea; LSD, least significant difference at P< 0.10).

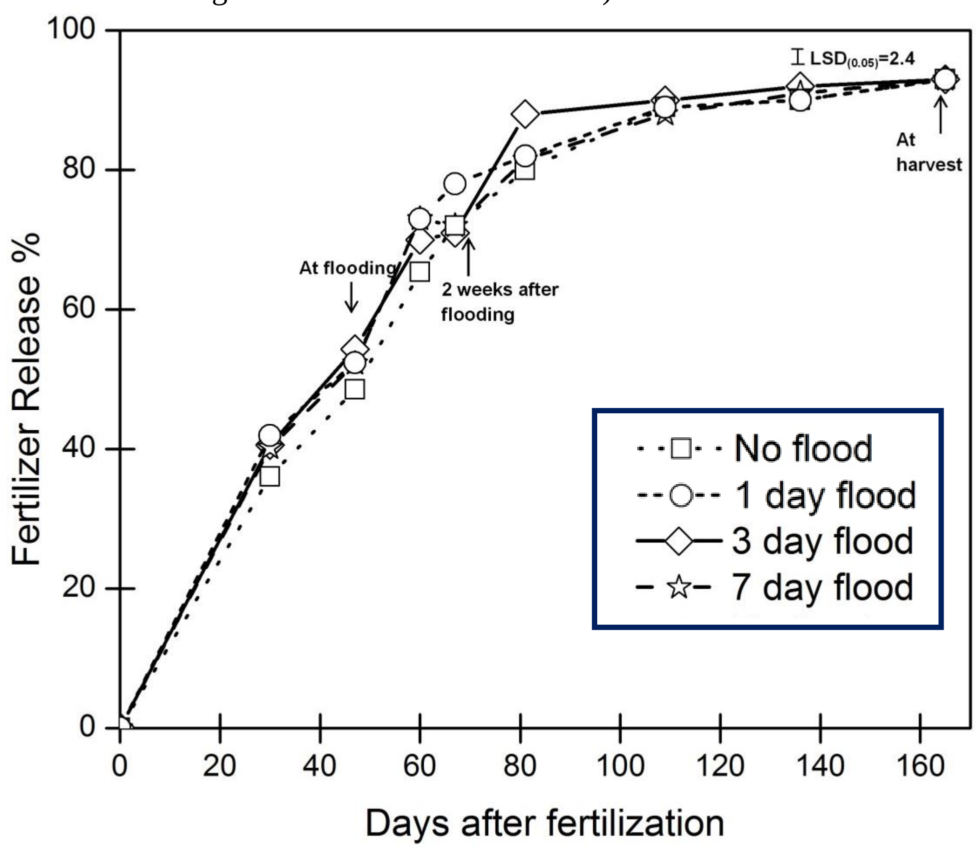

Figure 10. Fertilizer release from PCU at different timings during the 2014 growing season.

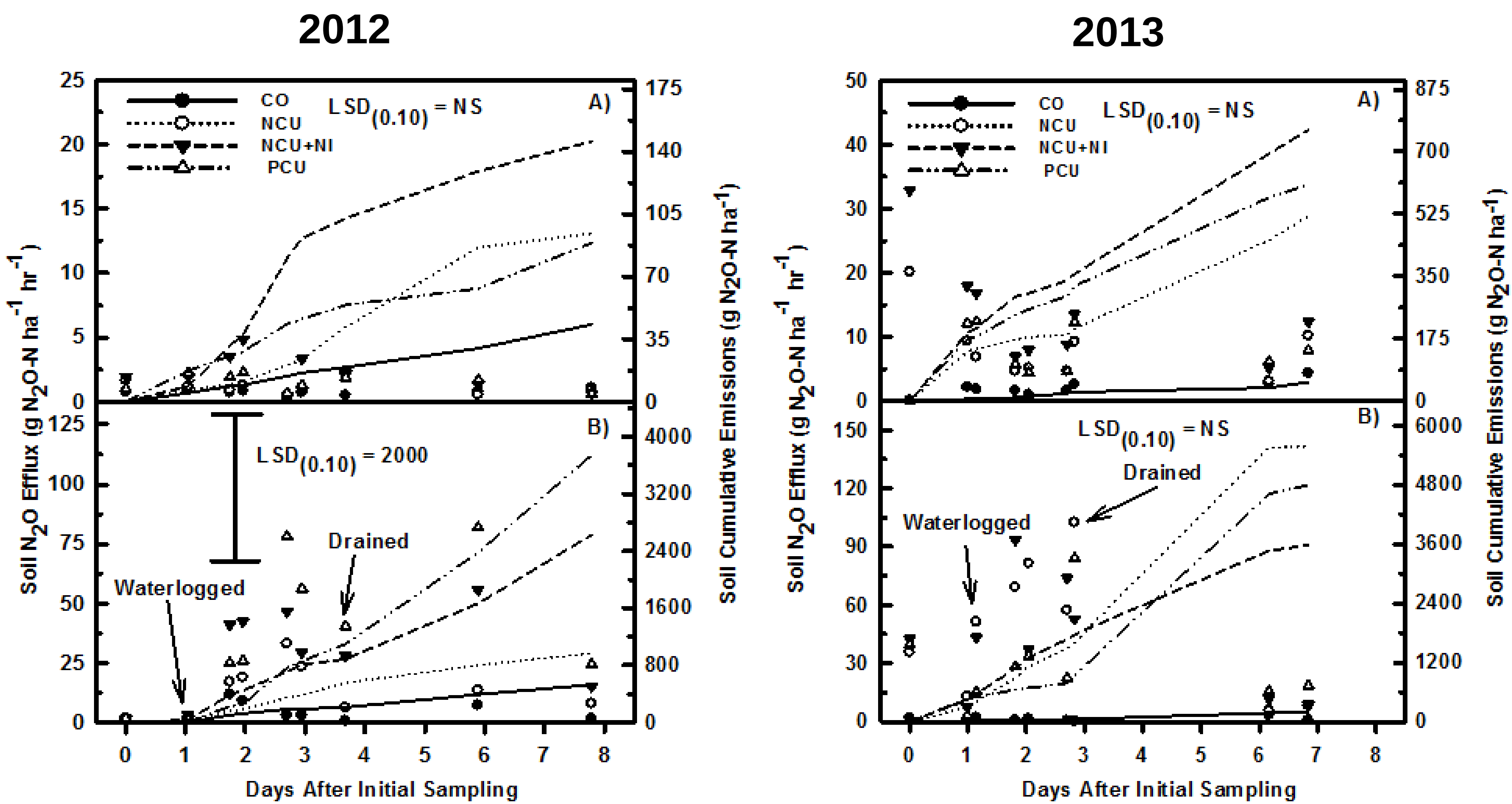

Figure 11. Soil nitrous oxide gas efflux and cumulative nitrous oxide emissions for each pre-plant N treatment in the non- flooded (A) and flooded treatment(B) in 2012 and 2013 (Abbreviations: CO, Control; NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea; LSD, least significant difference at $P < 0.10$ comparing cumulative gas emissions among pre-plant N treatments). Note scale change between both figures.

AMMONIA VOLATILIZATION FROM SURFACE APPLICATIONS OF UREA: Greenhouse study 2013

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University of Missouri-Fisher Delta Research Center
Portageville, MO

A series of ammonia volatilization experiments were conducted in 2013 at the University of Missouri-Fisher Delta Center, Portageville, MO. These experiments investigate the environmental conditions that control the rate of ammonia volitization for surface applied urea. The first experiment (EXP 1) was designed to determine the effect of soil moisture on ammonia volatilization from surface applied urea. The second experiment (EXP2) was designed to compare urea coated with nitrogen stabilization additives to uncoated urea and an untreated check. Both of these experiments were conducted indoors in a green house. For both experiments volitization chambers were established. Each chamber consisted of a 20 qt Sterilite clear plastic container with a removable, sealable lid (Figure 1). This container measured 16.5 X 11.5 X 9.75 inches. Into each container 1 gallon of soil (Bosket loamy sand, ph 5.7) was placed. Volatilization data was collected from each chamber during the experiment by the following method. Following urea application, an ammonia trap was constructed for each chamber. This trap consisted of a 2 dram plastic vial filled with 50 ml of 0.1M H_2SO_4 + H_2O solution. In this procedure the specific location of the trap within each chamber was selected randomly by dropping the top of each vial on to the chamber. At this point the 2 dram vial with H_2SO_4 solution was placed on the soil surface. The lid was then placed over the chamber and sealed in place. After establishment ammonia was collected for 48 hours. At this point the chamber was opened, the vial removed, capped and transported to the lab. A fresh 2 dram vial with H_2SO_4 solution was then placed on the soil surface and the chamber was the resealed until the next sampling period was scheduled to begin. After collection of the vials the liquid in each vial was analyzed for NH_4 content using the phenol-nitroprusside colorimetric method. This methodology allows for comparisons between the relative amounts of volatilization experienced by each fertilizer treatment. It does not allow for a calculation of the % of N lost to volatilization. This was the general set up for both experiments. The specific treatment details of each are discussed below.

EXP 1 A list of treatments used in EXP 1 is given in Table 1. This experiment compared ammonia volitization from surface applied urea with either dry or "field capacity" soil moisture conditions. Before the soil was placed in to the cambers it was dried to 0% moisture in a 40^{o}C soil drying oven. Field capacity treatment chambers were produced by adding 1 liter of distilled water. These chambers were sealed and allowed to sit for three days so the introduced water could become uniformly distributed. To quantify the effects of rainfall events following urea applications 3 different volumes of water representing rainfall events of 0.1, 0.25, 0.50 inches were added to the chambers by uniformly pouring water through a watering can. Urea at the rate of 50 lbs-N/acre was applied to all chambers except the untreated checks. Simulated rain fall was administered to the appropriate chambers. An acid trap was placed in each chamber then each camber was sealed until the traps were changed out. In this way data was collected at 1, 3, 7, 9, 12, 14, 16, and 21 days after treatment (DAT). The traps were then analyzed for ammonia content using the method described above. The data collected for EXP 1 is presented in Table 1.

Table 1. Acid trap recovery of volatized from surface applied urea in ppm NH4-N for soil moisture and simulated rainfall treatments.

		Acid trap recovery of NH4 given in ppm NH4-N								
Trt	Treatment	1 DAT	3 DAT	7 DAT	9 DAT	12 DAT	14 DAT	16 DAT	21 DAT	Cumulative
1	Dry check	0.6 d	1.3 c	1.3 de	0.8 b	1.8 a	1.0 a	1.0 a	0.9 a	8.9 e
2	Dry 50 lb urea	2.2 d	1.8 c	2.7 cde	2.7 ab	4.4 a	1.6 a	2.6 a	2.5 a	21.3 d
3	Dry 50 lbs urea + 0.1 H2O	38.9 a	18.8 a	12.1 bc	4.5 ab	4.4 a	1.4 a	6.0 a	1.6 a	86.2 ab
4	Dry 50 lbs urea + 0.25 H2O	13.3 bc	8.2 b	5.5 bcd	2.5ab	2.1 a	1.8 a	1.3 a	1.2 a	36.9 cd
5	Dry 50 lbs urea + 0.50 H2O	5.5 c	5.1 b	6.2 bcd	1.8 ab	1.7 a	1.2 a	1.0 a	0.9 a	24.5d
6	Wet check	0.7 d	1.2 c	0.5 e	1.8 ab	2.5 a	1.1 a	1.1 a	1.1 a	11.1 e
7	Wet 50 lb urea	11.7 bc	22.4 a	14.4 b	2.1 ab	1.9 a	1.6 a	3.9 a	0.9 a	63.5 abc
8	Wet 50 lbs urea + 0.1 H2O	16.3 b	16.9 a	10.5 bc	1.6 b	2.4 a	1.8 a	1.1 a	1.1 a	54.1 bc
9	Wet 50 lbs urea + 0.25 H2O	11.3 bc	26.3 a	55.0 a	10.9 a	7.0 a	2.1 a	1.2 a	2.3 a	123.4 a
10	Wet 50 lbs urea + 0.50 H2O	12.7 bc	26.9 a	57.4 a	11.3 a	10.0 a	2.3 a	2.9 a	2.3 a	132.1 a
LSD (P=.05)		0.253	0.255	0.406	0.404	6.808	0.287	4.158	1.882	0.260
CV		19.2	18.1	28.96	45.91	122.98	48.34	130.3	89.32	11.11

Means followed by the same letter do not differ significantly at the alpha= 0.05 level

Results from this experiment show the effect of soil moisture on ammonia loss from surface applied urea. Cumulative volatilization from the wet soil was 3X that dry soil. There was also a difference between wet and dry soil in the volitization following simulated rainfall events. For the dry soil the addition of 0.1 inches of water clearly increased the amount of volitization. This amount was not sufficient to move the urea below the soil surface. Instead the applied water served to allow volitization to proceed at an accelerated rate. The addition of 0.5 inches served to move the urea below the soil surface and effectively stop the volitization process. The 0.25 inch event was sufficient to move the majority of urea below the soil surface. In contrast the when rainfall was simulated to wet soil only the 0.1 inch treatment numerically lowered measured volitization. The results from the three rainfall amounts were statistically equivalent to the wet soil with no rainfall added. In these cases the soil water did not allow for movement of urea below the soil surface. Remaining on the surface the urea was subject to high rates of volitization.

EXP 2 A list of treatments used in EXP 2 is given in Tables 2 and 3. This experiment compared ammonia volitization from surface applied urea coated five with commercially available nitrogen stabilization products. These products were: Agrotain; Kock Industries, Factor, Rosens Inc.; NFixx, The Helena Chemical Company; Nutrisphere-N, Specialty Fertilizer Products; and Nutrisphere-N QDO, Specialty Fertilizer Products. Three of these products, Agrotain, Factor and NFixx, contain NBPT. They differ in NBPT content and formulation. Two of these products, Nutrisphere-N and Nutrisphere-N QDO, contain a maleic-itaconic copolymer. This experiment was conducted two times, once in the early spring with low ambient temperatures and again in the fall at higher temperature conditions. The data collected for EXP 2 is presented in Tables 2, 3, and 4.

Table 2. Acid trap recovery of volatized from surface applied urea in ppm NH4-N for urea coated with nitrogen stabilization products. Data collected in cold temperature conditions.

	Acid trap recovery of NH4 given in ppm NH4-N							
Treatment	2 DAT	4 DAT	7 DAT	9 DAT	14 DAT	16 DAT	18 DAT	21 DAT
untreated check	0.6 c	0.6 c	0.8 d	0.8 e	0.8 d	0.5 d	0.5 c	0.4 c
5o lb urea	4.6 a	5.1 a	13.5 a	11.0 a	12.1 a	11.0 a	10.9 a	6.8 a
50 lbs urea + Agrotain 3 qt	2.2 b	0.6 c	1.7 cd	2.8 d	3.7 b	3.1 bc	3.4 b	6.2 a
50 lbs urea + Factor 3 qt	2.0 b	0.5 c	1.6 cd	2.9 d	4.0 b	3.5 b	3.6 b	6.0 a
50 lbs urea + NFixx 3 qt	2.1 b	0.53	2.1 c	3.9 c	4.4 b	3.5 b	3.7 b	5.8 a
50 lbs urea + Nutrisphere-N 2qt	2.6 b	0.5 c	10.2 ab	3.5 cd	2.4 c	2.7 c	3.0 b	3.9 b
50 lbs urea + Nutrisphere-N QDO 2qt	2.6 b	4.8 a	10.6 a	4.7 b	2.6 c	2.9 bc	3.1 b	3.5 b
LSD (0.05)	0.486	0.666	0.845	0.0718	0.082	0.05	0.063	1.446
CV	13.77	20.13	10.92	7.38	8.83	5.55	6.83	8.32

Means followed by the same letter do not differ significantly at the alpha= 0.05 level

Table 3. Acid trap recovery of volatized from surface applied urea in ppm NH4-N for urea coated with nitrogen stabilization products. Data collected in warm temperature conditions.

	Acid trap recovery of NH4 given in ppm NH4-N							
Treatment	2 DAT	4 DAT	7 DAT	9 DAT	14 DAT	16 DAT	18 DAT	21 DAT
untreated check	0.4 d	0.4 d	0.5 b	0.8 d	0.6 c	0.6 c	0.3 d	0.7 c
50 lb urea	3.2 a	4.2 a	31.1 a	21.5 a	1.6 bc	2.5 a	1.9 a	2.3 a
50 lbs urea + Agrotain 3 qt	0.7 cd	1.7 bc	2.2 b	1.0 d	1.3 bc	1.0 bc	0.4 d	1.2 b
50 lbs urea + Factor 3 qt	1.0 bcd	2.1 bc	2.6 b	1.6 cd	1.4 bc	1.0 bc	0.8 cd	1.3 b
50 lbs urea + NFixx 3 qt	0.6 d	1.6 c	2.5 b	2.0 cd	1.0 bc	1.1 bc	0.6 cd	1.1 b
50 lbs urea + Nutrisphere-N 2qt	1.6 bc	2.7 b	11.9 a	3.1 bc	1.7 ab	1.6 ab	0.6 cd	1.5 b
50 lbs urea + Nutrisphere-N QDO 2qt	1.7 bc	2.8 b	14.9 a	5.5 b	3.1 a	1.9 ab	1.0 bc	1.2 b
LSD (0.05)	2.14	0.823	4.972	0.215t	0.143	0.109	0.111	1.077
CV	22.62	25.01	49.12	25.27	24.46	20.28	30.15	10.98

Means followed by the same letter do not differ significantly at the alpha= 0.05 level

All products tested in this evaluation offered some degree of protection against volitization. These results indicate the nitrogen stabilization products that contain NPBT (Agrotain, NFixx, Factor) offer better volitization protection than those that do not (Nutrisphere-N, Nutrisphere-N QDO).

Table 4. Cumulative acid trap recovery of volatized from surface applied urea in ppm NH4-N for urea coated with nitrogen stabilization products. Data collected in both cool warm temperature conditions.

	Cumulative acid trap recovery of NH4 given in ppm NH4-N					
	Cool temperature			Warm temperature		
Treatment	7 Day	14 Day	21 Day	7 Day	14 Day	21 Day
untreated check	1.9 d	3.4 e	4.7 d	1.4 c	2.7 d	4.3 d
5o lb urea	22.6 a	45.8 a	74.9 a	38.6 a	59.9 a	67.0 a
50 lbs urea + Agrotain 3 qt	4.3 c	10.8 d	23.5 c	4.6 bc	6.9 c	9.5 c
50 lbs urea + Factor 3 qt	4.0 c	10.9 d	23.9 c	5.8 bc	8.7 c	11.9 c
50 lbs urea + NFixx 3 qt	4.7 c	13.0 c	25.9 c	4.6 bc	7.7 c	10.7 c
50 lbs urea + Nutrisphere-N 2qt	16.6 b	22.5 b	32.2 b	16.4 b	20.6 b	24.4 b
50 lbs urea + Nutrisphere-N QDO 2qt	17.9 b	25.2 b	34.7 b	19.5 b	27.3 b	31.6 b
LSD (0.05)	0.083	0.06	0.042	9.843	0.167	0.1462
CV	5.82	3.32	2.01	51.92	9.77	7.87

Means followed by the same letter do not differ significantly at the alpha= 0.05 level

As the cumulative 21 day volatization results are approximately the same for both the cool and warm temperatures these results indicate that volitization may be a problem for both environmental conditions. When the rates of volitization are evidenced for the 7, 14, and 21 day cumulative results are compared in cool conditions approximately 1/3 of the total volitization occurred in each 7 day period. While in warm more than ½ occurred during the first 7 day period and very little occurred in the last 7 day period. This indicates that it is more critical to address volitization issues that might occur in the first week following surface urea applications during warm weather.

Conclusions:

- Urea surface applied to wet soil is vulnerable to aggressive ammonia volitization, dry soil conditions limit this effect.
- It takes a rainfall event of 0.25 inches or greater to move urea below the soil surface on dry soils. For wet soils rainfall in any amount may not move urea sufficiently to limit ammonia volitization.
- Ammonia volitization will occur in both cool and warm soil conditions. The rate that this proceeds is greater in warm soils.


Figure 1. Chamber used for measuring ammonia volatilization with 2 dram vial serving as acid trap, note granular urea on soil surface

Phosphorus Management

Progress Report
2012

(Reports received after publication of last Soil Fertility Update)

Managing phosphorus, manganese and glyphosate interactions to increase soybean yields

Felix B. Fritschi and James H. Houx III, Univ. of Missouri

Objectives and Relevance to the Missouri Fertilizer and Lime Industry

The overall objective of this project is to examine the two- and three-way interactions of P, Mn, and glyphosate in response to fertilizer treatments and herbicide regimes.

1) To determine if pop-up P applications will improve early season growth, soybean yield, and seed quality.
2) To determine if Mn fertilization will increase soybean yield and seed quality.
3) To examine if P and Mn fertilization individually or in concert increase yields of glyphosate and glufosinate tolerant soybeans.

A large number of soils in Missouri are low in plant available P (Bray-I P). It is well established that yields of P-deficient soybeans are reduced and that these soybeans have reduced N fixation rates. Low P can reduce the growth of the soybean plant *per se*, the growth and function of the nodules, and the growth of both the plant and the nodule (Israel, 1987; Israel, 1993; Sa and Israel, 1991; Almeida et al., 2000). Because P deficiency can strongly reduce yields, soil-test guided P fertilization recommendations have been developed and are commonly used by US farmers. However, because of its low mobility, P deficiencies can occur early in the season, even in soils with adequate soil-test P levels particularly when soil temperatures are cool and root growth is slow. Therefore, starter or pop-up fertilizers often contain P in an attempt to stimulate early growth. Glyphosate tolerant soybeans are an amazingly important contribution to our soybean industry. However, when concerned about production of glyphosate tolerant soybeans, the question is whether or not P fertilization can stimulate Mn uptake to overcome the Mn interaction with glyphosate. We suggest that, for maximum soybean yields, a combination of Mn treatments and P fertilization may be required. This project will provide information on the impact of pop-up P, supplemental Mn, and their interactions on soybean yield responses and seed composition.

2012 ACCOMPLISHMENTS:

- This year was the first year for the project evaluating application of starter or pop-up P fertilizer with and without Mn in order to stimulate early-season plant growth and improve yields.

- The following treatments were applied to MorSoy RT3930N RoundUp Ready and MorSoy LL3939N LibertyLink soybean. Each variety treated with and without its respective herbicide. Soybean were planted in 8-row, 32 feet long plots on a 15 inch row spacing. The following treatments were applied in 4 replications.

1) Pop-up P
2) Pop-up P and 3 lb Mn
3) Pop-up P and 7 lb Mn
4) 3 lb Mn
5) 7 lb Mn
6) Control (Nothing Applied)

2012 PRELIMINARY RESULTS:
NOTE: Results are from one field season and are considered preliminary

- Even though Missouri experienced a severe drought and above average temperatures this summer yields of this project remained above the average soybean yield at the Bradford Research Station near Columbia, Missouri (Fig 1,2,3,4).

- Pop-up P plus 3 lb Mn (P<0.01), Pop-up P plus 7 lb Mn (P<0.05,) and 3 lb Mn (P<0.01) increased yields when glyphosate was applied compared to the control and the 7 lb per acre Mn treatment (Fig. 1).

- When glyphosate was not applied to the RoundUp Ready variety, Pop-Up P plus 7 lb Mn increased yield compared to having no starter fertilizer and in-furrow 7 lb Mn treatment at P<0.10 (Fig. 2).

- No significant differences in yield were observed for the Liberty Link variety in either of the two herbicide treatments (Fig. 3 and Fig 4.).

- Across all varieties untreated or treated with respective herbicide, Pop-Up P and 7 lb Mn increased yields compared to both starter fertilizer treatments consisting of just Mn (3 lb and 7 lb Mn) and the control at P<0.10 (data not shown).

- Seed and plant samples are currently being processed for evaluation of seed quality and plant tissue micronutrient concentrations.

Figure 3. Liberty Link with Glufosinate Applied Treatment Yields

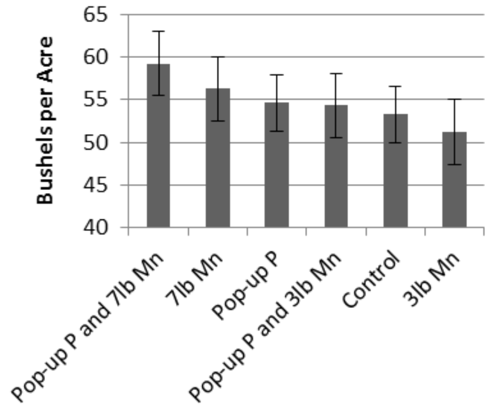


Figure 4. Untreated Liberty Link Yields

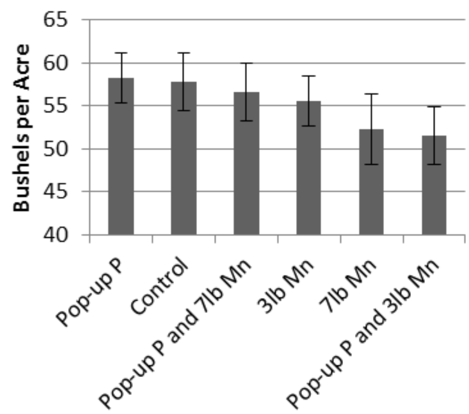
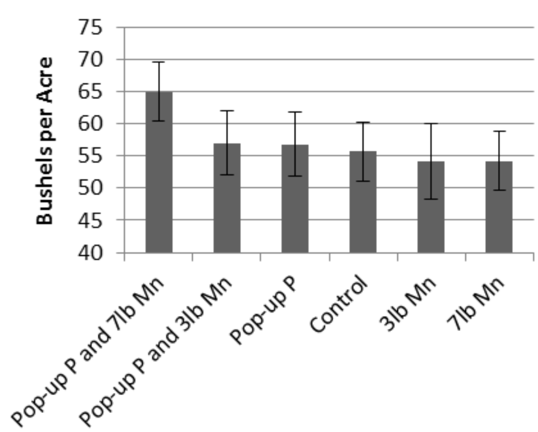


Figure 2. RoundUp Ready without Glyphosate Applied Treatment Yields



OBJECTIVES FOR YEAR 2:

In years two and three we will repeat the experiment as originally proposed. Further, we will plant the same or similar soybean varieties in a similar experimental design and measure plant growth at every growth stage. We will finish tissue nutrient and seed quality analyses from the 2012 season in year two. Preliminary results of this research will be presented at the 2013 ASA-CSSA-SSSA annual international meeting in October 2013.

PROPOSED BUDGET

Category	**Year 2**
Personnel	
PhD Student	$19,570
Undergraduate help	$3,200
Field cost (fertilizers, herbicide, bags, etc.)	$2,500
Tissue and seed analyses (ICP, NIR, ureide)	$3,200
Travel	$1,500
Total	**$29,970**

Yield response to P & K fertilizers over landscapes

Peter Scharf, Kent Shannon, and Vicky Hubbard
University of Missouri, Plant Sciences Division and MU Extension

Objective:
The objective of this project is to measure grain crop yield response to P and K over landscapes and identify factors that favor response. Soil tests are currently used as nearly the only tool to predict response, but we know that many other factors are involved.

Accomplishments for 2012:

- We set up five on-farm, field-scale P and K response tests with producers for 2012
  - All five tests were in northwest Missouri, the only quadrant of the state where we had not previously completed one of these tests.
    - Corn yield response to P was measured in 4 of the fields
    - Soybean yield response to K was measured in the fifth field.
  - Yields were low in all corn fields due to drought stress. Soybean yields were moderate due to late-season rains breaking the drought.
  - Analyses presented in this report are preliminary. Yield data were received starting 2.5 weeks before this report was due, and analyses are not yet completed.
    - Additional analyses of these tests will be completed during the winter.
    - Although 2012 is technically the last year for this project, another report will be submitted in 2013 to report on the full analyses.

- Additional funding has been obtained from the USDA-NRCS Conservation Innovation Grants program to continue this project. Seven producers have been recruited to cooperate in doing additional tests in 2013–four in northeast Missouri, two in west-central Missouri, and one in northwest Missouri.

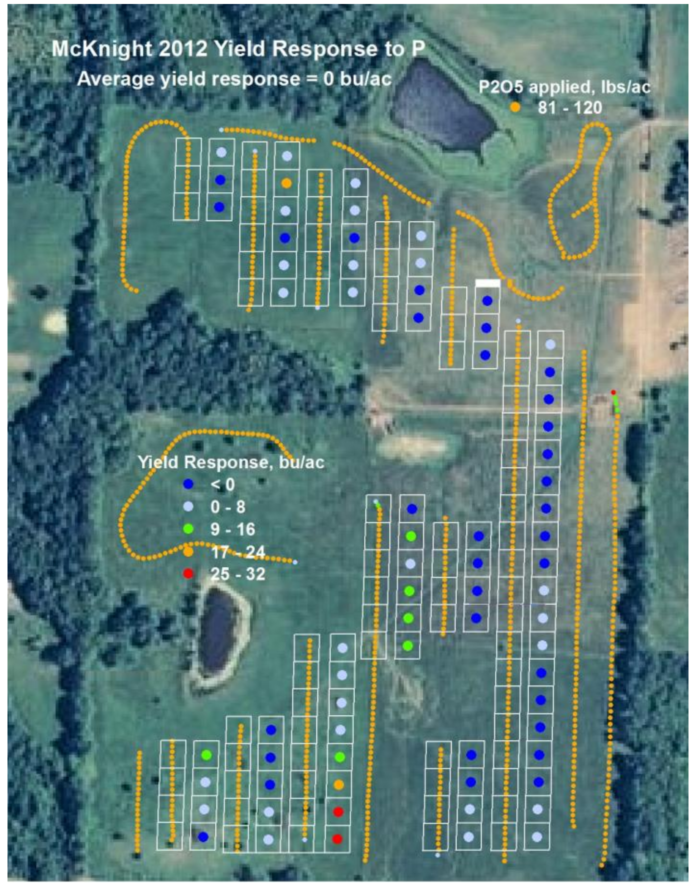
- Locations of field-scale P and K response tests to date are shown on the map to the right.

Corn field 1 (P)

- Average corn yield response to P in this field was 0.
- Average yield in the test areas of this field was 54 bushels/acre.
  - Drought severely limited yield in this field and in all corn fields.
  - Low yields may have limited the potential for yield response to P.
  - However, dry soil conditions are known to inhibit P diffusion and uptake, which

could result in greater P response during dry conditions than under ideal moisture.

- Yields with and without P fertilizer were compared on 12 pairs of side-by-side strips, as shown at right.
- In the strips receiving P, a variable-rate application was made with P rate ranging from 80 to 120 pounds of P_2O_5/acre.
- There were two parts of the field (central & south-central) where areas with apparent response to P were clustered. This suggests the possibility that there was a true yield response to P in these areas. We will further investigate whether this is correlated to landscape features.
- Yield response to P was not related to yield level in this field, although yields varied widely due to differences in water availability during the drought.



Corn field 2 (P)

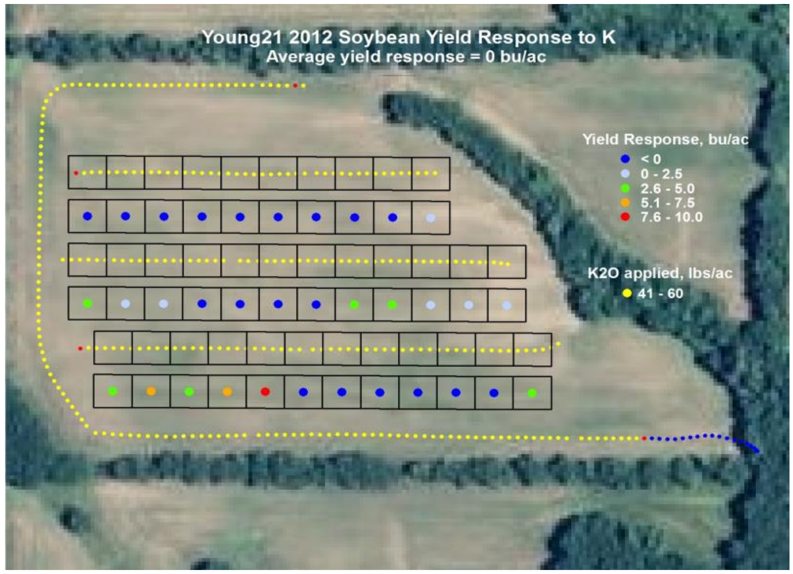
- Average corn yield response to P in this field was 2 bushels/acre.
- Average yield in this field was 56 bushels/acre.
- Yields with and without P fertilizer were compared on 7 pairs of side-by-side strips.
- In the strips receiving P, a variable-rate application was made with P rate ranging from 80 to 120 pounds of P_2O_5/acre.
- There were three areas of the field with apparent clusters of positive yield response to P. This suggests the possibility that there was a true yield response to P in these areas. We will further investigate whether this is correlated to landscape features.
- Yield response to P was not related to yield level in this field.

Corn field 3 (P)

- Average corn yield response to P in this field was 0 bushels/acre.
- Average yield in this field was 67 bushels/acre.
- Yields with and without P fertilizer were compared on 3 pairs of side-by-side strips.
- In the strips receiving P, a variable-rate application was made with P rate ranging from 80 to 120 pounds of P_2O_5/acre.
- Yield response to P was not related to yield level in this field.

Corn field 4 (P)

- Average corn yield response to P in this field was 5 bushels/acre.
- Average yield in this field was 42 bushels/acre.
- Yields were compared between 1 strip without P fertilizer and yields with P fertilizer in two adjacent strips, one on either side.
- In the strips receiving P, a variable-rate application was made with P rate ranging from 20 to 110 pounds of P_2O_5/acre.



Soybean field 5 (K)

- Average soybean yield response to K in this field was 0 bushels/acre.
- Average yield in this field was 35 bushels/acre.
- Yields with and without K fertilizer were compared on 3 pairs of side-by-side strips.
- In the strips receiving K, a variable-rate application was made with K rate ranging from 40 to 60 pounds of K_2O/acre.
- In the southwest part of the field, apparent responses to P were clustered. This suggests the possibility that there was a true yield response to P in these areas. We will further investigate whether this is correlated to landscape features.

SUMMARY

- Yield response to P and K in five fields in northwest Missouri in 2012 was minimal, with field-average response ranging from 0 to 5 bushels per acre.
- Low yield level resulting from drought, especially for the corn, may have contributed to low P and K responses.
- Little evidence was seen that yield response to P or K was greater in higher-yielding parts of the field.
- Additional analyses of spatial patterns of yield response will be conducted to see how soil test levels and landscape variables were related to yield response.

Conclusions from previous years:

- Yield response to P and K was concentrated in one or two soils in each field that we have analyzed.
- There is a tendency for the most responsive soil to also be:
  - The highest yielding soil
  - The best-drained soil
- Soil test values had no relationship to yield response to P and K in 2 of the 3 fields that we have completed our analyses on.

- In the third field, soil test values for both P and K were low, and yield responses were seen in areas with soil test P below 5 ppm or soil test K below 80 ppm. No yield response was seen in this field with soil test P of 5 ppm or greater, or soil test K of 80 ppm or greater.
- Strip trials to measure yield response to P and K are a practical and fairly simple way for producers to better understand how to optimize P and K management on their own farm.

2013

Managing phosphorus, manganese and glyphosate interactions to increase soybean yields

Felix B. Fritschi and James H. Houx III, Univ. of Missouri

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The overall objective of this project is to examine the two- and three-way interactions of P, Mn, and glyphosate in response to fertilizer treatments and herbicide regimes.

4) To determine if pop-up P applications will improve early season growth, soybean yield, and seed quality.
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Glyphosate tolerant soybeans are an amazingly important contribution to our soybean industry. However, when concerned about production of glyphosate tolerant soybeans, the question is whether or not P fertilization can stimulate Mn uptake to overcome the Mn interaction with glyphosate. We suggest that, for maximum soybean yields, a combination of Mn treatments and P fertilization may be required. This project will provide information on the impact of pop-up P, supplemental Mn, and their interactions on soybean yield responses and seed composition.

2013 ACCOMPLISHMENTS:

- This year was the second year for the project evaluating application of starter or pop-up P fertilizer containing Mn in order to stimulate plant growth and possibly overcome the Mn and glyphosate interaction resulting in increased yields.

- To assess the effect of herbicide interactions with starter or pop-up P fertilizer containing Mn applications the following herbicide x soybean treatments were imposed.
  1) RR soybean with glyphosate applications
  2) RR soybean without glyphosate applications
  3) LL soybean with glufosinate applications
  4) LL soybean without glufosinate applications

- The following treatments were applied to MorSoy RT3930N RoundUp Ready and MorSoy LL3939N LibertyLink soybean planted in 8-row, 15” row spacing, 32’ long plots that were replicated four times. All treatments are on a per acre basis.

7) Pop-up P
8) Pop-up P and 3 lb Mn
9) Pop-up P and 7 lb Mn
10) 3 lb Mn
11) 7 lb Mn
12) Control (Nothing Applied)

2012-2013 RESULTS:

- Even though Missouri experienced a severe drought and above average temperatures in 2012, yields of this project remained above the average soybean yield at the Bradford Research Station near Columbia, Missouri. (Table 1,2,3)

Yield (Table 1)

- Analysis of mean yield revealed no differences in yield between in-furrow treatments and the untreated control (Table 1).
- Spray treatments, spray or no-spray of respective herbicide, also showed no difference in yield.
- There was no difference in yield between glyphosate and glufosinate resistant soybeans.
- There was however, a difference in yield between 2012 and 2013 (P<0.001), with 2012 having the highest yield of 52.66 bu/ac (data not shown).

Table 1. Mean yield of MorSoy soybean varieties across two years (2012, 2013) following treatment with six in-furrow treatments sprayed with and without respective herbicide (Glufosinate or Glyphosate) at the Bradford Research Center.

	MorSoy RT3930N (Glyphosate tolerant)		**MorSoy LL3939N (Glufosinate tolerant)**	
In-Furrow Treatment	**Sprayed**	**No-sprayed**	**Sprayed**	**No-sprayed**
	----------------------------- bu/ac -----------------------------			
1) Pop-up P	48.10	46.95	48.34	47.73
2) Pop-up P and 3 lb Mn	52.66	48.54	45.81	45.43
3) Pop-up P and 7 lb Mn	47.33	54.84	46.21	46.48
4) 3 lb Mn	51.05	54.67	44.62	47.72
5) 7 lb Mn	47.87	49.56	45.06	40.86
6) Control	47.49	49.02	46.49	44.90
Statistical significance (Pr>0.05)	ns[†]	ns	ns	ns
Mean	49.08A[†]	50.00A	46.09A	45.52A

[†] ns = means within a column are not significantly different. Means within the same row followed by the same uppercase letter are not significantly different a P=0.05.

Seed Oil Concentration (Table 2)

- NIR spectroscopy was used to determine percent oil on a dry matter basis.
- Analysis of variance of the mean percent oil from 2012 and 2013 indicated there was no effect of in-furrow treatment on oil concentration in the seed at *($P<0.05$)*.
- There was a difference between years for seed oil concentration (P<0.0001), with 2012 having 20.86%.
- Analysis of mean oil also revealed a difference between varieties for oil concentration at (P<0.05) (table 2).

Table 2. Mean seed oil concentration (as percent) of MorSoy soybean varieties across two years (2012, 2013) following treatment with six in-furrow treatments sprayed with and without respective herbicide (Glufosinate or Glyphosate) at the Bradford Research Center.

	MorSoy RT3930N (Glyphosate tolerant)		**MorSoy LL3939N (Glufosinate tolerant)**	
In-Furrow Treatment	**Sprayed**	**No-sprayed**	**Sprayed**	**No-sprayed**
	------------------------------ % ------------------------------			
1) Pop-up P	20.61	20.49	19.82	20.16
2) Pop-up P and 3 lb Mn	20.51	20.15	19.98	20.32
3) Pop-up P and 7 lb Mn	20.53	20.54	19.74	19.87
4) 3 lb Mn	20.56	20.36	19.98	20.11
5) 7 lb Mn	20.32	20.87	19.95	19.79
6) Control	20.48	20.68	20.00	20.34
Statistical significance (Pr>0.05)	ns†	ns	ns	ns
Mean	20.50A†	20.52A	19.91B	20.10B

† ns = means within a column are not significantly different. Means within the same row followed by the same uppercase letter are not significantly different a P=0.05.

Seed Protein Concentration (Table 3)

- Seed protein concentration was also determined my NIR spectroscopy.
- Seed protein differed between years *($P<0.001$)*, with 2013 having the highest amount of protein at 42.28 (data not shown).
- In-furrow treatment did not influence seed protein concentration *($P>0.5719$)*.
- There was a difference between varieties for seed protein concentration at (P<0.05) with MorSoy LL3939N having more protein than MorSoy RT3930N.

Table 3. Mean seed protein concentration (as percent) of MorSoy soybean varieties across three years (2012, 2013) following treatment with six in-furrow treatments sprayed with and without respective herbicide (Glufosinate or Glyphosate) at the Bradford Research Center.

	MorSoy RT3930N (Glyphosate tolerant)		**MorSoy LL3939N (Glufosinate tolerant)**	
In-Furrow Treatment	**Sprayed**	**No-sprayed**	**Sprayed**	**No-sprayed**
	----------------------------	%	----------------------------	
1) Pop-up P	40.42	40.91	41.84	42.05
2) Pop-up P and 3 lb Mn	40.64	41.23	41.98	41.62
3) Pop-up P and 7 lb Mn	40.65	40.78	42.34	42.09
4) 3 lb Mn	40.88	41.28	41.78	41.87
5) 7 lb Mn	41.23	40.47	41.95	42.54
6) Control	40.99	40.78	41.88	41.58
Statistical significance (Pr>0.05)	ns†	ns	ns	ns
Mean	40.80B†	40.91B	41.96A	41.96A

† ns = means within a column are not significantly different. Means within the same row followed by the same uppercase letter are not significantly different a P=0.05.

OBJECTIVES FOR YEAR 3:

In year three we will repeat the experiment as originally proposed. Further, we will plant the same or similar soybean varieties in a similar experimental design and measure plant growth at every growth stage. We will finish tissue nutrient and seed quality analyses from the 2013 season and continue with sampling protocol of harvest yield at the end of the season. We intend to present preliminary results of this research at the 2014 ASA-CSSA-SSSA annual international meeting in October 2014.

Proposed Budget for 2014

Category	**Year 3**
Personnel	
PhD Student	$20,157
Undergraduate help	$3,200
Field cost (fertilizers, herbicide, bags, etc.)	$2,500
Tissue and seed analyses (ICP, NIR, ureide)	$3,200
Travel	$1,500
Total	**$30,557**

2014

Managing phosphorus, manganese and glyphosate interactions to increase soybean yields

Felix B. Fritschi and James H. Houx III, Univ. of Missouri

Objectives and Relevance to the Missouri Fertilizer and Lime Industry

The overall objective of this project is to examine the two- and three-way interactions of P, Mn, and glyphosate in response to fertilizer treatments and herbicide regimes.

7) To determine if pop-up P applications will improve early season growth, soybean yield, and seed quality.
8) To determine if Mn fertilization will increase soybean yield and seed quality.
9) To examine if P and Mn fertilization individually or in concert increase yields of glyphosate and glufosinate tolerant soybeans.

A large number of soils in Missouri are low in plant available P (Bray I P). It is well established that yields of P-deficient soybeans are reduced and that these soybeans have reduced N fixation rates. Low P can reduce the growth of the soybean plant *per se*, the growth and function of the nodules, and the growth of both the plant and the nodule (Israel, 1987; Israel, 1993; Sa and Israel, 1991; Almeida et al., 2000). Because P deficiency can strongly reduce yields, soil-test guided P fertilization recommendations have been developed and are commonly used by US farmers. However, because of its low mobility, P deficiencies can occur early in the season, even in soils with adequate soil-test P levels particularly when soil temperatures are cool and root growth is slow. Therefore, starter or pop-up fertilizers often contain P in an attempt to stimulate early growth. Glyphosate tolerant soybeans are an amazingly important contribution to our soybean industry. However, when concerned about production of glyphosate tolerant soybeans, the question is whether or not P fertilization can stimulate Mn uptake to overcome the Mn interaction with glyphosate. We suggest that, for maximum soybean yields, a combination of Mn treatments and P fertilization may be required. This project will provide information on the impact of pop-up P, supplemental Mn, and their interactions on soybean yield responses and seed composition.

RESULTS:

- Analyses for 2012 and 2013 experiments have been completed. Statistical and compositional analyses from the 2014 season are ongoing and not finalized yet.
- Even though Missouri experienced a severe drought and above average temperatures in 2012, yields of this project remained above the average soybean yield at the Bradford Research Station near Columbia, Missouri.
- Conditions in 2014 resulted in greater yields than in 2012 and 2013. The impact on seed oil and protein are yet to be determined.

Yield (Tables 1 and 2)

- Analysis of mean yield revealed no differences in yield between in-furrow treatments and the untreated control in years one and two (Table 1)
- Spray treatments, spray or no-spray of respective herbicide, also showed no difference in yield in the first two years. Analyses are underway for year 3 (Table 2).
- There was no difference in yield between glyphosate and glufosinate resistant soybeans.

- Yields among the three years compared as follows: 2014 > 2012 >2013

Table 1. Mean yield of MorSoy soybean varieties across two years (2012, 2013) following treatment with six in-furrow treatments sprayed with and without respective herbicide (Glufosinate or Glyphosate) at the Bradford Research Center.

	MorSoy RT3930N (Glyphosate tolerant)		**MorSoy LL3939N (Glufosinate tolerant)**	
In-Furrow Treatment	**Sprayed**	**No-sprayed**	**Sprayed**	**No-sprayed**
	----------------------------- bu/ac -----------------------------			
1) Pop-up P	48.10	46.95	48.34	47.73
2) Pop-up P and 3 lb Mn	52.66	48.54	45.81	45.43
3) Pop-up P and 7 lb Mn	47.33	54.84	46.21	46.48
4) 3 lb Mn	51.05	54.67	44.62	47.72
5) 7 lb Mn	47.87	49.56	45.06	40.86
6) Control	47.49	49.02	46.49	44.90
Statistical significance (Pr>0.05)	ns[†]	ns	ns	ns
Mean	49.08A[†]	50.00A	46.09A	45.52A

[†] ns = means within a column are not significantly different. Means within the same row followed by the same uppercase letter are not significantly different a P=0.05.

Table 2. Mean yield of MorSoy soybean varieties for 2014 following treatment with six in-furrow treatments sprayed with and without respective herbicide (Glufosinate or Glyphosate) at the Bradford Research Center.

	MorSoy RT3930N (Glyphosate tolerant)		**MorSoy LL3939N (Glufosinate tolerant)**	
In-Furrow Treatment	**Sprayed**	**No-sprayed**	**Sprayed**	**No-sprayed**
	----------------------------- bu/ac -----------------------------			
1) Pop-up P	70.55	58.38	62.47	62.67
2) Pop-up P and 3 lb Mn	61.30	59.12	71.76	64.66
3) Pop-up P and 7 lb Mn	64.26	64.76	63.80	60.78
4) 3 lb Mn	62.77	67.79	61.65	62.32
5) 7 lb Mn	62.73	66.14	71.13	61.41
6) Control	60.95	53.68	61.62	63.64

Seed Oil Concentration (Table 3)

- Compositional analyses from the 2014 season are not finalized yet (data not shown)
- NIR spectroscopy was used to determine percent oil on a dry matter basis.
- Analysis of variance of the mean percent oil from 2012 and 2013 indicated there was no effect of in-furrow treatment on oil concentration in the seed at ($P<0.05$).
- There was a difference between years for seed oil concentration (P<0.0001), with 2012 having 20.86%.
- Analysis of mean oil also revealed a difference between varieties for oil concentration at (P<0.05) (Table 3).

Table 3. Mean seed oil concentration (as percent) of MorSoy soybean varieties across two years (2012, 2013) following treatment with six in-furrow treatments sprayed with and without respective herbicide (Glufosinate or Glyphosate) at the Bradford Research Center.

	MorSoy RT3930N (Glyphosate tolerant)		**MorSoy LL3939N (Glufosinate tolerant)**	
In-Furrow Treatment	**Sprayed**	**No-sprayed**	**Sprayed**	**No-sprayed**
	------------------------------ % ------------------------------			
1) Pop-up P	20.61	20.49	19.82	20.16
2) Pop-up P and 3 lb Mn	20.51	20.15	19.98	20.32
3) Pop-up P and 7 lb Mn	20.53	20.54	19.74	19.87
4) 3 lb Mn	20.56	20.36	19.98	20.11
5) 7 lb Mn	20.32	20.87	19.95	19.79
6) Control	20.48	20.68	20.00	20.34
Statistical significance (Pr>0.05)	ns[†]	ns	ns	ns
Mean	20.50A[†]	20.52A	19.91B	20.10B

[†] ns = means within a column are not significantly different. Means within the same row followed by the same uppercase letter are not significantly different a P=0.05.

Seed Protein Concentration (Table 4)

- Compositional analyses from the 2014 season are not finalized yet (data not shown)
- Seed protein concentration was also determined by NIR spectroscopy.
- Seed protein differed between years *($P<0.001$)*, with 2013 having the highest amount of protein at 42.28 (data not shown).
- In-furrow treatment did not influence seed protein concentration *($P>0.5719$)*.
- There was a difference between varieties for seed protein concentration at (P<0.05) with MorSoy LL3939N having more protein than MorSoy RT3930N.

Table 4. Mean seed protein concentration (as percent) of MorSoy soybean varieties across three years (2012, 2013) following treatment with six in-furrow treatments sprayed with and without respective herbicide (Glufosinate or Glyphosate) at the Bradford Research Center.

	MorSoy RT3930N (Glyphosate tolerant)		**MorSoy LL3939N (Glufosinate tolerant)**	
In-Furrow Treatment	**Sprayed**	**No-sprayed**	**Sprayed**	**No-sprayed**
	------------------------------ % ------------------------------			
1) Pop-up P	40.42	40.91	41.84	42.05
2) Pop-up P and 3 lb Mn	40.64	41.23	41.98	41.62
3) Pop-up P and 7 lb Mn	40.65	40.78	42.34	42.09
4) 3 lb Mn	40.88	41.28	41.78	41.87
5) 7 lb Mn	41.23	40.47	41.95	42.54
6) Control	40.99	40.78	41.88	41.58
Statistical significance (Pr>0.05)	ns†	ns	ns	ns
Mean	40.80B†	40.91B	41.96A	41.96A

† ns = means within a column are not significantly different. Means within the same row followed by the same uppercase letter are not significantly different a P=0.05.

Remaining tasks:

Seed oil and protein compositional analyses for 2014 as well as associated statistical analyses remain to be completed. Once that data is in hand, analysis of data from all three years needs to be completed. Thus, we will conduct final analyses and data interpretation with all data in hand, and will derive conclusions that are based on the entirety of the project. We expect to present the study results at the Annual Meetings of the ASA-CSSA-SSSA in Minneapolis in 2015.

Micronutrient Studies

Progress Reports
2012
(Report received after publication of last Soil Fertility Update)

Impact of micronutrient packages on soybean yields in Missouri

Felix B. Fritschi and James H. Houx III, Univ. of Missouri

Objectives and Relevance to the Missouri Fertilizer and Lime Industry:
The main objective of this research is to determine the effect of various micronutrient packages offered by the fertilizer industry on soybean yield and seed quality.
The specific objectives are to:

10) quantify the impact of pre-formulated micronutrient packages on yield and seed quality of glyphosate as well as glufosinate resistant soybean cultivars.
11) measure micronutrient uptake by the soybean plants and develop nutrient response curves.
12) determine effects of applications on soil micronutrient status.

The use of micronutrients is increasing as the costs of fungicides and pesticides have many growers and producers focused on balanced plant nutrition to optimize plant health (Brown, 2008). Pre-formulated micronutrient packages are advertised to improve yields and nutritional content of Missouri's crops. Increased yields and grain quality would translate into greater returns for Missouri producers and increased fertilizer sales. Statistics on micronutrient use and yield improvement in Missouri are scant. However, ever-higher crop yields and, with the advent of cellulosic biofuel production, increases in whole plant removal will result in more micronutrients leaving farmers' fields. This increase in micronutrients leaving the field and the potential reduction in soil supply power (associated with reductions in soil organic matter caused by the removal of not only grain yield but also crop residues) emphasize the importance to critically examine the role of micronutrient fertilization in Missouri.

Dozens of micronutrient formulations are available for the Ag market in general and soybean producers in particular (SoyScience, Pro Bean Mix, Bean Mix, and Crop Mix among others). However, evaluation of product performance by independent researchers is largely lacking, complicating the decision making process for farmers. For producers like Kip Cullers, micronutrient packages are likely a necessary management practice to meet the demands of ever-more productive soybeans. Although most producers do not aspire to achieve world record yields, applications of micronutrients may increase their yields and economic bottom line. Because glyphosate interacts with Mn both in tank mixtures and in the plant (Bernards et al., 2005), products that aim to combat GIMD may be particularly promising. However, because these products are relatively new to the Missouri market, their effect on the "average" soybean grower's yield is uncertain.

2012 ACCOMPLISHMENTS:

- This year was the second year of the project evaluating micronutrient packages on soybean yield, micronutrient uptake and soil micronutrient status.
- We presented our preliminary data on both yield and seed quality at the 2012 ASA-CSA-SSSA Annual Meeting in Cincinnati Ohio. The data presented encompassed 2011 results and garnered considerable attention from private industry, government, and university researchers.

- The following treatments were applied to MorSoy RT3930N RoundUp Ready and MorSoy LL3939N LibertyLink soybean planted in 8-row, 15-inch row spacing, 30 feet long plots that were replicated five times.
  1) United Suppliers' Sovereign (foliar; liquid; EDTA chelate)
  2) Agrium's Bean Mix (soil; granular; non-chelated oxides and sulphates)
  3) Tetra Micronutrients' Pro Bean Mix (foliar; liquid; citric acid and EDTA chelates)
  4) Helena's HM609 (foliar or soil; liquid; Lignosulphonate sequestered)
  5) AgExplore's SoyScience (foliar; liquid; non-chelated sulphates)
  6) Stoller's X-tra Power (liquid; foliar or soil; MEA chelate)
  7) Tetra Micronutrient's ManGro (foliar Mn; specifically for GIMD)
  8) untreated control

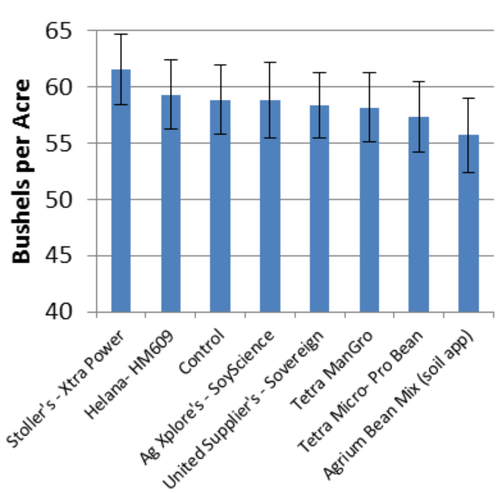
- To assess the effect of herbicide interactions with the micronutrient applications the following herbicide by soybean cultivar treatments were imposed.
  5) RR soybean with glyphosate applications
  6) RR soybean without glyphosate applications
  7) LL soybean with glufosinate applications
  8) LL soybean without glufosinate applications

2012 PRELIMINARY RESULTS:

- Two years of data from 2011 and 2012 have been combined and are presented in following figures. Despite the severe drought this past summer and the use of rescue irrigation, soybean yields in this experiment were above average for the Bradford Research and Extension Center (Fig. 1, 2, 3, 4).

- After combining two years of data statistical analysis found no significant difference between any treatments in RR soybeans treated with glyphosate. (Fig. 1).

Figure 1. RoundUp Ready Sprayed Variety Yield



- A marginally significant yield increase (P<0.10) in response to Tetra Micro ProBean application was found in MorSoy RT when conventional (no glyphosate) weed management practices were applied (Fig. 2).

- No significant yield differences among micronutrient treatments were observed for MorSoy LL when glufosinate was applied as part of a typical weed management program (Fig. 3).

- No significant yield differences were observed for MorSoy LL when conventional (no glufosinate) weed management practices were applied. (Fig 4)

- Seed and plant samples are currently being processed for evaluation of seed quality and plant tissue micronutrient concentrations

OBJECTIVES FOR YEAR 3:

In year three we will repeat the experiment again as originally proposed. We will plant the same or similar soybean varieties in a similar experimental design and sample plants five times from emergence to early reproductive stage. We will finish tissue nutrient and seed quality analyses from the 2011 and 2012 season. We intend to present our results of this research at the 2013 ASA-CSSA-SSSA annual meeting in October 2013. As well, manuscripts of the research findings will be prepared.

PROPOSED BUDGET:

Category	Year 3
Personnel	
Graduate Student	$18,000
Undergraduate help	$3,200
Field cost (fertilizers, herbicide, bags, etc.)	$2,000
Tissue and seed analyses	$4,300
Travel	$1,200
Total	**$28,700**

Figure 2. RoundUp Ready NonSprayed Variety

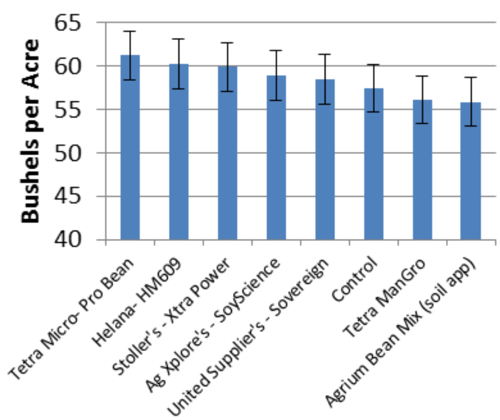


Figure 3. Liberty Link Sprayed Variety

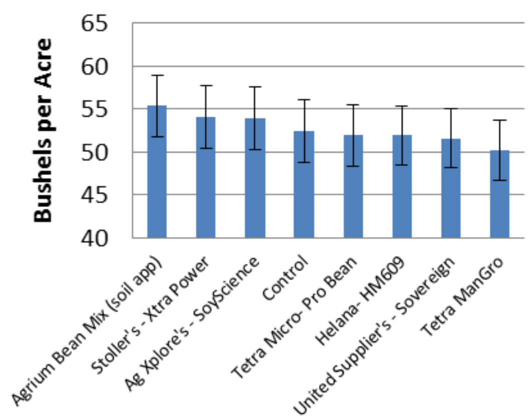
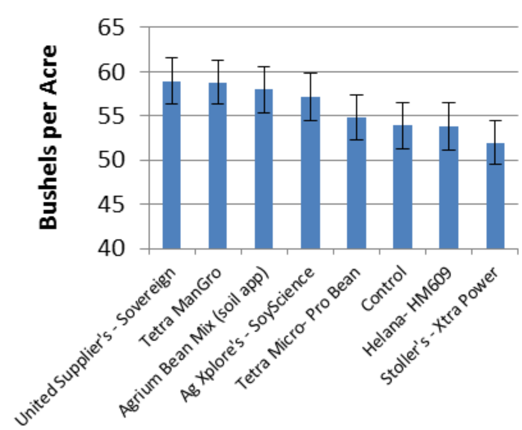


Figure 4. Liberty Link NonSprayed Variety



2013

Comparison of Impregnated Dry Fertilizer with S and Zn to Blends for Corn

Investigators:
Kelly Nelson, Div. of Plant Sci., Univ. of MO, Novelty
Bruce Burdick, Hundley-Whaley Center, Univ. of MO, Albany
Peter Motavalli, Dep. of Soil, Environ., and Atmos. Sci., Univ. of MO, Columbia
Manjula Nathan, Div. of Plant Sci., Univ. of MO, Columbia.
Matthew Caldwell, Div. of Plant Sci., Univ. of MO, Novelty

Objective and Relevance:

High yielding corn and soybean production systems in Missouri have renewed an interest in micronutrient management such as sulfur which is essential for protein formation and Zn which is important for enzymes and metabolic reactions. Yield increases to sulfur applications are more likely to occur during cool, wet springs when mineralization and crop growth are slow as a result of a decrease in atmospheric sulfur deposition. Soil tests in 2010 indicated that over 60% of the samples in upstate Missouri had low ($\leq$0.6 ppm) to medium (0.7 to 1.0 ppm) soil test Zn (Nathan, unpublished). Similarly, over 70% of the soil test samples were very low to medium for Bray 1P.

Fertilizer manufacturing has progressed to accommodate more uniform distribution of nutrients in an individual fertilizer granule. Each prill is formulated to contain N, P, S, and/or Zn rather than a blended product that includes individual prills of individual nutrients. In a blend, there may be a certain amount of segregation that may occur which often affects the uniformity of distribution when the blended fertilizer is applied in the field. This poor distribution of applied blended fertilizer may be significant for recommendations of 5 to 10 lbs of Zn/acre. Typically, soluble S sources, such as ammonium sulfate or ammonium thiosulfate, are recommended over elemental S and $ZnSO_4$ is a common source of Zn.

Impregnated granules where S and Zn are added in layers to the MAP prill allows for a more uniform distribution of fertilizer which allows roots to have a higher probability of contact with the fertilizer granule and may enhance fertilizer efficiency. Mosaic has formulated MES10 (12-40-0-10S) and MESZ (12-40-0-10S-1Zn) with two forms of sulfur (50% sulfate and 50% elemental S). MESZ includes Zn as zinc oxide. These formulations are targeted primarily for corn, soybean, wheat and rice. This combination has been promoted to increase P uptake up to 30%. The availability of Zn to the plant has been promoted as being 10 to 45% greater with the Mosaic product.

The objectives of this research are to 1) evaluate P rates of MES10 and MESZ formulations to equivalent blends of MAP, Zn, and S, and 2) evaluate $ZnSO_4$ rates in a blend with MAP or DAP compared to MES10 and MESZ formulations on grain yields and uptake of micronutrients in a corn-soybean rotation.

Materials and Methods:

- Field research was conducted at two locations (Novelty and Albany) in 2013.
  - Corn plots were established in 2013 at both locations. Previous research conducted in 2011 and 2012 at Novelty was also reported. Initial soil characteristics 0-6 inches deep for objectives 1 and 2 are reported in Table 1.

  - Additional corn plots will be established in 2014 and followed by soybean in 2015 for objective #1.
  - Objective #2 will evaluate corn response in 2014 and the subsequent soybean response in 2014 and 2015.
  - The treatments at each site were arranged as randomized complete block designs with 4 and 5 replications at Albany and Novelty, respectively.
  - Soil test P, Zn, and SO_4-S at a 6 inch depth following corn was evaluated in 2013 and will be evaluated in 2014.
  - Corn ear leaf tissue P, Zn and SO_4-S samples for 2013 were analyzed by the University of Missouri Soil and Plant Testing Lab, and will be collected and determined at both locations in 2014.
- Objective 1: Evaluate P rates of MES10 and MESZ formulations compared to equivalent blends of MAP, Zn, and S. Treatments are listed in Table 4.
  - Field management information for the corn sites at Albany in 2013 and Novelty in 2011, 2012, and 2013 as well as the rotational crop (soybean) at Novelty in 2012 and 2013 is reported in Table 2. Soybean plots had no additional fertilizer application and were in the same location as the corn plots the previous year.
  - Corn yields were reported for Albany in 2013 and Novelty in 2011, 2012, and 2013. Yields were adjusted to 15% prior to analysis.
  - Soybean yields following corn treatments in 2011 and 2012 were reported for Novelty. Yields were adjusted to 13% prior to analysis.
- Objective 2: Evaluate $ZnSO_4$ rates in a blend with MAP or DAP compared to MES10 and MESZ formulations. Treatments are listed in Table 6.
  - Field management information for the corn sites at Albany in 2013 (continuous corn and corn following soybean sites) and Novelty in 2011, 2012, and 2013 as well as the rotational crop (soybean) at Novelty in 2012 and 2013 is reported in Table 3. Soybean plots had no additional fertilizer application and were in the same location as the corn plots the previous year.
  - Corn yields were reported for Albany continuous corn and corn following soybean (rotation) in 2013 and Novelty in 2011, 2012, and 2013. Yields were adjusted to 15% prior to analysis.
  - Soybean yields following corn treatments in 2011 and 2012 were reported for Novelty. Yields were adjusted to 13% prior to analysis.

Results:

All of the sites had very low to medium soil test P, except for the corn-soybean rotation site at Albany for objective 2 (Table 1). Similarly, soil test SO_4-S was medium for all of the sites except for the corn-soybean rotation site at Albany for objective 2. Soil test Zn was low at all of the Novelty sites, but was medium to high at the two Albany sites in 2013 for objective 2.

Objective 1

Corn plant population was 27,000 to 32,000 plants/acre at Novelty (2011-2013) and no differences among treatments were observed at Albany in 2013 (data not presented). There was no effect of fertilizer treatments on grain moisture at Albany or Novelty, while there was no difference in test weight at Novelty (data not presented).

Rainfall was above average in the spring of 2011 which was followed by moderately dry conditions during the summer. Corn grain yields were greatest with MESZ at 110 lbs P_2O_5/acre

(151 bu/acre), MES10 at 110 lbs P_2O_5/acre (150 bu/acre), and MAP at 110 lbs P_2O_5/acre (150 bu/acre) at Novelty in 2011 (Table 4). All treatments were similar to MESZ at 110 lbs P_2O_5/acre except MAP at 70 lbs P_2O_5/acre, urea at 28 lbs N/acre, and urea at 46 lbs N/acre. No significant differences among treatments were observed at Novelty in 2012 or 2013, which was probably related to extremely dry conditions in 2012 and a flash drought in 2013. Grain yields at Albany in 2013 were greatest with MAP + $ZnSO_4$ + AMS at 110 lbs P_2O_5/acre (148 bu/acre), MAP at 110 lbs P_2O_5/acre (147 bu/acre), MAP + AMS at 110 lbs P_2O_5/acre (147 bu/acre), MES10 at 110 lbs P_2O_5/acre (146 bu/acre), and MESZ at 110 lbs P_2O_5/acre (145 bu/acre). Reduced rates of MAP (75 lbs P_2O_5/acre) were generally lower than MAP + $ZnSO_4$ + AMS at 110 lbs P_2O_5/acre. No differences among soybean yields were detected in 2012 at Novelty following fertilizer treatments to corn in 2011. However, soybean yields (35 to 36 bu/acre) were similar for MESZ at 110 lbs P_2O_5/acre, MAP + AMS at 110 lbs P_2O_5/acre, MAP + $ZnSO_4$ + AMS at 75 or 110 lbs P_2O_5/acre, and urea at 46 lbs N/acre in 2012.

There was no difference in soil test P levels following corn at Novelty in 2013 (Table 5). All fertilizer treatments with Zn except MESZ at 110 lbs P_2O_5/acre increased soil test Zn concentration compared to treatments without Zn at Novelty in 2013. No differences among Zn rates were detected. Soil test SO_4-S was greatest with MES10 at 18 lbs S/acre, which was similar to MES 10 at 28 lbs S/acre, MESZ at 18 or 28 lbs S/acre, and MAP + AMS at 28 lbs S/acre. These treatments increased soil test SO_4-S concentrations compared to the other treatments. Soil samples at the Albany location will be collected in the spring, 2014. At Novelty, ear leaf P concentration increased with MESZ at 110 lbs P_2O_5/acre, and all MAP treatments except MAP + $ZnSO_4$ + AMS at 70 lbs P_2O_5/acre compared to the non-treated control. MAP + AMS at 110 lbs P_2O_5/acre had the highest ear leaf P concentration (0.308 %) which was similar to MESZ and the other MAP treatments applied at 110 lbs P_2O_5/acre.

In summary, average corn grain yields were greatest (114 bu/acre) with MAP at 110 lbs P_2O_5/acre followed by MESZ at 110 lbs P_2O_5/acre (113 bu/acre) and MAP + $ZnSO_4$ + AMS at 110 lbs P_2O_5/acre (111 bu/acre). However, MESZ at 110 lbs P_2O_5/acre, MAP + AMS at 110 lbs P_2O_5/acre, and urea at 46 lbs N/acre had the highest average soybean yields (38 bu/acre) the following year.

Objective 2

Grain moisture and plant populations were similar among treatments following corn or soybean at Albany and following soybean at Novelty (data not presented). Corn test weight was lowest in the non-treated, no N control at Novelty, but limited differences were observed among Zn treatments (data not presented).

MAP or DAP were treated with a liquid formulation of Super Zinc (Helena Chemical Co., 2255 Schilling Blvd, Suite 300, Collierville, NT 38017) in 2013. At Novelty, corn grain yield was highest with MESZ and MAP + SuperZn + AMS in 2011; MESZ, non-treated and no N control, and N only in 2012, and MESZ, MAP + $ZnSO_4$ (5 lbs Zn/acre) + AMS, MAP + SuperZn (5 lbs Zn/acre) + AMS, and DAP + AMS in 2013 (Table 6). Average corn yield for the 5 site-years evaluated to date ranked MESZ (109 bu/acre), MES10 (105 bu/acre) = MAP + $ZnSO_4$ (5 lb Zn/acre) + AMS (105 bu/acre), and DAP (104 bu/acre). Average soybean yields were 40 bu/acre with the non-treated and no N control, N only control, MESZ, and DAP for Novelty in 2012 and 2013, but there was no significant treatment effect on soybean yields within 2012 or 2013.

All treatments increased ear leaf P concentration compared to the non-treated, no N control at Novelty in 2013 (Table 7). The inclusion of MAP or DAP generally increased ear leaf P concentration compared to the N only treatment. There were limited differences in P concentration among P treatments at Novelty. All treatments increased ear leaf S and Zn concentration compared to the non-treated, no N control at Novelty, but treatments with S and Zn had ear leaf concentrations that were similar to the N only control. Ear leaf Zn concentration was greatest with MESZ and DAP + AMS at Albany in continuous corn, but inconsistent differences among treatments were observed at this location. Ear leaf S was greatest with DAP + AMS, but differences among treatments were inconsistent.

At Novelty, all treatments increased soil test P compared to the non-treated, no N control (Table 8). MAP or DAP + $ZnSO_4$ + AMS at 2 lbs Zn/acre and MAP or DAP + Super Zn + AMS at 5 lbs Zn/acre increased soil test Zn 1.2 to 2.9 ppm compared to the non-treated controls. MES 10 and MESZ increased soil test S compared to the N only control, while blends of MAP +/- Zn at 2 lbs/a + AMS and DAP + Super Zn at 2 lbs/a or $ZnSO_4$ + AMS significantly increased soil test S compared to the N only control.

There was no difference in ear leaf P, Zn, or S concentration among treatments at Albany with a corn-soybean rotation (Table 7), which was probably due to the high soil test P, Zn, and S at this location (Table 1). Similarly, no difference in soil test P or Zn was observed at the Albany site in a corn-soybean rotation (Table 8). Nonetheless, S concentrations were increased with MES10, MAP + AMS, and DAP + Super Zn + AMS.

The continuous corn site at Albany had several treatments that increased soil test P concentration, but Zn treatments had no significant impact on soil test Zn concentration when compared to the no-treated controls. When compared to the N only control, SO_4–S in the soil increased with all treatments that included a S additive. Soil test SO_4–S was similar between MES10 and MESZ when compared to the addition of AMS.

Summary:

- In objective 1, the carry over effect of fertilizer treatments from corn to soybean indicated MESZ at 110 lbs P_2O_5/acre had high average corn (4 site-years) and soybean (2 site-years) yields. Soil test Zn increased with all treatments that included Zn regardless of rate, and soil test SO_4-S increased with MES10 at 18 lbs S/acre, MES 10 at 28 lbs S/acre, MESZ at 18 or 28 lbs S/acre, and MAP + AMS at 28 lbs S/acre at Novelty in 2013. Ear leaf P concentration was greatest with MAP + AMS at 110 lbs P_2O_5/acre and was similar to the high rates of MAP or MESZ.
- In objective 2, MESZ at 110 lbs P_2O_5/acre had the greatest yield average for corn (5 site-years) and the non-treated and no N control, N only control, MESZ, and DAP had similar soybean yields (2 site-years). At sites with low soil test P and S, selective fertilizer treatments significantly increased soil test P and S following corn in 2013. Soil test Zn increased with selective treatments at Novelty in 2013, but not at Albany with low or high initial soil test Zn.

Table 1. Initial soil characteristics 0-6 inches deep for Objectives 1 and 2 at Albany in 2003 and Novelty in 2011, 2012, and 2013.

	Objective 1			Objective 2				
	2011	2012	2013	2011	2012	2013	2013 Albany	2013 Albany
Soil characteristics	Novelty	Novelty	Novelty	Novelty	Novelty	Novelty	Rotation	Continuous corn
pH_s	6.2 ± 0.2	5.9 ± 0.2	5.7 ± 0.6	6.0 ± 0.1	6.2 ± 0.2	5.1 ± 0.6	6.4 ± 0.4	5.1 ± 0.2
Neutralizable acidity (meq/100 g)	1.9 ± 0.4	1.7 ± 0.3	3.5 ± 2.5	1.9 ± 0.2	1.1 ± 0.4	5.4 ± 5.5	1.9 ± 1.4	4.5 ± 1.1
Organic matter (%)	2.4 ± 0.2	2.7 ± 0.2	2.1 ± 0.2	2.3 ± 0.1	2.9 ± 0.2	2.0 ± 0.2	4.4 ± 0.3	2.6 ± 0.3
Bray 1P (lb/acre)	22.6 ± 3.8	16.8 ± 1.8	32.8 ± 2.6	14.0 ± 2.1	14.0 ± 1.9	19.6 ± 8.0	140 ± 5	22.0 ± 6.7
	(L)[†]	(VL)	(M)	(VL)	(VL)	(L)	(E)	(L)
Ca (lb/acre)	4140 ± 160	4080 ± 340	3230 ± 580	4060 ± 210	4290 ± 280	3280 ± 340	5590 ± 670	3230 ± 380
Mg (lb/acre)	369 ± 25	305 ± 28	270 ± 30	350 ± 33	310 ± 30	293 ± 44	650 25	410 ± 57
K (lb/acre)	176 ± 8	162 ± 11	162 ± 24	144 ± 10	160 ± 20	114 ± 34	400 ± 30	209 ± 39
SO_4-S (ppm)	7.3 ± 1.2	7.3 ± 0.6	2.0 ± 0.2	5.8 ± 1.1	6.4 ± 0.7	1.6 ± 0.3	8.6 ± 0.8	5.7 ± 0.4
	(M)	(M)	(M)	(M)	(M)	(M)	(H)	(M)
Zn (ppm)	0.3 ± 0.1	0.4 ± 0.1	0.5 ± 0.1	0.2 ± 0.1	0.5 ± 0.1	0.3 ± 0.1	1.8 ± 0.1	1.0± 0.3
	(L)	(L)	(L)	(L)	(L)	(L)	(H)	(M)
Mn (ppm)	16.1 ± 0.6	20.8 ± 2.1	22.3 ± 2.7	16.7 ± 0.8	49.3 ± 7.4	17.2 ± 1.7	---[‡]	---
Fe (ppm)	45.0 ± 2.8	64.8 ± 8.2	64.2 ± 5.5	38 ± 1.0	49.3 ± 7.4	48.3 ± 12.4	---	---
Cu (ppm)	0.6 ± 0.1	0.7 ± 0.1	0.6 ± 0.1	0.6 ± 0.1	0.6 ± 0.1	0.4 ± 0.1	---	---
CEC (meq/100 g)	14.0 ± 0.7	13.4 ± 0.9	12.9 ± 2.5	13.7 ± 0.8	13.3 ± 0.7	14.2 ± 3.2	19.1 ± 1.4	14.6 ± 1.1

[†]Abbreviations: E, excessive; VH, very high; H, high; M, medium; L, low; and VL, very low.

[‡]Not determined at this site.

Table 2. Field and management information for the corn sites at Novelty in 2011, 2012, and 2013 as well as Albany in 2013 to evaluate phosphorus rates of MES10 and MESZ formulations compared to equivalent blends of MAP, Zn, and S and the subsequent effect on soybean the following year (Objective #1).

	2011	2012	2012	2013	2013	
	Novelty		Novelty			
Management information	Corn fb Soybean		Corn fb Soybean		Novelty	Albany
Plot size (ft)	10 by 40	10 by 40	10 by 40	10 by 40	10 by 50	10 by 30
Hybrid or cultivar	DKC 63-84	Ag3730	DKC 63-84	Morsoy LL 3759N	DKC 63-25 VT3	DK 61-89
Planting date	12 Apr.	25 Apr.	2 Apr.	17 May	15 May	30 Apr.
Row spacing (inches)	30	15	30	7.5	30	30
Seeding rate (seeds/acre)	31,000	180,000	33,000	160,000	33,000	29,000
Harvest date	22 Sep.	9 Oct.	28 Aug.	10 Oct.	7 Oct.	5 Nov.
Maintenance fertilizer	31 Mar. 2011	NA	18 Nov. 2011	NA	30 Nov. 2012	
Nitrogen	180 lbs N/acre (AA)		190 lbs N/acre (AA) + N-serve at 1 qt/acre		180 lbs N/acre (AA)	180 lbs N/acre (AN)
P-S-Zn application date	6 May	NA	28 Nov. 2011	NA	25 Apr.	26 Apr.
Tillage	No-till	No-till	No-till	No-till	No-till	Minimum
Weed management						
Burndown/Preemergence	5 Apr., Roundup Power MAX 32 oz/a + Verdict 5 oz/a + AMS 17 lb/100 gal	25 Apr., Sharpen 1 oz/a + 0.25% v/v NIS + UAN 1 qt/a + Roundup PowerMAX 32 oz/a	19 Mar., Verdict 5 oz/a + Roundup PowerMAX 32 oz/a + AMS 17 lb/100 gal	17 May, Sharpen 1 oz/a + Roundup PowerMAX 32 oz/a + UAN 1 qt/a + MSO 1% v/v	17 May, Lexar 3 qt/a + MSO 1% v/v + UAN 1 qt/a + Roundup PowerMAX 32 oz/a	30 Apr. Lexar 3.1 qt/a
Postemergence	17 May, Degree Xtra 3 qt/a	24 May, Reflex 1.25 pt/a + Roundup PowerMAX 32 oz/a + UAN 1 qt/a + 0.25% v/v NIS 22 June, Roundup PowerMAX 32 oz/a + AMS 17 lb/100 gal + 0.25% v/v NIS	10 May, Lexar 2.25 qt/a + Roundup PowerMAX 32 oz/a + 0.25% v/v NIS	4 June, Liberty 32 oz/a + AMS 17 lb/100 gal 1 July, Liberty 32 oz/a + Prefix 2.25 pt/a + AMS 17 lb/100 gal + 0.25% v/v NIS		3 June Roundup PowerMAX 32 oz/a
Insect management	17 May, Warrior II 2 oz/a	NA	10 May, Warrior II 2 oz/a	NA	NA	NA
Disease management	NA	NA	NA	NA	NA	NA

[†]Abbreviations: AA, anhydrous ammonia; AN, ammonium nitrate; fb, followed by; MSO, methylated seed oil; NA, none applied; and UAN, urea ammonium nitrate.

Table 3. Field and management information for the corn sites established at Albany in 2013 (corn-soybean rotation and continuous corn) and Novelty in 2011, 2012, and 2013 to evaluate Zn rates in a blend with MAP or DAP compared to MES10 and MESZ formulations (Objective #2).

	2011 Novelty	2012 Novelty	2011 Novelty	2012 Novelty	2013		
Management information	Corn fb Soybean		Corn fb Soybean		Novelty	Albany Rotation	Albany Continuous corn
Plot size (ft)	10 by 40	10 by 40	10 by 40	10 by 40	10 by 50	10 by 35	10 by 35
Hybrid or cultivar	DKC 63-84	Ag3730	DKC 63-84	Morsoy LL 3759N	DKC 63-25 VT3	DK 64-69	DK64-69
Planting date	12 Apr.	26 Apr.	2 Apr.	17 May	15 May	14 May	14 May
Row spacing (inches)	30	17	30	7.5	30	30	30
Seeding rate (seeds/acre)	31,000	180,000	32,000	160,000	33,000	29,000	29,000
Harvest date	22 Sep.	9 Oct.	28 Aug.	10 Oct.	7 Oct.	10 Oct.	10 Oct.
Maintenance fertilizer	31 Mar. 2011	NA	18 Nov. 2011	NA			
Nitrogen	180 lbs N/acre (AA)		190 lbs N/acre (AA) + N-serve at 1 qt/acre		180 lbs N/acre (AA)	180 lbs N/acre (AN)	180 lbs N/acre (AN)
P-S-Zn application date	6 May		28 Nov. 2011		29 Apr.	10 May	7 May
Tillage	No-till	No-till	No-till	No-till	No-till	Minimum	Minimum
Weed management							
Burndown/Preemergence	5 Apr., Roundup Power MAX 32 oz/a + Verdict 5 oz/a + AMS 17 lb/100 gal	25 Apr., Sharpen 1 oz/a + 0.25% v/v NIS + UAN 1 qt/a + Roundup PowerMAX 32 oz/a	19 Mar., Verdict 5 oz/a + Roundup PowerMAX 32 oz/a + AMS 17 lb/100 gal	17 May, Sharpen 1 oz/a + Roundup PowerMAX 32 oz/a + UAN 1 qt/a + MSO 1% v/v	17 May, Lexar 3 qt/a + MSO 1% v/v + UAN 1 qt/a + Roundup PowerMAX 32 oz/a	14 May, Lexar 3 qt/a	14 May, Lexar3 qt/a
Postemergence	17 May, Degree Xtra 3 qt/a	24 May, Reflex 1.25 pt/a + Roundup PowerMAX 32 oz/a + UAN 1 qt/a + 0.25% v/v NIS 22 June, Roundup PowerMAX 32 oz/a + AMS 17 lb/100 gal + 0.25% v/v NIS	10 May, Lexar 2.25 qt/a + Roundup PowerMAX 32 oz/a + 0.25% v/v NIS	4 June, Liberty 32 oz/a + AMS 17 lb/100 gal 1 July, Liberty 32 oz/a + Prefix 2.25 pt/a + AMS 17 lb/100 gal + 0.25% v/v NIS		11 June, Roundup PowerMAX (32 oz/a)	11 June, Roundup PowerMAX (32 oz/a)
Insect management	17 May, Warrior II 2 oz/a	NA	10 May, Warrior II 2 oz/a	NA	NA	NA	NA
Disease management	NA	NA	NA	NA	NA	NA	NA

†Abbreviations: AA, anhydrous ammonia; AN, ammonium nitrate; fb, followed by; MSO, methylated seed oil; NA, none applied; and UAN, urea ammonium nitrate.

Table 4. Grain yield response of corn (2011, 2012, and 2013) and the subsequent soybean crop (2012 and 2013) to phosphorus rates of MES10 and MESZ formulations compared to equivalent blends of MAP, Zn, and S (Objective #1).

				Corn fb 2011	Soybean 2012	Corn fb 2012	Soybean 2013	Corn 2013		Corn	Soybean
Fertilizer treatment	P_2O_5	Zn	S	Novelty		Novelty		Novelty	Albany	Average[†]	Average[†]
	lbs/a	lbs/a	lbs/a	bu/acre							
Non-treated				37	37	26	32	123	117	76	35
MES10	70	0	18	144	38	23	34	117	142	107	36
MES10	110	0	28	150	39	21	34	118	146	109	37
MESZ	70	1.8	18	141	37	20	34	126	141	107	36
MESZ	110	2.8	28	151	40	29	35	126	145	113	38
MAP[‡]	70			130	38	24	33	118	141	103	36
MAP	110			150	36	29	33	129	147	114	35
MAP + AMS	70		18	142	39	22	34	120	136	105	37
MAP + AMS	110		28	144	40	23	36	120	147	109	38
MAP + $ZnSO_4$ + AMS	70	1.8	18	148	38	23	35	124	138	108	37
MAP + $ZnSO_4$ + AMS	110	2.8	28	146	38	22	36	129	148	111	37
Urea at 14 lbs N/acre[¶]				140	36	26	34	117	135	105	35
Urea at 21 lbs N/acre[¶]				142	38	22	34	123	135	106	36
Urea at 28 lbs N/acre[¶]				133	36	23	34	121	141	105	35
Urea at 33 lbs N/acre[¶]				144	38	24	33	121	138	107	36
Urea at 46 lbs N/acre[¶]				134	39	25	36	121	140	105	38
LSD (*P*=0.1)				13	NS	NS	2	NS	9		

[†]Grain yield averages were calculated for corn (Novelty 2011, 2012, 2013, and Albany 2013) and soybean (Novelty 2011 and 2012).
[‡]Abbreviations: AMS, ammonium sulfate; C-C, continuous corn; DAP, diammonium phosphate; fb, followed by; MAP monoammonium phosphate.
[¶]Additional N was added to balance the N contribution from MAP and/or AMS N sources. All treatments had a base N application as denoted in Table 2.

Table 5. Soil test P, Zn, and SO_4-S in the top 6 inches of soil after corn was harvested and ear leaf tissue P, Zn, and SO_4-S concentration as affected by phosphorus rates of MES10 and MESZ formulations compared to equivalent blends of MAP, Zn, and S at Novelty in 2013 (Objective #1).

				Soil			Ear leaf tissue		
Fertilizer treatment†	P_2O_5	Zn	S	P‡	Zn	SO_4-S	P‡	Zn	SO_4-S
	lbs/a	lbs/a	lbs/a	lb/a	ppm	ppm	%	ppm	%
Non-treated				35	1.0	3.8	0.261	29.6	0.215
MES10	70	0	18	50	0.9	6.8	0.269	25.0	0.202
MES10	110	0	28	59	1.4	6.6	0.281	27.7	0.217
MESZ	70	1.8	18	51	1.6	6.4	0.277	26.0	0.208
MESZ	110	2.8	28	56	1.3	6.6	0.293	25.2	0.209
MAP	70			53	1.2	4.2	0.285	26.2	0.209
MAP	110			68	0.8	4.2	0.293	25.2	0.209
MAP + AMS	70		18	51	0.9	4.8	0.284	26.6	0.215
MAP + AMS	110		28	65	0.8	6.5	0.308	27.6	0.221
MAP + $ZnSO_4$ + AMS	70	1.8	18	49	1.6	3.9	0.268	28.1	0.215
MAP + $ZnSO_4$ + AMS	110	2.8	28	57	1.7	4.4	0.302	29.2	0.220
Urea at 14 lbs N/acre¶				40	0.9	3.4	0.272	29.7	0.221
Urea at 21 lbs N/acre¶				45	0.9	3.4	0.258	26.0	0.203
Urea at 28 lbs N/acre¶				34	0.9	3.0	0.263	29.3	0.218
Urea at 33 lbs N/acre¶				41	0.7	3.9	0.265	26.4	0.209
Urea at 46 lbs N/acre¶				41	1.0	3.5	0.261	26.9	0.215
LSD (*P*=0.1)				NS	0.5	1.1	0.022	NS	NS

†Anhydrous ammonia at 180 lbs N/acre was applied to all treatments.
‡Bray I P.
¶Additional N was added to balance the N contribution from MAP and/or AMS N sources. All treatments had a base N application as denoted in Table 2.

Table 6. Grain yield response of corn and the subsequent soybean crop to Zn rates in a blend with MAP or DAP compared to MES10 and MESZ formulations (Objective #2).

				Corn 2011 fb[‡]	Soybean 2012	Corn 2012 fb	Soybean 2013	Corn 2013				
Fertilizer treatment[†]	P_2O_5	Zn	S	Novelty	Novelty	Novelty	Novelty	Novelty	Albany Rotation	Albany C-C	Corn[‡‡] Average	Soybean[‡‡] Average
		lbs/a		bu/acre								
Non-treated, no N				36	42	26	37	101	104	97	73	40
Nitrogen only				135	42	26	38	135	113	104	103	40
MES10	80	0	20	147	41	21	37	141	118	98	105	39
MESZ	80	2	20	153	42	26	37	143	122	101	109	40
MAP	80			145	41	18	35	137	114	98	102	38
MAP + AMS	80		20[¶]	---[§]	---	---	---	139	120	99	---	---
MAP + $ZnSO_4$ + AMS	80	2	20[¶]	144	42	17	36	141	116	99	103	39
MAP + SuperZn[††] + AMS	80	2	20[¶]	---	---	---	---	141	116	108	---	---
MAP + $ZnSO_4$ + AMS	80	5	20[¶]	153	42	17	35	143	112	98	105	39
MAP + SuperZn[††] + AMS	80	5	20[¶]	---	---	---	---	143	118	99	---	---
DAP	80			140	43	21	36	140	116	103	104	40
DAP + AMS	80		20[¶]	---	---	---	---	143	117	99	---	---
DAP + $ZnSO_4$ + AMS	80	2	20[¶]	141	41	24	37	134	110	97	101	39
DAP + SuperZn[††] + AMS	80	2	20[¶]	---	---	---	---	141	112	99	---	---
DAP + $ZnSO_4$ + AMS	80	5	20[¶]	137	42	24	36	134	113	97	101	39
DAP + SuperZn[††] + AMS	80	5	20[¶]	---	---	---	---	140	109	103	---	---
LSD (*P*=0.1)				16	NS	7	NS	7	NS	NS		

[†]Nitrogen was balanced with urea to reach an equivalent N rate for all treatments except for the non-treated, no N control.
[‡]Abbreviations: AMS, ammonium sulfate; C-C, continuous corn; DAP, diammonium phosphate; fb, followed by; MAP monoammonium phosphate.
[¶]Balance of S with MES10.
[§]Treatments weren't applied these years.
[††]MAP or DAP were impregnated with Super Zinc (Helena Chemical Co., 2255 Schilling Blvd, Suite 300, Collierville, NT 38017) prior to application in 2013.
[‡‡]Grain yield averages were calculated for corn (Novelty 2011, 2012, 2013, and Albany 2013) and soybean (Novelty 2011 and 2012).

Table 7. Ear leaf P, Zn, and SO_4-S concentration in 2013 (Objective #2).

				Novelty 2013			Albany 2013 corn-soybean			Albany 2013 continuous corn		
Fertilizer treatment[†]	P_2O_5	Zn	S	P[‡]	Zn	SO_4-S	P[‡]	Zn	SO_4-S	P[‡]	Zn	SO_4-S
		lbs/a		%	ppm	%	%	ppm	%	%	ppm	%
Non-treated, no N				0.200	19.4	0.155	0.260	22.2	0.180	0.324	14.1	0.167
Nitrogen only				0.261	27.6	0.209	0.277	28.5	0.197	0.354	15.7	0.170
MES10	80	0	20	0.289	26.2	0.211	0.322	26.1	0.209	0.327	13.0	0.170
MESZ	80	2	20	0.301	27.5	0.209	0.303	28.1	0.202	0.401	17.2	0.190
MAP	80			0.291	26.4	0.207	0.303	24.4	0.190	0.376	14.6	0.172
MAP + AMS	80		20	0.296	25.7	0.207	0.308	29.3	0.196	0.350	14.1	0.191
MAP + $ZnSO_4$ + AMS	80	2	20	0.290	27.8	0.210	0.336	28.7	0.220	0.374	15.5	0.177
MAP + SuperZn + AMS	80	2	20	0.290	24.6	0.196	0.307	27.0	0.198	0.412	15.3	0.199
MAP + $ZnSO_4$ + AMS	80	5	20	0.301	29.6	0.220	0.326	26.8	0.208	0.330	13.3	0.174
MAP + SuperZn + AMS	80	5	20	0.278	24.3	0.192	0.303	28.5	0.194	0.362	14.8	0.189
DAP	80			0.287	29.0	0.208	0.321	25.1	0.197	0.397	16.3	0.186
DAP + AMS	80		20	0.284	26.0	0.202	0.312	26.9	0.198	0.423	17.2	0.204
DAP + $ZnSO_4$ + AMS	80	2	20	0.292	29.0	0.214	0.315	28.2	0.204	0.417	15.6	0.195
DAP + SuperZn + AMS	80	2	20	0.283	25.4	0.202	0.300	28.1	0.196	0.386	15.0	0.190
DAP + $ZnSO_4$ + AMS	80	5	20	0.273	28.4	0.205	0.314	27.9	0.208	0.329	13.3	0.168
DAP + SuperZn + AMS	80	5	20	0.283	26.6	0.200	0.313	26.2	0.197	0.395	15.8	0.187
LSD (*P*=0.1)				0.019	3.6	0.014	NS	NS	NS	0.052	2.3	0.016

[†]N was balanced with additional N as urea for all treatments.
[‡]Bray I P.

Table 8. Soil test P, Zn, and SO_4-S in the top 6 inches of soil after corn was harvested in 2013 (Objective #2).

Fertilizer treatment[†]	P_2O_5	Zn	S	Novelty 2013 P[‡]	Novelty 2013 Zn	Novelty 2013 SO_4-S	Albany 2013 corn-soybean P[‡]	Albany 2013 corn-soybean Zn	Albany 2013 corn-soybean SO_4-S	Albany 2013 continuous corn P[‡]	Albany 2013 continuous corn Zn	Albany 2013 continuous corn SO_4-S
		lbs/a		lb/a	ppm	ppm	lb/a	ppm	ppm	lb/a	ppm	ppm
Non-treated, no N				31	0.6	5.1	140	1.8	8.6	21	0.9	5.6
Nitrogen only				38	0.6	4.3	138	1.8	8.0	18	1.0	5.2
MES10	80	0	20	79	0.7	7.0	174	3.5	12.5	31	1.0	6.3
MESZ	80	2	20	71	1.1	6.1	171	2.7	9.5	28	1.1	6.2
MAP	80			58	0.7	4.9	161	2.0	8.3	27	1.0	5.8
MAP + AMS	80		20	62	0.7	5.8	180	2.3	8.5	24	1.0	6.7
MAP + $ZnSO_4$ + AMS	80	2	20	68	1.8	5.9	173	3.8	11.3	27	2.2	6.0
MAP + SuperZn + AMS	80	2	20	60	1.0	4.8	180	6.1	9.9	35	1.6	6.3
MAP + $ZnSO_4$ + AMS	80	5	20	71	1.2	4.8	155	3.0	9.1	23	1.2	5.9
MAP + SuperZn + AMS	80	5	20	97	1.8	5.0	181	4.8	10.0	31	1.1	6.1
DAP	80			64	0.7	4.6	174	2.0	8.1	24	0.8	5.0
DAP + AMS	80		20	64	0.8	5.4	168	1.9	8.7	29	0.8	6.1
DAP + $ZnSO_4$ + AMS	80	2	20	70	2.0	5.1	176	4.1	8.8	29	1.9	6.3
DAP + SuperZn + AMS	80	2	20	60	1.2	6.0	169	2.5	10.2	25	1.2	6.1
DAP + $ZnSO_4$ + AMS	80	5	20	56	1.1	6.4	179	2.7	9.6	29	1.7	6.3
DAP + SuperZn + AMS	80	5	20	82	3.5	5.3	176	3.3	8.8	31	1.1	6.3
LSD (*P*=0.1)				25	1.0	1.4	NS	NS	2.0	8	NS	0.7

[†]N was balanced with additional N as urea for all treatments.
[‡]Bray I P.

Timetable:

2014

Feb.-April	Prepare equipment, sample soil, and apply fertilizer treatments
April-September	Manage plots and demonstrate at local field day
September	Harvest corn ear leaf tissue for fertilizer uptake and collect grain samples
Nov.-Dec.	Analyze results
December	Submission of annual report

2015 Rotate the 2014 trials into soybean (Objective #1). This will be at no additional cost.

Proposed Budget:

CATEGORIES	Year 2014
A. Salaries	
Research Specialist or M.S. Graduate Research Assistant (50%)	$14,670
B. Fringe Benefits	$2,095
TOTAL SALARIES AND FRINGE BENEFITS	$16,765
C. Travel	
Travel to field site	$0
To present research findings at National Meetings	$1,000
TOTAL TRAVEL COSTS	$1,000
D. Equipment	$0
TOTAL EQUIPMENT use and maintenance COSTS	$0
E. Other Direct Costs	
Soil analysis	$2380
Tissue analysis	$3560
Field supplies	$2060
Publication cost	$750
Off-site PI	$4,000
TOTAL OTHER DIRECT COSTS	$12,750
TOTAL REQUEST	**$30,515**

Budget narrative:

Salaries and fringe benefits: Funds are requested for partial support of a M.S. student or a research specialist.

Presentations, publications, and documentation: This will help defray cost of publication and documentation of results and conclusions as well as assist travel and board for presentation of results

Other Direct Costs: Covers cost of analysis, sample containers, fertilizer, seed, plot preparation, planting, weed control harvesting, flags, and other field supplies and operations.

Importance of micronutrients in maximizing corn yield

Felix B. Fritschi and James H. Houx III, Univ. of Missouri

Objectives and Relevance to the Missouri Fertilizer and Lime Industry:

The main objective of this research is to determine the impact of various micronutrient packages offered by the fertilizer industry on corn yield.

The specific objectives are to:

13) Quantify the impact of pre-formulated micronutrient packages on corn yield.
14) Determine plant tissue concentration of applied micro- and macronutrients.
15) Determine differences in nutrient uptake and yield between glyphosate- and non-glyphosate treated corn.

The use of micronutrients is increasing as the costs of fungicides and pesticides have many growers and producers focused on balanced plant nutrition to optimize plant health (Brown, 2008). Pre-formulated micronutrient packages are advertised to improve yields and nutritional content of Missouri's crops. Increased yields would translate into greater returns for Missouri producers and increased fertilizer sales. Statistics on micronutrient use and yield improvement in Missouri are scant. However, ever-higher crop yields and, with the advent of cellulosic biofuel production, increases in whole plant removal will result in more micronutrients leaving farmers' fields. This increase in micronutrients leaving the field and a potential reduction in soil supply power (associated with reductions in soil organic matter caused by the removal of not only grain yield but also crop residues) emphasize the importance to critically examine the role of micronutrient fertilization on corn in Missouri.

2013 ACCOMPLISHMENTS:

- This year was the first year for the project evaluating micronutrient applications on corn yield and development.
- The following treatments were applied to Pioneer corn hybrid 32D79 treated with and without glyphosate. Corn was planted in 34' long plots on a 30" row spacing and emerged at 32,584 plants per acre. The following treatments were applied in six replicates.
    1) AgXplore's MicroStarter
    2) Agrisolutions' Ultra-Che Corn Mix
    3) Agrigaurdian's MOLY
    4) Wuxall Top 3
    5) Agrisolutions Max IN ZMB + Max-IN Boron
    6) Inorganic Zn sulfate, Mn sulfate, Molybdate
    7) untreated control

- In-furrow treatments (treatments 1 and 2 above) were applied at recommended rates at planting with a 4-row planter equipped with an in-furrow liquid application system.
- Foliar treatments (treatments 3-6 above) were applied at recommended rates and times with a three-point tractor mounted, telescoping sprayer with a 10' boom length.
- Data were taken on plant height and chlorophyll concentration (SPAD) during the growing season.
- Whole plant samples were taken at V6 and dough developmental stages.
- Grain yield and yield components were determined at the end of the season.
- Tissue analysis is on-going at this time.

2013 PRELIMINARY RESULTS:

NOTE: Results are from one field season and are considered preliminary

At the first biomass sampling at V6 developmental stage, when glyphosate was not applied, corn leaf dry matter ranged from 100.4 g to 119.3 g with a mean weight of 112.3 g. When glyphosate was applied, leaf dry matter ranged from 82.5 g to 114.1 g with a mean weight of 106.4 g (Table 1). When glyphosate was not applied, corn stem dry matter ranged from 57.0 g to 67.3 g with a mean weight of 62.5 g, and when glyphosate was applied ranged from 42.4 g to 66.2 g with a mean of 59.3 g. There were no differences in leaf or stem dry matter yield between glyphosate-treated and non-treated plants and between the products applied.

Table 1. Dry matter yield of six corn plants harvested at V6 stage after being treated with seven micronutrient products and treated with or without glyphosate as part of standard weed control.

	Leaf		stem	
product	**no glyphosate**	**glyphosate**	**no glyphosate**	**glyphosate**
	------------------------------ grams (g) ------------------------------			
AgXplore MicroStarter	119.3	111.6	66.2	63.0
Agrisolution Ultra-Che	112.1	82.5	62.6	42.4
Agriguardian MOLY	100.4	105.9	57.0	58.5
Wuxall Top 3	116.5	110.8	67.3	62.6
Winfield Max-IN Ultra ZMB + Max-IN Boron	110.8	114.1	62.3	63.4
ZnSO4 + MnSO4+Molybdate	118.0	107.7	63.3	58.8
Control (no product applied)	109.2	111.9	59.3	66.2
Pr>f	**ns**[†]	**ns**	**ns**	**ns**
Mean	112.3	106.4	62.5	59.3

[†] ns = no statistical difference within a column at P≥0.05.

At the second biomass sampling at dough stage, when glyphosate was not applied leaf dry matter ranged from 121.8 g to 134.5 g with a mean weight of 129.5 g (Table 2). When glyphosate was applied leaf dry matter ranged from 115.4 g to 136.6 g with a mean of 126.7 g. Corn stem dry matter when glyphosate was not applied ranged from 232 g to 259 g with a mean of 243 g. When glyphosate was applied stem dry matter ranged from 230 g to 254 g with a mean of 244 g. Ear dry matter when glyphosate was not applied ranged from 274 g to 291 g with a mean of 283 g. When glyphosate was applied, ear dry matter ranged from 250 g to 308 g with a mean of 289g. There were no differences in leaf, stem, or ear matter yield between glyphosate-treated and non-treated plants and between the products applied.

SPAD readings (a surrogate estimate of nitrogen status) were taken approximately six times during the growing season (Table 3). Five measurements were taken on the most recent, fully expanded leaf of five different plants in each plot. As expected, SPAD increased as the season progressed and the highest readings were taken approximately two weeks after tasseling. Within dates and herbicide treatment SPAD readings were not different between the products.

Grain yield when glyphosate was not applied ranged from 186 bu/ac to 206 bu/ac with a mean of 193 bu/ac (Table 4). When glyphosate was applied grain yield ranged from 169 bu/ac to 194 bu/ac with a mean of 183bu/ac. Kernels per ear ranged from 594 to 651 with a mean of 632 kernels per ear when glyphosate was not applied and ranged from 596 to 648 with a mean of 624 kernels per ear when glyphosate was applied. Weight of 100 kernels ranged from 29.7 g to 31.5 g with a mean of 30.6 g when glyphosate was not applied, and ranged from 29.5 g to 31.3 g with a mean of 30.1 g when glyphosate was applied. There were no differences in grain yield, kernels per ear, or 100-kernel weight between glyphosate treatments or micronutrient products.

Table 2. Dry weight of three corn plants harvested at dough stage after being treated with seven micronutrient products and treated with or without glyphosate as part of standard weed control.

	Leaf		Stem		Ear	
product	**no glyphosate**	**glyphosate**	**no glyphosate**	**glyphosate**	**no glyphosate**	**glyphosate**
	---------- grams ----------					
AgXplore MicroStarter	121.8	136.6	232	254	275	308
Agrisolution Ultra-Che	133.3	115.4	250	233	287	250
Agriguardian MOLY	128.6	128.2	243	251	283	300
Wuxall Top 3	134.5	127.7	242	247	291	308
Winfield Max-IN Ultra ZMB + Max-IN Boron	128.8	127.5	236	245	283	280
ZnSO4 + MnSO4+Molybdate	130.3	120.9	259	230	288	279
Control (no product applied)	129.5	130.5	238	246	274	297
Pr>F	**ns**†	**ns**	**ns**	**ns**	**ns**	**ns**
Mean	129	126	243	244	283	289

† ns = no statistical difference within a column at P≥0.05.

Table 3. SPAD readings (avg of 5 per plant) of corn at six dates after being treated with seven micronutrient products and treated with or without glyphosate as part of standard weed control.

	Herbicide Treatment													
Product	**no glyphosate**							**glyphosate**						
	June 18	**June 26**	**July 9**	**July 16**	**Aug 1**	**Aug 10**	**mean**	**June 18**	**June 26**	**July 9**	**July 16**	**Aug 1**	**Aug 10**	**mean**
AgXplore MicroStarter	44.8	45.8	52.0	48.3	59.0	44.9	49.1	43.7	49.0	53.3	50.3	59.5	48.4	50.7
Agrisolution Ultra-Che	43.5	51.7	51.6	49.2	57.6	48.9	50.4	42.3	51.5	50.5	49.7	56.7	45.1	49.3
Agriguardian MOLY	41.7	47.3	51.4	48.4	58.0	46.8	48.9	39.8	49.7	53.6	51.2	57.9	47.3	49.9
Wuxall Top 3	44.6	50.5	53.1	48.6	56.5	47.3	50.1	45.0	49.1	51.1	47.8	57.3	44.6	49.1
Winfield Max-IN Ultra ZMB + Max-IN Boron	43.8	51.2	53.3	48.0	60.8	50.8	51.3	42.4	50.8	52.1	51.1	58.1	49.7	53.8
ZnSO4 + MnSO4+Molybdate	44.0	50.5	51.1	50.3	58.8	49.3	50.7	43.3	51.2	50.9	51.2	57.7	46.9	50.2
Control (no product applied)	43.3	49.3	51.8	49.8	59.5	45.8	49.9	43.7	50.7	52.6	50.9	57.6	47.1	50.4
Pr>F	**ns**†	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**
Mean of dates	43.8	49.6	51.7	49.0	58.4	46.5	42.9	42.9	50.4	52.4	50.3	57.3	45.9	49.6

† ns = no statistical difference within a column at P≥0.05

Table 4. Yield and yield components of corn after being treated with seven micronutrient products and treated with or without glyphosate as part of standard weed control.

product	Yield		Kernels per ear		100 kernel wt	
	no glyphosate	glyphosate	no glyphosate	glyphosate	no glyphosate	glyphosate
	----------- bu/ac ----------		-------------- No. ------------		---------- grams ----------	
AgXplore MicroStarter	190	177	628	648	29.7	29.7
Agrisolution Ultra-Che	188	177	642	637	30.0	29.9
Agriguardian MOLY	186	169	594	632	30.4	31.3
Wuxall Top 3	201	189	644	596	30.8	29.7
Winfield Max-IN Ultra ZMB + Max-IN Boron	206	194	629	607	31.5	30.5
ZnSO4 + MnSO4+Molybdate	189	189	651	610	30.7	29.5
Control (no product applied)	191	182	634	639	30.9	30.5
Pr>F	**ns**†	**ns**	**ns**	**ns**	**ns**	**ns**
Mean	193	183	632	624	30.6	30.1

† ns = no statistical difference within a column at P≥0.05.

OBJECTIVES FOR YEAR 2:

In year two we will repeat the experiment as originally proposed. We will finish tissue nutrient analyses from the 2013 season and continue with treatment and sampling protocol, and harvest yield at the end of the season. We intend to present preliminary results of this research at the 2014 ASA-CSSA-SSSA annual international meeting.

Category	**Year 2**
Personnel PhD Student	$18,500
Field cost (fertilizers, herbicide, bags, etc.)	$1,800
Tissue and seed analyses (ICP, NIR, ureide)	$2,000
Travel	$1,200
Total	**$23, 500**

Impact of micronutrient packages on soybean yields in Missouri

Felix B. Fritschi and James H. Houx III, Univ. of Missouri

Objectives and Relevance to the Missouri Fertilizer and Lime Industry:

The main objective of this research was to determine the effect of various micronutrient packages offered by the fertilizer industry on soybean yield and seed quality.
The specific objectives were to:

16) quantify the impact of pre-formulated micronutrient packages on yield and seed quality of glyphosate as well as glufosinate resistant soybean cultivars.
17) measure micronutrient uptake by the soybean plants and develop nutrient response curves.
18) determine effects of applications on soil micronutrient status.

The use of micronutrients is increasing as the costs of fungicides and pesticides have many growers and producers focused on balanced plant nutrition to optimize plant health (Brown, 2008). Pre-formulated micronutrient packages are advertised to improve yields and nutritional content of Missouri's crops. Increased yields and grain quality would translate into greater returns for Missouri producers and increased fertilizer sales. Statistics on micronutrient use and yield improvement in Missouri are scant. However, ever-higher crop yields and, with the advent of cellulosic biofuel production, increases in whole plant removal will result in more micronutrients leaving farmers' fields. This increase in micronutrients leaving the field and the potential reduction in soil supply power (associated with reductions in soil organic matter caused by the removal of not only grain yield but also crop residues) emphasize the importance to critically examine the role of micronutrient fertilization in Missouri.

Dozens of micronutrient formulations are available for the Ag market in general and soybean producers in particular (SoyScience, Pro Bean Mix, Bean Mix, and Crop Mix among others). However, evaluation of product performance by independent researchers is largely lacking, complicating the decision making process for farmers. For producers like Kip Cullers, micronutrient packages are likely a necessary management practice to meet the demands of ever-more productive soybeans. Although most producers do not aspire to achieve world record yields, applications of micronutrients may increase their yields and economic bottom line. Because glyphosate interacts with Mn both in tank mixtures and in the plant (Bernards et al., 2005), products that aim to combat glyphosate induced manganese deficiency (GIMD) may be particularly promising. However, because these products are relatively new to the Missouri market, their effect on the " average" soybean grower's yield is uncertain.

MATERIALS AND METHODS:

The study was conducted in each of three years (2011, 2012, 2013) at the Bradford Research Center near Columbia, MO. Soil pHs averaged 6.7, 7.2, and 6.9 across the research plots in 2011, 2012, and 2013, respectively. MorSoy soybean varieties RT3930N RoundUp Ready and MorSoy LL3939N LibertyLink were strip planted in 8-row, 30' long plots, in 15" rows on May 11, May 16, and June 6 in 2011, 2012, and 2013, respectively.

The following micronutrient product treatments were applied:

1) United Suppliers' Sovereign (foliar; liquid; EDTA chelate)
2) Agrium's Bean Mix (soil; granular; non-chelated oxides and sulphates)
3) Tetra Micronutrients' Pro Bean Mix (foliar; liquid; citric acid and EDTA chelates)
4) Helena's HM609 (foliar or soil; liquid; Lignosulphonate sequestered)
5) AgExplore's SoyScience (foliar; liquid; non-chelated sulphates)
6) Stoller's X-tra Power (liquid; foliar or soil; MEA chelate)
7) Tetra Micronutrient's ManGro (foliar Mn; specifically for GIMD)
8) Untreated Control

To assess the effect of herbicide interactions with the micronutrient applications the following herbicide x soybean treatments were imposed:

9) RR soybean with glyphosate applications
10) RR soybean without glyphosate applications
11) LL soybean with glufosinate applications
12) LL soybean without glufosinate applications

Foliar treatments were applied according to labeled rates and application times with a three-point tractor-mounted, telescoping sprayer with a 10' boom length. Granular, soil-applied treatments were applied with a hand spreader according to labeled rates and application times by applying one-half of the treatment while walking one direction, and the other one-half of the treatment by walking perpendicular to the first one-half application.

Final yield was determined with a research combine by harvesting the center 5 rows of each plot each year. Soybean oil and protein concentrations on a dry matter basis were determined with NIR spectroscopy on a subsample from each plot each year. Seed nutrient concentrations were determined on a subsample each year with Inductively Coupled Plasmolysis-Optical Emission Spectroscopy (ICP-OES).

Data were subjected to analysis of variance and treatment means were compared with Tukey's Honest Significant Difference test which individually compares treatment means via t-tests.

RESULTS

Biomass at R5

- Dry matter yield differed between years (P>0.0021) with 2008 resulting in the highest mean at 209 grams per five plants.
- Within any year, dry matter did not differ between soybean treated with the micronutrient products and untreated soybean.
- Across all years (2011, 2012 and 2013) and within soybean varieties and respective herbicide spray treatment, dry matter yield did not differ between soybean treated with the micronutrient products and untreated soybean (Table 1).
- Dry matter did not differ between the two soybean varieties.

Table 1. Aboveground dry matter yield of MorSoy soybean varieties at R5 across three years (2011, 2012, 2013) following treatment with seven micronutrient products and sprayed with and without respective herbicide (Glufosinate or Glyphosate) at the Bradford Research Center.

	MorSoy RT3930N (Glyphosate tolerant)		**MorSoy LL3939N (Glufosinate tolerant)**	
Micronutrient product	**Sprayed**	**No-sprayed**	**Sprayed**	**No-sprayed**
	---------------------------- grams -----------------------------			
1) United Suppliers' Sovereign	174	174	168	187
2) Agrium's Bean Mix	170	187	183	147
3) Tetra Micronutrients' Pro Bean Mix	156	182	177	162
4) Helena's HM609	158	184	183	158
5) AgExplore's SoyScience	166	172	181	178
6) Stoller's X-tra Power	184	195	190	171
7) Tetra Micronutrient's ManGro	168	169	174	167
8) Untreated Control	168	162	194	184
Mean	168	178	181	169
Statistical significance (Pr>F)	ns[†]	ns	ns	ns

[†] ns =values within the column are not statistically different from each other at the 0.05 probability level.

Soybean yield

- Yield differed among years (P>0.0021) with 2012 resulting in the highest mean at 56.96 bu/ac.
- Within any year, yields were not different between soybean treated with the micronutrient products and untreated soybean.
- Across all years (2011, 2012 and 2013) and within soybean varieties and respective herbicide spray treatment, yields did not differ between soybean treated with the micronutrient products and untreated soybean (Table 2).
- Yield did not differ between the two soybean varieties.

Table 2. Mean yield of MorSoy soybean varieties across three years (2011, 2012, 2013) following treatment with seven micronutrient products and sprayed with and without respective herbicide (Glufosinate or Glyphosate) at the Bradford Research Center.

	MorSoy RT3930N (Glyphosate tolerant)		**MorSoy LL3939N (Glufosinate tolerant)**	
Micronutrient product	**Sprayed**	**No-sprayed**	**Sprayed**	**No-sprayed**
	---------------------------- bu/ac -----------------------------			
1) United Suppliers' Sovereign	49.06	52.21	51.08	51.67
2) Agrium's Bean Mix	45.09	49.35	48.86	53.13
3) Tetra Micronutrients' Pro Bean Mix	44.22	51.18	45.13	48.07
4) Helena's HM609	53.32	51.90	45.21	46.94
5) AgExplore's SoyScience	49.18	48.64	46.89	47.66
6) Stoller's X-tra Power	52.09	48.89	50.10	43.74
7) Tetra Micronutrient's ManGro	49.07	50.80	42.97	43.92
8) Untreated Control	50.39	47.74	42.44	49.39
Mean	49.05	50.09	46.59	48.06
Statistical significance (Pr>F)	ns[†]	ns	ns	ns

[†] ns =values within the column are not statistically different from each other at the 0.05 probability level.

Seed Oil Concentration

- There was no difference in soybean oil concentration among years.
- Within any year, soybean oil concentration did not differ between soybean treated with the micronutrient products and untreated soybean.
- Across all years (2011, 2012 and 2013) and within varieties and respective herbicide spray treatments, soybean oil concentration did not differ between soybean treated with the micronutrient products and untreated soybean (Table 3).
- Oil concentration did not differ between the two soybean varieties.
- However, across years, varieties, and spray treatments oil concentration was greater in soybean treated with Helena HM609 than in soybean treated with United Supplier's Sovereign.
- There was no difference in oil concentration between each cultivar and herbicide application, nor a difference in oil between years.

Table 3. Mean seed oil concentration (as percent) of MorSoy soybean varieties across three years (2011, 2012, 2013) following treatment with seven micronutrient products and sprayed with and without respective herbicide (Glufosinate or Glyphosate) at the Bradford Research Center.

Micronutrient product	MorSoy RT3930N (Glyphosate tolerant)		MorSoy LL3939N (Glufosinate tolerant)		Mean across years, varieties, and herbicide applications
	Sprayed	Not sprayed	Sprayed	Not sprayed	
	%				
1) United Suppliers' Sovereign	21.29	19.70	20.88	20.93	20.70 b
2) Agrium's Bean Mix	21.44	21.23	21.11	21.08	21.22 ab
3) Tetra Micronutrients' Pro Bean Mix	21.00	21.32	20.86	20.90	21.02 ab
4) Helena's HM609	21.48	21.65	21.18	21.04	21.34 a
5) AgExplore's SoyScience	21.23	21.55	20.94	21.14	21.22 ab
6) Stoller's X-tra Power	21.06	21.44	20.89	21.10	21.12 ab
7) Tetra Micronutrient's ManGro	21.21	21.42	20.84	21.07	21.14 ab
8) Untreated Control	21.30	21.46	21.23	21.26	21.31 ab
Mean	21.25	21.22	20.99	21.07	21.13
Statistical significance (adj. P)	ns	ns	ns	ns	0.05

Seed Protein Concentration

- Seed protein concentration differed among years *($P<0.001$)*, with 2013 having the highest amount of protein at 41.68 %.
- Within any year, soybean protein concentration did not differ between soybean treated with the micronutrient products and untreated soybean.
- Across all years (2011, 2012 and 2013) and within varieties and respective herbicide spray treatments, soybean protein concentration did not differ between soybean treated with the micronutrient products and untreated soybean (Table 4).
- Protein concentration did not differ between the two soybean varieties.

Table 4. Mean seed protein concentration (as percent) of MorSoy soybean varieties across three years (2011, 2012, 2013) following treatment with seven micronutrient products and sprayed with and without respective herbicide (Glufosinate or Glyphosate) at the Bradford Research Center.

Micronutrient product	MorSoy RT3930N (Glyphosate tolerant) Sprayed	MorSoy RT3930N (Glyphosate tolerant) No-sprayed	MorSoy LL3939N (Glufosinate tolerant) Sprayed	MorSoy LL3939N (Glufosinate tolerant) No-sprayed
	%			
1) United Suppliers' Sovereign	40.13	37.00	40.77	40.49
2) Agrium's Bean Mix	40.23	40.62	40.48	40.38
3) Tetra Micronutrients' Pro Bean Mix	40.19	40.13	40.58	40.61
4) Helena's HM609	39.94	39.90	40.44	40.59
5) AgExplore's SoyScience	40.33	39.88	40.60	40.22
6) Stoller's X-tra Power	40.12	39.87	40.74	40.64
7) Tetra Micronutrient's ManGro	40.35	40.74	40.76	40.34
8) Untreated Control	40.34	40.37	40.39	40.52
Mean	40.20	39.81	40.59	40.47
Statistical significance (Pr>F)	ns	ns	ns	ns

Seed ICP Nutrient Analysis

- Total nutrient analysis of seed from 2011 revealed there was no influence of micronutrient product application on seed nutrient concentration (P, K, Ca, Mg, S, Fe, Mn, Cu, and B) (Table 5).
- Zinc concentration was greater from the untreated control than from Stoller's X-tra Power treatment.
- Seed micronutrient composition was different between varieties, MorSoy RT3930N and MorSoy LL3939N *(P<0.001)*, but there was no difference between spray treatments within a variety.

Table 5. Mean soybean seed composition averaged across soybean variety and herbicide spray regimen as affected by six micronutrient treatments.

	P	K	Ca	Mg	SO_4	Fe	Mn	Zn	Cu	B
	g/kg					mg/kg				
United Suppliers' Sovereign	0.51	1.64	0.23	0.19	0.26	62.1	0.88	32.5AB	10.3	16.9
Tetra Micronutrients' Pro Bean Mix	0.52	1.64	0.23	0.19	0.26	58.5	0.93	31.7AB	10.2	17.6
AgExplore's SoyScience	0.50	1.64	0.23	0.18	0.26	60.6	0.93	31.0AB	10.1	16.5
Stoller's X-tra Power	0.51	1.66	0.23	0.19	0.26	62.7	0.88	30.5 B	10.3	18.1
Tetra Micronutrient's ManGro	0.51	1.64	0.23	0.18	0.26	58.9	0.88	32.0AB	10.0	16.2
Untreated Control	0.51	1.64	0.24	0.18	0.26	63.5	0.90	33.1 A	10.3	18.3
Pr>F†	0.63	0.90	0.07	0.41	0.43	0.13	0.30	0.01	0.74	0.31

† values greater than 0.05 are not considered statistically significant.

Conclusion:

The lack of yield response or differences in oil and protein concentration during this three year study suggest that micronutrient treatments of soybean using commercially available products may not influence yield and seed quality in this region of Missouri. Soybeans did not benefit from additional micronutrients applied to them when grown in soils that are not considered micronutrient deficient even when soil pH is greater than 6.5. These products may work to alleviate specific soil micronutrient deficiencies in fields were soil test indicate low levels of micronutrients, but this was not tested in this study.

- This year was the third and final year of the project evaluating micronutrient packages on soybean yield, micronutrient uptake and soil micronutrient status.

We presented our preliminary data on both yield and seed quality at the 2012 ASA-CSA-SSSA Annual Meeting in Cincinnati Ohio. We had a great deal of interest in our project poster and our findings from

Evaluation of Micronutrient Packages for Cool-season grass Pastures

Investigator: Robert L. Kallenbach and Brent Myers

Objectives and relevance of project: Several new fertilizer products are being offered to forage producers. Although some of these products have no real scientific basis (raw milk, sea salt, etc.), there are several new products that legitimately could alleviate secondary or micronutrient deficiencies. Fertilization with secondary and micro-nutrients has not been widely recommended or practiced in Missouri, but interest in these nutrients has increased as feed prices have jumped. Offered by several well-established fertilizer companies, producers and fertilizer dealers are naturally curious as to the effectiveness of these products on pastures. At present, there is little independent research data examining the use of these products on cool-season grass pastures.

The **overall objective** is to develop research-based recommendations that help industry personnel and farmers determine if fertilization with commercially available secondary and/or micro-nutrient packages improves cool-season grass pasture growth. Specific objectives are:

Objective 1: Determine if adding a commercially-available secondary or micro-nutrient product to an existing fertilizer program improves the growth response of cool-season grass pastures.

Objective 2: Determine if these products change forage palatability or utilization by livestock.

Objective 3: Determine if these products change forage nutritive value.

Procedures:
Treatments: This experiment tested 12 unique fertilizer products on cool-season grass pastures. The products are listed in the table below.

Product	Supplier
MicroEssentials SZ	Mosaic
MicroEssentials S15	Mosaic
Megafol	Valagro
Elemax	Helena
Bio-Forge	Stoller
Humic 20	United Suppliers
Black Label Zn	Loveland
LoKomotive	Loveland
Versa Max	Rosens
Lignin Magnesium	AgXplore
Lignin Manganese	AgXplore
MicroScience	AgXplore

Each product was tested under both a low and a high yield scenario. In the low yield scenario, 50 lb/acre of N was applied as a basic fertility treatment and then the products listed above applied at the manufacturers recommended rate. For the high yield scenario, N-P-K was applied according to soil test results with a yield goal of 3 tons per acre. This low/high yield scenario comparison should indicate if the use of these new products is more likely to be beneficial at higher production levels or if it is beneficial at all production levels. Finally, check treatments where no fertilizer was applied were included. In total there were 27 treatment combinations tested [12 fertilizer products x 2 yield scenarios = 24 treatment plus 3 controls (low yield, high yield, and no fertilizer)].

Cultural practices: This study was conducted on established tall fescue pastures at the Forage Systems Research Center near Linneus, MO.
Design: Treatments were replicated six times in a randomized complete block design of a split block arrangement. Individual plots were 20 ft. x 20 ft.
Measurements:

Forage yield and growth rates. Pasture yield was measured weekly using an ultra-sonic feed reader (Figure 1). The ultra-sonic reader was calibrated by mechanically harvesting forage from dedicated yield strips.

Animal palatability and utilization.

In order to best evaluate the products for pasture use, we tested under grazing conditions. Once the pasture reached about 8 inches, livestock were introduced at a temporal stocking rate of 50 to 60 hd/acre (Figure 2). At this stocking rate, forage was grazed to a 2-3 inch stubble within 24 hours. To assess palatability of the forage, a representative set of livestock were fitted with GPS collars. The GPS collars track and record livestock location every second (1 Hz). Each recording or "fix" during the grazing period was associated with an individual plot. Previous research from our lab shows that these fixes correlate well with grazing time, and thus animal preference for forage.

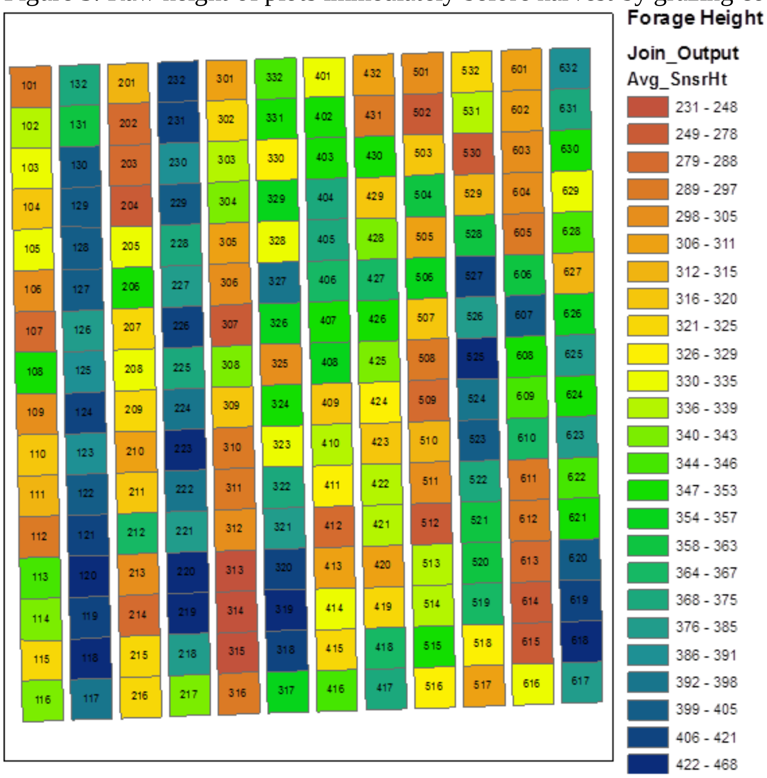
Preliminary Results:

Forage yield was about 11% greater under the high yield scenario when compared to the low yield scenario (Figure 3). Micronutrient packages that contained Zn appeared to yield slightly more than the controls, however, the yield differences in 2013 were small (less than 100 lb/acre). We are still analyzing the GPS collar data, but it appears that animal preference is not altered by application of micronutrients. We want to stress our data are preliminary and that further long-term testing will be needed to confirm these results.

Figure 3. Forage height being measured with an ultrasonic reader.

Figure 4. Cows grazing tall fescue treated with different micronutrient products under high and low soil fertility scenarios.

Figure 5. Raw height of plots immediately before harvest by grazing cows.



Budget for 2014:

YEAR 2 (2014)

<u>Salary and Benefits</u>	
Research Specialist (20% of $58,710)	$11,742
Benefits for Research Specialist	$3,757
Total Salary and Benefits	$15,499
<u>Operating Expenses</u>	
Fertilizer, bags, repair parts for harvester and other field supplies	$3,740
NIR charges for forage quality analysis (216 samples @ $5 each)	$1,080
Wet chemistry for NIR calibration (60 samples @ $24 each)	$1,440
Travel to research location (mileage, lodging, and meals for 8 trips/yr)	$1,600
Total Operating Expenses	$7,860
<u>Equipment</u>	
None requested	$0
Total Equipment	$0
Total Proposal Request for Year #2	$23,359

2014

Comparison of Impregnated Dry Fertilizer with S and Zn to Blends for Corn

Investigators:
Kelly Nelson, Div. of Plant Sci., Univ. of MO, Novelty; Matthew Caldwell, Div. of Plant Sci., Univ. of MO, Novelty; Chris Dudenhoeffer, Greenley Research Center, Univ. of MO, Novelty; Bruce Burdick, Hundley-Whaley Center, Univ. of MO, Albany; Peter Motavalli, Dep. of Soil, Environ., and Atmos. Sci., Univ. of MO, Columbia; and Manjula Nathan, Div. of Plant Sci., Univ. of MO, Columbia.

Objective and Relevance:

High yielding corn and soybean production systems in Missouri have renewed an interest in secondary macronutrient management such as sulfur which is essential for protein formation and Zn which is important for enzymes and metabolic reactions. Yield increases to sulfur applications are more likely to occur during cool, wet springs when mineralization and crop growth are slow as a result of a decrease in atmospheric sulfur deposition. Soil tests in 2010 indicated that over 60% of the samples in upstate Missouri had low ($\leq$0.6 ppm) to medium (0.7 to 1.0 ppm) soil test Zn (Nathan, unpublished). Similarly, over 70% of the soil test samples were very low to medium for Bray 1P.

Fertilizer manufacturing has progressed to accommodate more uniform distribution of nutrients in an individual fertilizer granule. Each prill is formulated to contain N, P, S, and/or Zn rather than a blended product that includes individual prills of individual nutrients. In a blend, there may be a certain amount of segregation that may occur which often affects the uniformity of distribution when the blended fertilizer is applied in the field. This poor distribution of applied blended fertilizer may be significant for recommendations of 5 to 10 lbs of Zn/acre. Typically, soluble S sources, such as ammonium sulfate or ammonium thiosulfate, are recommended over elemental S and $ZnSO_4$ which is a common source of Zn.

Impregnated granules where S and Zn are added in layers to the MAP prill allows for a more uniform distribution of fertilizer which allows roots to have a higher probability of contact with the fertilizer granule and may enhance fertilizer efficiency. Mosaic has formulated MES10 (12-40-0-10S) and MESZ (12-40-0-10S-1Zn) with two forms of sulfur (50% sulfate and 50% elemental S). MESZ includes Zn as zinc oxide. These formulations are targeted primarily for corn, soybean, wheat, and rice. This combination has been promoted to increase P uptake up to 30%. The availability of Zn to the plant has been promoted as being 10 to 45% greater with the Mosaic product.

The objectives of this research are to 1) evaluate P rates of MES10 and MESZ formulations to equivalent blends of MAP, Zn, and S, and 2) evaluate $ZnSO_4$ rates in a blend with MAP or DAP compared to MES10 and MESZ formulations on grain yields and uptake of micronutrients in a corn-soybean rotation.

Materials and Methods:

- Field research was conducted at two locations (Novelty and Albany) in 2013 and 2014.
    - Corn plots were established in 2013 at both locations. Previous research conducted in 2011 and 2012 at Novelty was also reported. Initial soil characteristics 0-6 inches deep for objectives #1 and #2 are reported in Table 1.
    - Additional corn plots were established in 2014 and will be followed by soybean in 2015 for objective #1.
    - For objective #2, corn response was evaluated in 2014 and the subsequent soybean response will be evaluated in 2015.

- The treatments at each site were arranged as randomized complete block designs with 4 and 5 replications at Albany and Novelty, respectively.
- Soil test P, Zn, and SO_4-S at a 6 inch depth following corn was evaluated in 2013 and 2014.
- Corn ear leaf tissue P, Zn and SO_4-S samples for 2013 were analyzed by the University of Missouri Soil and Plant Testing Lab, and are currently being analyzed for 2014.
- Field and management formation for objective #1 is presented in Table 2 and objective #2 is presented in Table 3.

- Objective 1: Evaluate P rates of MES10 and MESZ formulations compared to equivalent blends of MAP, Zn, and S. Treatments are listed in Tables 4 and 5.
  - Field management information for the corn sites at Albany in 2013 & 2014 and Novelty in 2011-2014 as well as the rotational crop (soybean) response at Albany in 2014 and Novelty in 2012-2014 are reported in Table 2. Soybean plots had no additional fertilizer application and were in the same location as the corn plots the previous year.
  - Corn grain yields were reported for Albany in 2013 & 2014 and Novelty in 2011-2014. Yields were adjusted to 15% moisture content prior to analysis.
  - Soybean yields following corn treatments were reported for Novelty (2011-2013) and Albany (2013). Yields were adjusted to 13% moisture content prior to analysis.
- Objective 2: Evaluate $ZnSO_4$ rates in a blend with MAP or DAP compared to MES10 and MESZ formulations. Treatments are listed in Table 6.
  - Field management information for the corn sites at Albany in 2013 (continuous corn and corn following soybean sites) & 2014 as well as Novelty (2011-2014), while the rotational crop (soybean) response at Albany in 2014 and Novelty in 2012-2014 is reported in Table 3. Soybean plots had no additional fertilizer application and were in the same location as the corn plots the previous year.
  - Corn yields were reported for Albany continuous corn and corn following soybean (rotation) in 2013 & 2014 and Novelty (2011-2014). Yields were adjusted to 15% moisture content prior to analysis.
  - Soybean yields following corn treatments in 2011-2013 were reported for Novelty as well as Albany in 2013. Yields were adjusted to 13% moisture content prior to analysis.

Results:

All of the sites had very low to medium soil test P, except for the corn-soybean rotation site at Albany for objective 2 (Table 1). Similarly, soil test SO_4-S was medium for all of the sites except for the corn-soybean rotation site at Albany for objective 2. Soil test Zn was low to medium at all of the Novelty sites, but was medium to high at the Albany sites.

Objective 1

Corn plant population was 27,000 to 33,000 plants/acre at Novelty (2011-2013) and no differences among treatments were observed at Albany (data not presented). There was no effect of fertilizer treatments on grain moisture at Albany or Novelty, while there was no difference in test weight at Novelty (data not presented).

Rainfall was above average in the spring of 2011 which was followed by moderately dry conditions during the summer. Corn grain yields were greatest with MESZ at 110 lbs P_2O_5/acre (151 bu/acre), MES10 at 110 lbs P_2O_5/acre (150 bu/acre), and MAP at 110 lbs P_2O_5/acre (150 bu/acre) at Novelty in 2011 (Table 4). All treatments were similar to MESZ at 110 lbs P_2O_5/acre except MAP at 70 lbs P_2O_5/acre, urea at 28 lbs N/acre, and urea at 46 lbs N/acre. No significant differences among treatments were observed at Novelty in 2012 or 2013, which was probably related to extremely dry conditions in 2012 and a flash drought in 2013. Grain yields at Albany in 2013 were greatest with MAP + $ZnSO_4$ + AMS at 110 lbs P_2O_5/acre (148 bu/acre), MAP at 110 lbs P_2O_5/acre (147 bu/acre), MAP + AMS at 110 lbs P_2O_5/acre (147 bu/acre), MES10 at 110 lbs P_2O_5/acre (146 bu/acre), and MESZ at 110 lbs P_2O_5/acre (145 bu/acre). Reduced rates of MAP (75 lbs P_2O_5/acre) were generally lower than MAP + $ZnSO_4$ + AMS at 110 lbs P_2O_5/acre. In 2014, the Novelty site experienced a high yield environment. At Novelty, treatments with the higher rate of P (100 lbs P_2O_5/acre) had higher yields compared to no additional P in 2014. All treatments increased corn yields compared to the P control at Albany in 2014. In general there was no significant difference between P applied at 70 and 110 lbs P_2O_5/acre, but yields were usually greater at 110 lbs P_2O_5/acre compared to 70 lbs P_2O_5/acre.

No differences among soybean yields were detected in 2012 or 2014 following fertilizer treatments to corn in 2011 and 2013, respectively. However, soybean yields (35 to 36 bu/acre) were similar for MESZ at 110 lbs P_2O_5/acre, MAP + AMS at 110 lbs P_2O_5/acre, MAP + $ZnSO_4$ + AMS at 75 or 110 lbs P_2O_5/acre, and urea at 46 lbs N/acre in 2012.

There was no difference in soil test P levels following corn at Novelty in 2013 (Table 5). All fertilizer treatments with Zn except MESZ at 110 lbs P_2O_5/acre increased soil test Zn concentrations compared to treatments without Zn at Novelty in 2013. No differences among Zn rates were detected. Soil test SO_4-S was greatest with MES10 at 18 lbs S/acre, which was similar to MES 10 at 28 lbs S/acre, MESZ at 18 or 28 lbs S/acre, and MAP + AMS at 28 lbs S/acre. These treatments increased soil test SO_4-S concentrations compared to the other treatments. At Novelty, ear leaf P concentration increased with MESZ at 110 lbs P_2O_5/acre, and all MAP treatments except MAP + $ZnSO_4$ + AMS at 70 lbs P_2O_5/acre compared to the non-treated control in 2013. MAP + AMS at 110 lbs P_2O_5/acre had the highest ear leaf P concentration (0.308 %) which was similar to MESZ and the other MAP treatments applied at 110 lbs P_2O_5/acre. In 2014, MAP at 70 lbs P_2O_5/acre, MAP at 110 lbs P_2O_5/acre + $ZnSO_4$, and all MES10 and MESZ treatments increased ear leaf P concentration compared to the non-treated control. However, no differences in Zn or S concentrations were detected in 2013 or 2014 on soils with medium S and low to medium Zn. Soil test Zn levels were greatest at Novelty (Table 1) compared to previous years.

In summary, average corn grain yields were similar with MAP at 110 lbs P_2O_5/acre and MESZ at 110 lbs P_2O_5/acre (146 bu/acre) followed by MAP + $ZnSO_4$ + AMS at 110 lbs P_2O_5/acre (144 bu/acre). However, MESZ at 110 lbs P_2O_5/acre, MES10 at 110 lbs P_2O_5/acre, MAP at 110 lbs P_2O_5/acre + AMS, MAP at 110 lbs P_2O_5/acre + $ZnSO_4$ + AMS, and urea at 46 lbs N/acre had the highest average soybean yields (47 bu/acre) the following year.

Objective 2

Grain moisture and plant populations were generally similar among treatments following corn or soybean at Albany and following soybean at Novelty (data not presented). Corn test weight was lowest in the non-treated, no N control at Novelty and N only treatments in two of the years evaluated, but limited differences were observed among Zn treatments (data not presented).

MAP or DAP were treated with a liquid formulation of Super Zinc (Helena Chemical Co., 2255 Schilling Blvd, Suite 300, Collierville, NT 38017) in 2013 and 2014. At Novelty, corn grain yield was highest with MESZ and MAP + SuperZn + AMS in 2011; MESZ, non-treated and no N control, and N only in 2012, and MESZ, MAP + $ZnSO_4$ (5 lbs Zn/acre) + AMS, MAP + SuperZn (5 lbs Zn/acre) + AMS, and DAP + AMS in 2013 (Table 6). In 2014, several high yielding treatments MAP + $ZnSO_4$ at 5 lbs/acre + AMS and DAP + $ZnSO_4$ at 2 lbs/acre + AMS had yields that were 10 bu/acre greater than MAP alone. Average corn yield for the 5 site-years evaluated to date ranked MESZ (109 bu/acre), MES10 (105 bu/acre) = MAP + $ZnSO_4$ (5 lb Zn/acre) + AMS (105 bu/acre), and DAP (104 bu/acre). Average soybean yields were 49 bu/acre with the N only control, MESZ, DAP, and DAP + $ZnSO_4$ at 5 lbs/acre + AMS, but there was no significant treatment effect on soybean yields within 2012, 2013, or 2014.

All treatments increased ear leaf P concentration compared to the non-treated, no N control at Novelty in 2013 (Table 7). The inclusion of MAP or DAP generally increased ear leaf P concentration compared to the N only treatment. There were limited differences in P concentration among P treatments at Novelty in 2013 and no differences between treatments in 2014. In general, treatments increased ear leaf S and Zn concentration compared to the non-treated, no N control at Novelty in 2013 and ear leaf Zn concentration at Novelty in 2014, but treatments with S and Zn had ear leaf concentrations that were similar to the N only control. Ear leaf Zn concentration was greatest with MESZ and DAP + AMS at Albany in continuous corn, but inconsistent differences among treatments were observed at this location. Ear leaf S was greatest with DAP + AMS, but differences among treatments were inconsistent.

At Novelty, all treatments increased soil test P compared to the non-treated, no N control (Table 8). MAP or DAP + $ZnSO_4$ + AMS at 2 lbs Zn/acre and MAP or DAP + Super Zn + AMS at 5 lbs Zn/acre increased soil test Zn 1.2 to 2.9 ppm compared to the non-treated controls. MES 10 and MESZ increased soil test S compared to the N only control, while blends of MAP +/- Zn at 2 lbs/a + AMS and DAP + Super Zn at 2 lbs/a or $ZnSO_4$ + AMS significantly increased soil test S compared to the N only control.

There was no difference in ear leaf P, Zn, or S concentration among treatments at Albany with a corn-soybean rotation (Table 7), which was probably due to the high soil test P, Zn, and S at this location (Table 1). Similarly, no difference in soil test P or Zn was observed at the Albany site in a corn-soybean rotation (Table 8). Nonetheless, S concentrations were increased with MES10, MAP + AMS, and DAP + Super Zn + AMS.

The continuous corn site at Albany had several treatments that increased soil test P concentration, but Zn treatments had no significant impact on soil test Zn concentration when compared to the no-treated controls. When compared to the N only control, SO_4–S in the soil increased with all treatments that included a S additive. Soil test SO_4–S was similar between MES10 and MESZ when compared to the addition of AMS.

Summary:

- In objective 1, the carry over effect of fertilizer treatments from corn to soybean indicated MESZ and MAP at 110 lbs P_2O_5/acre had the highest average corn (6 site-years) yields, while urea at 46 lbs N/acre, MES10, MESZ, MAP + AMS, and MAP + $ZnSO_4$ + AMS at 110 lbs P_2O_5 had the highest average soybean yields (4 site-years).
- In objective 2, corn grain yields were ranked MAP + $ZnSO_4$ at 5 lbs/acre + AMS (133 bu/acre), MAP (131 bu/acre), and MAP + $ZnSO_4$ at 2 lbs/acre + AMS = DAP + $ZnSO_4$ at 2 lb/acre + AMS (130 bu/acre) for 7 site-years. Soybean yields following the same plots as corn were similar for the N only control, MESZ, DAP, and DAP + $ZnSO_4$ at 5 lbs/acre + AMS treatments.

Importance of micronutrients in maximizing corn yield

Felix B. Fritschi and James H. Houx III Univ. of Missouri

Objectives and Relevance to the Missouri Fertilizer and Lime Industry:

The main objective of this research is to determine the impact of various micronutrient packages offered by the fertilizer industry on corn yield.

The specific objectives are to:

19) Quantify the impact of pre-formulated micronutrient packages on corn yield.
20) Determine plant tissue concentration of applied micro- and macronutrients.
21) Determine differences in nutrient uptake and yield between glyphosate- and non-glyphosate treated corn.

The use of micronutrients is increasing as the costs of fungicides and pesticides have many growers and producers focused on balanced plant nutrition to optimize plant health (Brown, 2008). Pre-formulated micronutrient packages are advertised to improve yields and nutritional content of Missouri's crops. Increased yields would translate into greater returns for Missouri producers and increased fertilizer sales. Statistics on micronutrient use and yield improvement in Missouri are scant. However, ever-higher crop yields and, with the advent of cellulosic biofuel production, increases in whole plant removal will result in more micronutrients leaving farmers' fields. This increase in micronutrients leaving the field and a potential reduction in soil supply power (associated with reductions in soil organic matter caused by the removal of not only grain yield but also crop residues) emphasize the importance to critically examine the role of micronutrient fertilization on corn in Missouri.

2014 ACCOMPLISHMENTS:

- This year was the second year for the project evaluating micronutrient applications on corn yield and development.
- Treatments 1 through 7 listed below were applied to Pioneer corn hybrid 32D79 in 2013 and in 2014 treatment 8 was also included and Pioneer corn hybrid P0636AMX was planted. Main plots were weed control with glyphosate and weed control based on conventional herbicides. Corn was planted in 40' long plots on a 30" row spacing for a target stand density of 32,000 plants per acre. The following treatments were applied in six replicates.
    1) AgXplore's MicroStarter
    2) Agrisolutions' Ultra-Che Corn Mix
    3) Agrigaurdian's MOLY
    4) Wuxall Top 3
    5) Agrisolutions Max IN ZMB + Max-IN Boron
    6) Inorganic Zn sulfate, Mn sulfate, Molybdate
    7) untreated control
    8) Biotic 8-5-5 Chicken Litter Fertilizer
- In-furrow treatments (treatments 1 and 2 above) were applied at recommended rates at planting with a 4-row planter equipped with an in-furrow liquid application system.
- Foliar treatments (treatments 3-6 above) were applied at recommended rates and times with a three-point tractor mounted, telescoping sprayer with a 10' boom length.
- Treatment 8 was applied and incorporated prior to planting.

- Data were taken on plant height and chlorophyll concentration (SPAD) over the course of the growing season.
- Whole plant samples were collected at V6 and dough developmental stages.
- Grain yield and yield components were determined at the end of the season.
- Tissue processing for compositional analysis is on-going at this time.

2014 PRELIMINARY RESULTS:
NOTE: Results are preliminary
Biomass sampling at V6: No differences in leaf or stem biomass were found between fertilizer treatments. Similarly, no differences were observed between herbicide regimes. At the first biomass sampling at V6, with conventional herbicides, corn leaf dry matter averaged 116.8g and corn stem dry matter averaged 76.8 g. In the glyphosate treated plots, leaf dry matter averaged 122.7 g and corn stem dry matter averaged 76.9g (Table 1).

Table 1. Dry matter yield of six corn plants harvested at V6 stage divided by treated with or without glyphosate as part of standard weed control.

PLANT PART	no glyphosate	glyphosate
	grams	
STEM	76.79	76.89
LEAF	116.77	122.74
TOTAL	193.56	199.63
Pr>f	**ns**[†]	**ns**

[†] ns = no statistical difference within a column at P≥0.05.

Biomass sampling at dough stage: At the second biomass sampling at dough stage, leaf dry matter averaged 239.6g and stem dry matter averaged 98.05 g in the treatment with weed control based on conventional herbicide. In the glyphosate treatment, leaf dry matter averaged 200.8 g and stem dry matter averaged 98.04g. Remaining samples are still being processed.

SPAD readings: SPAD readings (a surrogate estimate of nitrogen status) were taken approximately six times during the growing season. Five measurements were taken on the most recent, fully expanded leaf of five different plants in each plot. As expected, SPAD increased as the season progressed and the highest readings were taken approximately two weeks after tasseling. Further analysis of SPAD data is necessary for reporting.

Grain yield: Grain yields did not differ among fertilization treatments. Grain yield in the conventional herbicide treatment, ranged from 128 bu/ac to 144 bu/ac with a mean of 136 bu/ac (Table 3). In the glyphosate treatment grain yield ranged from 119 bu/ac to 134 bu/ac with a mean of 127 bu/ac. Analysis of yield components is ongoing.

Table 3. Yield in response to eight nutrient products and weed control based on conventional herbicides and glyphosate.

Product	Yield	
	no glyphosate	**glyphosate**
	----------- bu/ac ----------	
AgXplore MicroStarter	128	119
Agrisolution Ultra-Che	144	128
Agriguardian MOLY	130	124
Wuxall Top 3	144	130
Winfield Max-IN Ultra ZMB + Max-IN Boron	140	134
ZnSO4 + MnSO4+Molybdate	139	127
Control (no product applied)	132	126
Biotic 8-5-5 Chicken fert.	135	130
Pr>F	**ns**	**ns**
Mean	136	127

† ns = no statistical difference within a column at P≥0.05.

OBJECTIVES FOR YEAR 3:

The third year of field experiments will be conducted and nutrient analyses will be completed. We intend to present preliminary results of this research at the 2015 ASA-CSSA-SSSA annual international meeting.

Category	**Year 3**
Personnel PhD Student	$18,500
Field cost (fertilizers, herbicide, bags, etc.)	$1,800
Tissue and seed analyses (ICP, NIR)	$2,000
Travel	$1,200
Total	**$23, 500**

Evaluation of Micronutrient Packages for Cool-season grass Pastures

Investigator: Robert L. Kallenbach and Brent Myers

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The **overall objective** is to develop research-based recommendations that help industry personnel and farmers determine if fertilization with commercially available secondary and/or micro-nutrient packages improves cool-season grass pasture growth. Specific objectives are:

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Procedures:
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Lignin Magnesium	AgXplore
Lignin Manganese	AgXplore
MicroScience	AgXplore

Each product was tested under both a low and a high yield scenario. On 20 March 2013, 50 lb/acre of N was applied as a basic fertility treatment to plots in the low yield scenario, and then the products listed above were applied at the manufacturers recommended rate. For the high yield scenario, N-P-K was applied to the appropriate plots at 200-75-250, according to soil test results with a yield goal of 3 tons per acre. Lime was not required on the plots this year. This low/high yield scenario comparison should indicate if the use of these new products is more likely to be beneficial at higher production levels or if it is beneficial at all production levels. Finally, check treatments where no fertilizer was applied were included. In total there were 27 treatment combinations tested [12 fertilizer products x 2 yield scenarios = 24 treatment plus 3 controls (low yield, high yield, and no fertilizer)].

Cultural practices: This study was conducted on established tall fescue pastures at the Forage Systems Research Center near Linneus, MO.
Design: Treatments were replicated six times in a randomized complete block design of a split block arrangement. Individual plots were 20 ft. x 20 ft.
Measurements:

<u>Forage yield and growth rates</u>. Pasture yield was measured weekly using an ultra-sonic feed reader (Figure 1). The ultra-sonic reader was calibrated by mechanically harvesting forage from dedicated yield strips.

<u>Animal palatability and utilization.</u>

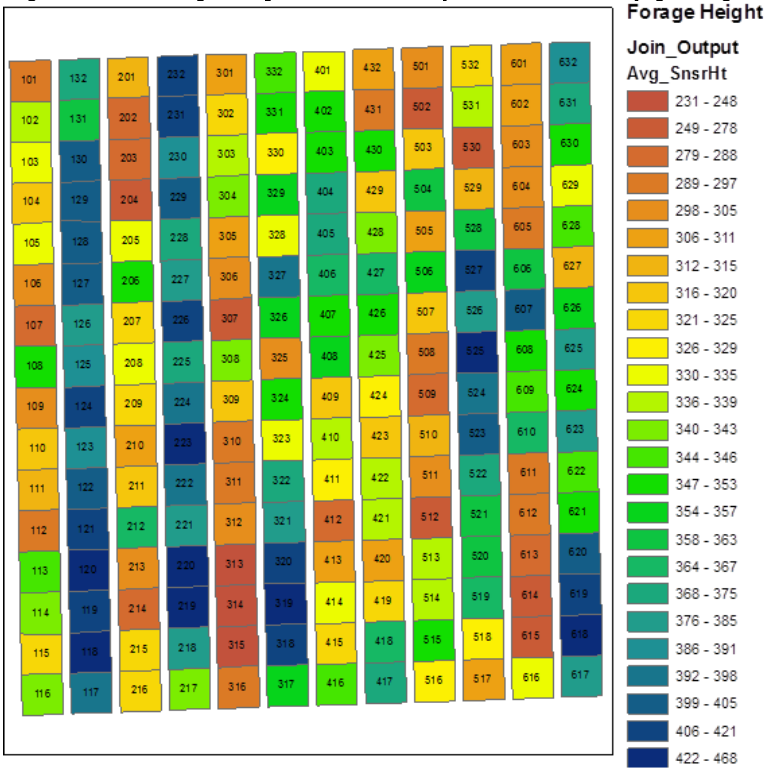
In order to best evaluate the products for pasture use, we tested under grazing conditions. Once the pasture height reached about 8 inches, livestock were introduced at a temporal stocking rate of 50 to 60 hd/acre (Figure 2). At this stocking rate, forage was grazed to a 2-3 inch stubble within 24 hours. To assess palatability of the forage, a representative set of livestock were fitted with GPS collars. The GPS collars track and record livestock location every second (1 Hz). Each recording or "fix" during the grazing period was associated with an individual plot. Previous research from our lab shows that these fixes correlate well with grazing time, and thus animal preference for forage.

Preliminary Results:
Forage yield was about 30% greater under the high yield scenario when compared to the low yield scenario (Figure 3). Micronutrient packages that contained Zn appeared to yield slightly more than the controls, however, the yield differences in 2014 were small (less than 100 lb/acre). We are still analyzing the GPS collar data, but it appears that animal preference is not altered by application of micronutrients. We want to stress our data are preliminary and that further long-term testing will be needed to confirm these results.

Figure 6. Forage height being measured with an ultrasonic reader.

Figure 7. Cows grazing tall fescue treated with different micronutrient products under high and low soil fertility scenarios.

Figure 8. Raw height of plots immediately before harvest by grazing cows.



Budget for 2015:

YEAR 3 (2015)

<u>Salary and Benefits</u>	
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Benefits for Research Specialist	$3,757
Total Salary and Benefits	$15,499
<u>Operating Expenses</u>	
Fertilizer, bags, repair parts for harvester and other field supplies	$3,740
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Travel to research location (mileage, lodging, and meals for 8 trips/yr)	$1,600
Total Operating Expenses	$7,860
<u>Equipment</u>	
None requested	$0
Total Equipment	$0
Total Proposal Request for Year #2	$23,359

Miscellaneous Studies

Progress Reports

2013

A Long-Term Study to Further Enhance Variable Rate Fertility Management

Investigator(s):
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Objectives:

The objectives of this project are:

1) To evaluate proposed changes in University of Missouri fertilizer recommendations in variable rate fertility management of P and K as relates to soil test critical values.

2) To gain a better understanding of how yield map data can be used to fine tune removal rates of P and K in a variable rate fertility system.

3) Provide producers and service providers the production and economic information necessary to make more informed variable rate fertility management decisions.

The main goal of the project is to better understand how producers can further improve the efficiency of variable rate fertility management of P and K while maintaining or improving crop yields. With the volatility of P and K prices, being able to further improve fertilizer use efficiency is important in today's production system. The result of the project also has the potential to further increase the adoption of variable rate technologies which not only effects profitability but in the end it also protects the environment.

Procedures:

In the spring of 2010, three crop fields were chosen for the project. Fields ranged in size from 63 to 108 acres. The fields selected are in a corn-soybean rotation for the duration of the project with the possible addition of wheat depending on the year. All three fields have been grid soil sampled on a 1 acre grid. The three fields received fertility treatments in the fall of 2013.

There were four treatments applied to be used to evaluate the effectiveness and economics of furthering enhancing variable rate fertility management. These treatments included:

1) A control which receives no fertilizer.
2) Whole field management of P and K fertilizer.
3) Variable rate fertility management of P and K based on grid soil sampling using current University of Missouri fertilizer recommendations.
4) Variable rate fertility management of P and K based on grid soil sampling using proposed University of Missouri fertilizer recommendations using soil test critical values of 30 lbs/acre for P and 150 lbs/acre for K.

The four treatments were laid out to minimize any differences in soil type and terrain within the field. Each treatment was replicated at least 12 times in each of the three fields where treatments were applied in the fall of 2012. Plots were 80’ x 300’ in size. The 80’ width was chosen because of the width of fertilizer application equipment and the 300’ length to assure quality as-applied fertilizer rate data and yield map data for analysis. Plot layout for the three fields implemented can be seen in Figure 1. Plots were embedded in a variable rate application map and applied with standard variable rate fertilizer application equipment. Plots were harvested with a yield mapping equipped combine collecting data using a one second time interval.

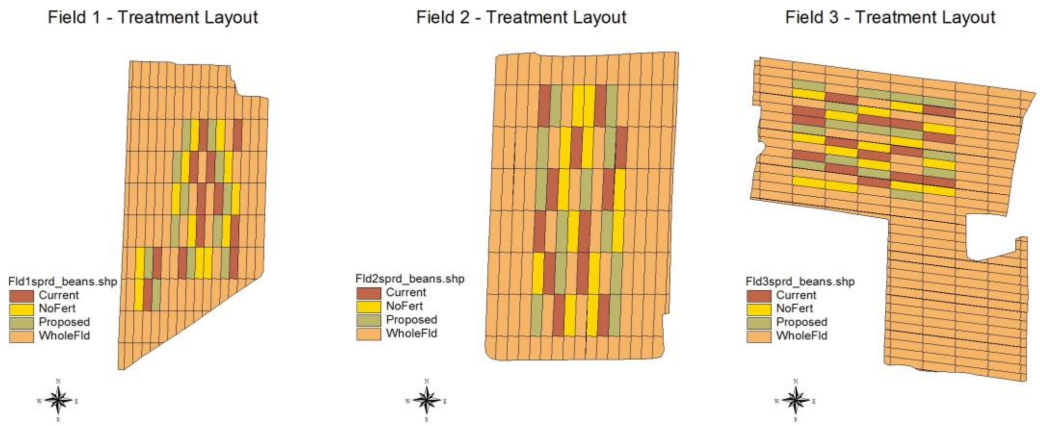

Figure 9. Plot Layout for Field 1, 2, and 3

<u>Results for 2013:</u>

Because of technical issues with the cooperator’s yield monitoring system, yield data for the fields was not collected for the 2013 harvest. In lieu of the technical issues, the cooperator has agree to apply treatments for the upcoming 2014 growing season to finalize the project with one final year of yield data collection in the fall of 2014. Also because of the lack of yield data for 2013, a final comprehensive soil sampling of each of the fields was not conducted and will be finalized after the 2014 grain harvest.

In lieu of no yield data from the 2013 harvest, two preliminary analysis have been included in the report on changes in soil test values and economics of the fertilizer treatments.

Initial analysis of fall 2012 soil sampling results compared to the original baseline soil sampling conducting in 2010 has been conducted. Results are summarized below for each field showing changes in soil test Bray I P and K.

Soil Test Analysis Comparison from Spring 2010 to Fall 2012 for Field 1 – Bray I P

Treatment	2010 – Bray I P (lbs/acre)	2012 – Bray I P (lbs/acre)
Whole Field	62	82
Current Recommendations	61	69
Proposed Recommendations	55	51
No Fertilizer	57	59

Soil Test Analysis Comparison from Spring 2010 to Fall 2012 for Field 2 – Bray I P

Treatment	2010 – Bray I P (lbs/acre)	2012 – Bray I P (lbs/acre)
Whole Field	16	45
Current Recommendations	16	53
Proposed Recommendations	14	34
No Fertilizer	18	36

Soil Test Analysis Comparison from Spring 2010 to Fall 2012 for Field 3 – Bray I P

Treatment	2010 – Bray I P (lbs/acre)	2012 – Bray I P (lbs/acre)
Whole Field	59	50
Current Recommendations	58	55
Proposed Recommendations	56	52
No Fertilizer	58	49

Soil Test Analysis Comparison from Spring 2010 to Fall 2012 for Field 1 – K

Treatment	2010 – K (lbs/acre)	2012 – K (lbs/acre)
Whole Field	232	236
Current Recommendations	247	253
Proposed Recommendations	229	157
No Fertilizer	230	187

Soil Test Analysis Comparison from Spring 2010 to Fall 2012 for Field 2 – K

Treatment	2010 – K (lbs/acre)	2012 – K (lbs/acre)
Whole Field	228	136
Current Recommendations	228	140
Proposed Recommendations	223	148
No Fertilizer	234	143

Soil Test Analysis Comparison from Spring 2010 to Fall 2012 for Field 3 – K

Treatment	2010 – K (lbs/acre)	2012 – K (lbs/acre)
Whole Field	183	216
Current Recommendations	176	223
Proposed Recommendations	185	207
No Fertilizer	182	195

Initial analysis does show some possible trends between treatments but it should be noted the methodology of conducting the original baseline soil sampling and the fall 2012 soil sampling were not conducted in the exact locations. Interpolated soil test data was used for the 2010 results.

As in past years, tables summarizing fertilizer recommendations for P_2O_5 and K_2O for the three fields by treatment for the 2013 growing season. As in the past two years, it should be noted by using the proposed University of Missouri fertilizer recommendations decreased fertilizer requirements of both P_2O_5 and K_2O in all fields. These differences were considerably less than current University of Missouri recommendations. In Field 1, the P_2O_5 recommendation was 2624 lbs less and the K_2O recommendation was 4048 lbs less. Field 2 and 3 shows the same trend. The P_2O_5 recommendation was 4886 lbs less and the K_2O recommendation was 3663 lbs less for Field 2. In Field 3, the P_2O_5 recommendation was 2160 lbs less and the K_2O recommendation was 7753 lbs less.

Fertilizer Recommendations for P_2O_5 and K_2O by Treatment for Field 1 - Corn

Treatment	Total Pounds of P_2O_5	Total Pounds of K_2O
Whole Field	3920	6770
Current Recommendations	3607	5810
Proposed Recommendations	983	1762

Fertilizer Recommendations for P_2O_5 and K_2O by Treatment for Field 2 - Soybeans

Treatment	Total Pounds of P_2O_5	Total Pounds of K_2O
Whole Field	8866	7916
Current Recommendations	9299	8371
Proposed Recommendations	4413	4708

Fertilizer Recommendations for P_2O_5 and K_2O by Treatment for Field 3 - Soybeans

Treatment	Total Pounds of P_2O_5	Total Pounds of K_2O
Whole Field	2046	14332
Current Recommendations	2160	13935
Proposed Recommendations	0	6182

Initial economic analysis has been conducted utilizing 2010 and 2011, yield data and fertilizer applied according to treatments. The following is a summary of this analysis:

Treatment	Difference in Crop Value Minus Cost of P and K Fertilizer (per acre)
Current Recommendations	$644.70
Proposed Recommendations	$712.77
No Fertilizer	$732.64
Whole Field	$631.76

Analysis assumed P205 cost of $0.46/lb, K2O cost of $0.50/lb, corn price of $5.50/bu, and soybean price of $14.20/bu. At this point in time the analysis, an economic advantage of the proposed recommendations over current recommendations for variable rate P and K management has been shown. It should also be noted any soil sampling cost and variable rate application costs have not been included in the analysis.

Objectives for finalizing the project in 2014:

1. Applied final fertilizer treatments to all fields in the spring of 2014.
2. Conduct a field day in the summer of 2014 to discuss results from the past years.
3. Conduct final after harvest soil sampling of plots in fall of 2014 to finalize analysis effects of fertilizer treatments as related to yield data.
4. Finalize all year’s results and publish a final report for the project.

Continuing BUDGET for 2014 from monies not spent in 2013

Item	Description	2013
Soil Tests		
800 post harvest @ $10.00		4,000
Plot Specific Soil Tests – *40 post @$10.00*		200
Supplies	bags, markers, sign	125
Field Days		500
Publication		400
Travel		780
Sub total	by year	$6,005
Support Salary	25% of the above total	$1,501
Grant Total	by year total	$7,506

Continuation of Budget Request for 2014 $7,506

Plant Sap Test for Foliar N, K, Mn, and Lime on Soybean and Cotton

Gene Stevens, Matt Rhine, Kelly Nelson, Jim Heiser, and David Dunn

Objective and Relevance: Soybean and cotton farmers could benefit from rapid, inexpensive methods to evaluate crop tissue or sap to determine when mid-season foliar sprays are needed to maximize yields. Horticulture crop growers measure plant sap in tomatoes, potatoes, and lettuce as a tool for managing N. Water districts in California published leaf sap nitrate-nitrogen sufficiency guide sheets for testing fresh sap from broccoli, brussel sprouts, cabbage, cauliflower, celery, lettuce, spinach, and onions.

The objective of this study is to evaluate field ion-selective electrode meters, colorimeters, and color indicator strip tests on soybean and cotton plants growing on a range of soil test levels and foliar fertilizer N, K, and Mn applications. We hope to develop a fast testing process which works like a diabetic person pricking his finger and testing for blood sugar.

Procedure: Soil samples were collected from fields at the Fisher Delta Center at Portageville, Rhodes Farm at Clarkton and the Greenley Center at Novelty, Missouri. Soybean and cotton was planted in small plots in fields with soil test levels in the low and medium ranges for potassium and manganese. Cotton was also planted at Clarkton to evaluate N quick tests. Fertilizer treatments for K , Mn, and N included a untreated check, recommended dry preplant fertilizer and several timings and sources of foliar fertilizer. Each treatment was replicated five times. Leaves and petioles from each soybean and cotton plot were collected. Samples were collected at V7 or 12, R1, and R1+ 1 week growth stages followed by foliar sprays of each nutrient on treatments using a CO_2 backpack sprayer. Plots were visually rated for leaf burn at 3, 7, and 14 days after foliar applications. Leaf and petiole samples were frozen in plastic bags until they could be processed. A garlic press was used to squeeze leaf and petiole sap. Cotton tissue nitrate-N was measured by Horiba® Cardy nitrate meter, Hach® Colorimeter, and Quant® Nitrate test Strips. Duplicate samples were oven dried and tested in the Delta Center Lab with a nitrate ion-selective electrode. A plot combine and cotton picker were used to mechanically harvest plots. Yield response to foliar spray will be correlated with leaf sap meter reading to determine best growth stages and leaf stems to sample.

Results: No significant differences in soybean yield were found among potassium sources or timings at Novelty in 2013. Yields of this study ranged from 29 to 33 bu ac^{-1} (Table 1). At the Clarkton location, significant decreases in soybean yield were found after three applications of white soluble potash or Re-Nforce K compared to the untreated check. These applications resulted in 8 and 9 bu ac^{-1} losses, respectively. Accompanying this yield loss was a high incidence of leaf burn, which could attribute to the yield loss.

In the cotton potassium study, yields were numerically highest when potassium nitrate (KNO3) was applied at R1 and R1 + 1 Wk (Table 1). However, this yield was not significantly higher than the untreated check. Reduced cotton yields were found with all but the highest application of Re-Nforce K, as well as the highest application of white soluble potash. The 189 lb lint yield reduction with three applications of white soluble potash could be attributed to the leaf burn associated with the application of this product. No combination of fertilizer or treatment was determined to yield significantly higher than the untreated check.

In the manganese study, the highest yields at the Novelty location came from MnSO4 soil applied and Gluco Mn + glyphosate, which were both 35 bu ac^{-1} (Table 2). These yields, although not statistically significant, were 2 bu ac^{-1} higher than the untreated check. Yields were significantly reduced when chelated EDTA Mn was applied after R1. Also, yield loss occurred when either chelated EDTA Mn or MnSO4 was applied with glyphosate. However, tank mixing Gluco Mn with glyphosate did not cause the same yield loss. No significant leaf burn was found due to any fertilizer treatment. At the Clarkton location, no significant differences were found among Mn treatments or timings. Average yields ranged from 52 to 60 bu ac^{-1} (Table 2).

In the foliar nitrogen study, cotton yields were numerically highest when the source fertilizer included ammonium nitrate (NH4NO3). One application of NH4NO3 + KNO3 one week after bloom increased yields by 95 lb lint ac^{-1} (Table 2). Again, however, although numerical differences were found, no significant yield differences were found among foliar nitrogen treatments. This field had been used in winter legume cover crop research in the past and may have N released from organic matter during the year.

We are currently in the process of making quick test measurements from frozen samples collected during the 2013 season and comparing the results to duplicate leaf and petiole samples test at the Delta Center Soil Lab (Figure 1).

Sap analysis was conducted on these experiments for the 2012 season. No significant differences in soybean tissue K content could be found among treatments at either the Novelty or Clarkton locations, although significant yield differences were found between those treatments shown (Figures 2 & 3). In the cotton experiment, however, differences could be found between tissue K contents of plots that received KNO3 one week after R1 and untreated checks (P = 0.0644; Figure 4). These treatments were also significantly different in cotton lint yield.

Differences in soybean tissue Mn content were found among manganese treatments in 2012 (P = 0.0834; Figure 5). Applications of chelated EDTA Mn or MnSO4 + glyphosate were found to increase tissue Mn compared to untreated checks. No significant differences in cotton tissue N content were found among foliar nitrogen treatments in 2012.

Table 1. Soybean and cotton yield response to soil and foliar potassium treatments at Novelty, Qulin, and Clarkton, Missouri in 2013.

Trt	Fertililizer	Preplant	V7	R1	R1 + 1 wk	Novelty	Clarkton	Clarkton
						soybean		cotton
		----------------lb K20/a--------------			----	---------bu/a---------		lb lint /a
Check			0	0	0	31 a†	70 a	633 ab
Soil	Potash	120	0	0	0	32 a	62 bcd	574 abc
Bdcst	Potash	0	0	0	60	29 a	66 abc	514 abc
Bdcst	White Sol Potash	0	19	19	19	32 a	62 cd	444 bc
Bdcst	White Sol Potash	0	0	19	19	30 a	65 abcd	574 abc
Bdcst	White Sol Potash	0	0	0	19	30 a	67 ab	490 abc
Foliar	KNO3	0	4.62	4.62	4.62	32 a	68 ab	622 abc
Foliar	KNO3	0	0	4.62	4.62	31 a	66 abcd	696 a
Foliar	KNO3	0	0	0	4.62	29 a	65 abcd	479 bc
Foliar	Re-NforceK	0	4.68	4.68	4.68	33 a	61 d	552 abc
Foliar	Re-NforceK	0	0	4.68	4.68	32 a	65 abcd	411 c
Foliar	Re-NforceK	0	0	0	4.68	31 a	67 abc	431 bc

†Yields followed by the same letter were not significantly different at the 0.05 level.

Table 2. Soybean yield response to soil and foliar manganese treatments at Novelty and Clarkton, Missouri in 2013.

Trt	Fertililizer	Preplant	V7	R1	R1+1 wk	Novelty	Clarkton
			----------lb Mn/acre--------			-----bu/acre----	
Check		0	0	0	0	33 abc†	56 a
Soil	Mn sulfate 6%	4	0	0	0	35 a	58 a
Foliar	Chelated EDTA Mn	0	0.25	0.25	0.25	30 d	53 a
Foliar	Chelated EDTA Mn	0	0	0.25	0.25	30 cd	60 a
Foliar	Chelated EDTA Mn	0	0	0.5	0	32 abcd	57 a
Foliar	Chelated EDTA Mn + glyphosate	0	0	0.5	0	30 bcd	52 a
Foliar	Mn sulfate + glyphosate	0	0	0.5	0	30 bcd	56 a
Foliar	Gluco Mn + glyphosate	0	0	0.5	0	35 a	57 a
Foliar	glyphosate alone	0	0	0.5	0	33 ab	58 a

†Yields followed by the same letter were not significantly different at the 0.05 level.

Table 3. Cotton yield response to soil and foliar nitrogen treatments at Clarkton, Missouri in 2013.

Treatment	Fertilizer	Preplant	V12	First Blm	Blm +1 wk	Cotton
		-----------------lb N/acre----------------				lb lint/acre
Check	----	0	0	0	0	558 a†
med N	soil	40	0	0	0	582 a
high N	soil	120	0	0	0	587 a
low N foliar	Foliar KNO3	0	4.62	4.62	4.62	512 a
low N foliar	Foliar KNO3	0	0	4.62	4.62	578 a
low N foliar	Foliar KNO3	0	0	0	4.62	571 a
med N foliar	Am nitrate + foliar KNO3	40	4.62	4.62	4.62	620 a
med N foliar	Am nitrate + foliar KNO3	40	0	4.62	4.62	618 a
med N foliar	Am nitrate + foliar KNO3	40	0	0	4.62	653 a

†Yields followed by the same letter were not significantly different at the 0.05 level.

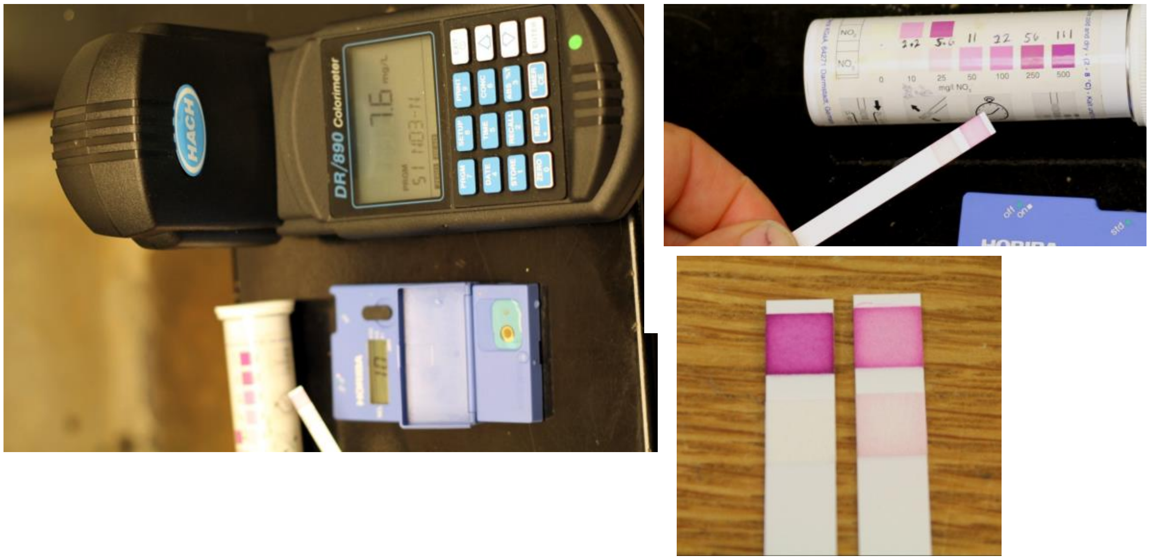

Figure 1. Portable nitrate meter, colorimeter, and nitrate test strips used to measure sap nitrate.

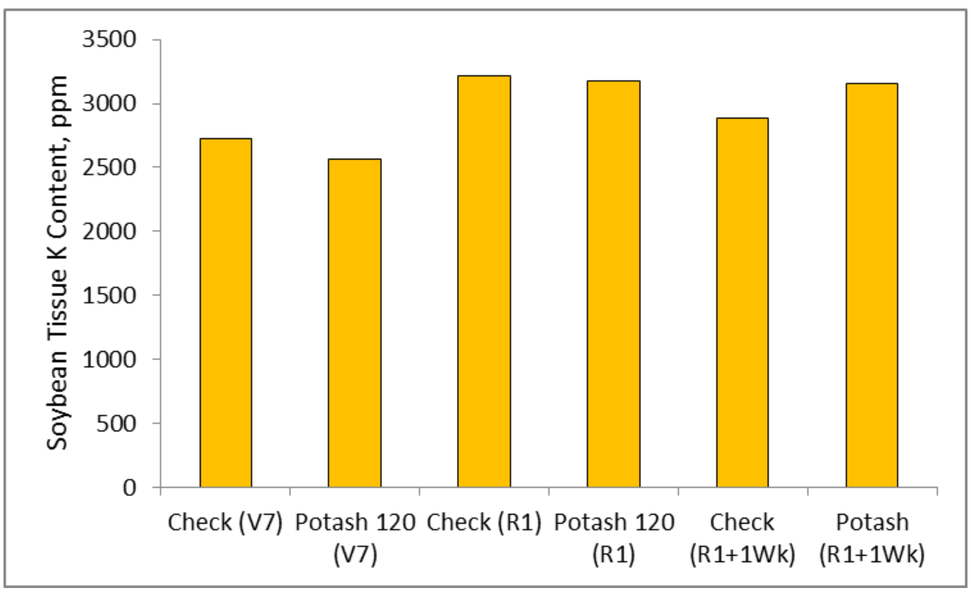

Figure 2. Comparison of soybean tissue K content between plots fertilized with 120 lb ac^{-1} soil applied K and the untreated checks at Novelty, Missouri in 2012.

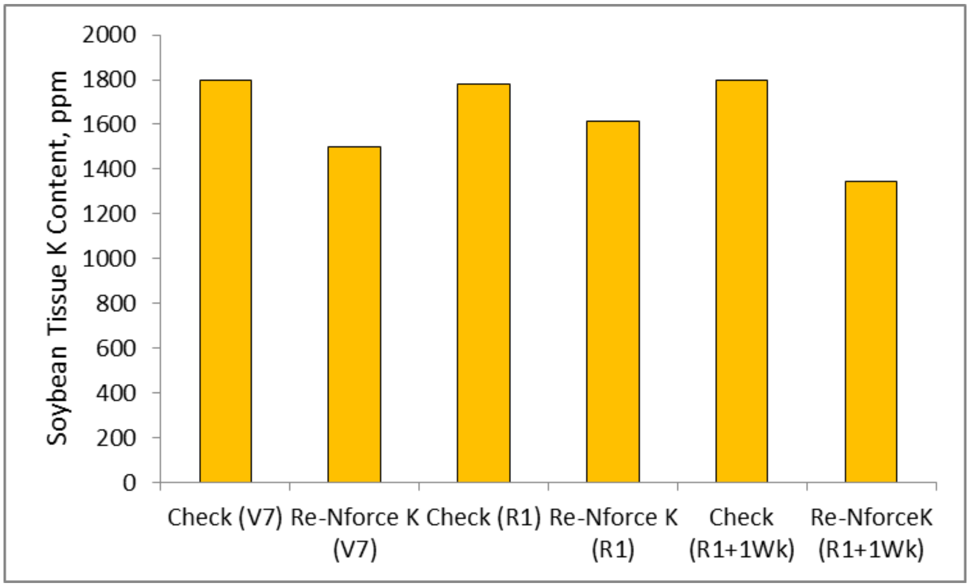

Figure 3. Comparison of soybean tissue K content between plots fertilized with two applications of Re-Nforce K and the untreated checks at Clarkton, Missouri in 2012.

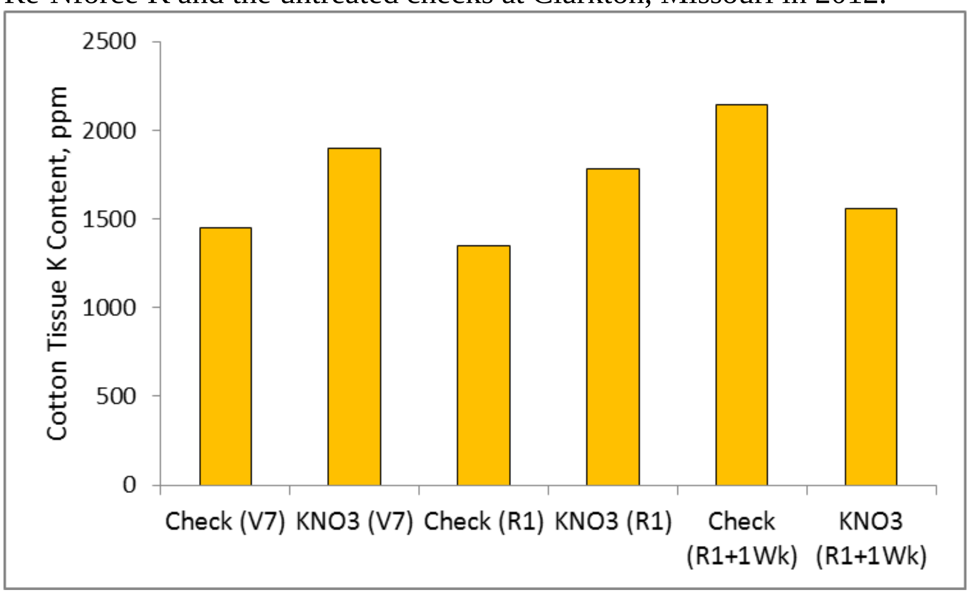

Figure 4. Comparison of cotton tissue K content between plots fertilized with one application of KNO3 and the untreated checks at Clarkton, Missouri in 2012.

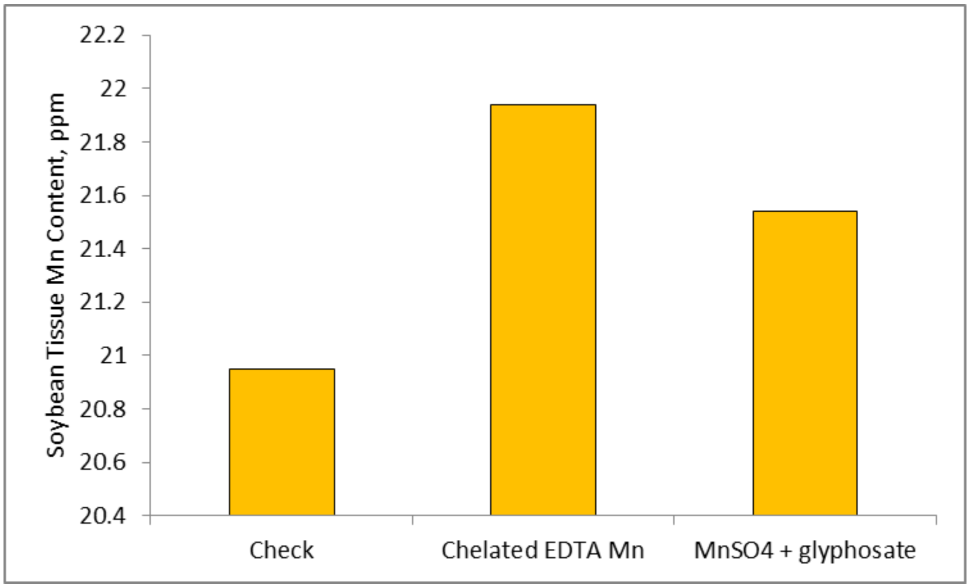

Figure 5. Comparison of soybean tissue Mn content between plots fertilized with three applications of chelated EDTA Mn, one application of MnSO4 + glyphosate, and the untreated checks at Clarkton, Missouri in 2012.

Soils Lab Yearly Status Report

Tuesday, February 25, 2014

Overview

Substantial progress on the Soils Lab rewrite has been made over the preceding year. In January of 2013, the rewrite was only the barest skeleton of the main menu. The Data Entry page could only enter and save data. It could not edit the existing data. This and the majority of the data structure was the extent of the development of the system.

As of December of 2013, the Soils Lab rewrite could successfully collect data for soil samples of field crops, lawn and garden, and commercial horticultural crops. The results for each sample could be displayed, edited and saved. The recommendation engine was in place waiting for the definition of all the various rules. The screens and reports for the accounting system have been developed and are waiting for review.

The assistance of Dr. John Lory for significantly organizing the progress of the Soils Lab rewrite needs to be recognized and appreciated.

Database

The database structure is well established, and has had few changes in the past year. The changes to the database have occurred in the areas of Recommendations Rules, and Accounting. The changes in Rules and Recommendations to are designed to enhance the support for different types of samples.

Program

Data Entry page of the Soils Lab rewrite is nearly fully functioning. The data entry page needs some tweaks to the user interface to improve speed of data entry. There are two additional features to be added to the data entry page. The direct connection from the data entry page to the recommendation display needs to be completed. The other feature is much more complicated and involved. The complication is not on the data entry page, but in the special tests page itself. The ability to add special tests to a sample is well supported by the data structure, but with the Soils Testing Lab supporting 116 different tests the challenge comes from the need to make the selection of special tests as easy as possible.

The manual Results Entry page is fully functioning allowing the user to display, edit and save the results of tests. However, no formal review has been done of the results entry page has been performed. Problems are always found when the page is first put under the stress of use.

The Recommendations system is nearly fully functioning. The recommendation page depends on the recommendation rules to be described before it can generate accurate recommendations. Other parts of the Soils Lab rewrite associated with recommendations are: Rule Editor, Message Editor, and Rule Engine

The Rule Editor is currently being used to manage the recommendation rules. There are two additional features to be added to the rule editor: message display and rule syntax checking.

The Message Editor is fully functioning. There are no changes are currently anticipated. The message editor is being used in association with the Rule Editor to enter the rules associated with the recommendations.

The Rule Engine is a simple run-time mathematical interpreter. It processes a sequence of rules performing numerical actions on the test results and other values about the sample being processed. In the tests run, the rule engine has shown itself to be in functioning condition. Until the rules are entered and applied against testing sets, it is not possible to identify additional issues with the rule engine.

The Recommendation display for Soil Analysis recommendations is been hard coded[1] into the system. The Soil Analysis recommendation report support standard and infrequent tests. It provides the results as well as providing the recommendations.

Pending

Work has been started Lab Data Upload for the automated upload of lab results to the Soils Lab rewrite database. The limited testing has been successful for the limited records that we have already imported into the database.

The Accounting portion of the Soils Lab rewrite has been initially sketched, however, no systematic review of what is desired and needed has been done.

[1] Hard coded implies that a programmer is required to make changes. The recommendation display is the single major system that is hard coded in the entire Soils Lab rewrite. The guiding principle for the entire system is to make it table driven allowing all changes and extensions to be done by the end user.

Updating University of Missouri Soil Test Based Fertilizer and Lime Recommendations Program: Status Report

Manjula Nathan, Associate Professor /Director, MU Soil and Plant Testing Laboratory
Division of Plant Sciences, University of Missouri
Peter Scharf, Professor, State Nutrient Management Specialist, Division of Plant Sciences, University of Missouri
David Dunn, Extension Associate/Manager, Delta Soil Testing Lab

Objectives, including relevance of project to Missouri fertilizer/lime use:

- Update and re-write the University of Missouri Soil Test Recommendations Program to include the revisions and updates made by the University of Missouri Soil Fertility Working Group.
- Update the soil test to a web based system that is independent of operating systems, offices systems, and web browsers.

University of Missouri (MU) soil test and fertilizer recommendation program is used by the MU Soil Testing Laboratories located at Columbia and Portageville to provide fertilizer and lime recommendations for row and forage crops to about 40,000 farmers each year. The soil test based recommendations from University of Missouri soil testing labs are being used to apply fertilizer and lime for about 4,000,000 acres of row crops and forages for efficient use of fertilizer and lime, and to achieve economical returns from crop production. In addition, the state and federal agencies such as the Natural Resources Conservation Service (NRCS), Farm Service Agency (FSA), Missouri Department of Natural Resources (MDNR), Missouri Department of Agriculture, and agricultural industry personnel, (crop consultants and fertilizer dealers) and individual producers rely on the MU soil testing database program to get unbiased, research based fertilizer and lime recommendations from University of Missouri.

During the past 15 years, there has been significant research in Missouri and other states on soil testing and crop fertilizer needs relevant to Missouri conditions. Some of that research was due to the result of support by the Missouri Fertilizer and Ag Lime Board.

The Soil Fertility Working Group is the committee charged with reviewing and approving changes to MU recommendations. This committee includes research and extension faculty working on soil fertility issues at MU and the heads of the Columbia and Delta soil testing labs. The members of these committee has been working for the past few years on revising the fertilizer and lime recommendations based on research findings, and has come up with significant updates. Some areas where significant changes have been made in the soil test based fertilizer recommendations include:

- Integrating economics into corn nitrogen recommendations.
- Updates to the buildup equations for soil test phosphorus and potassium.
- Updates on crop removal values.
- Revisions to Missouri lime and magnesium recommendations.
- Changes to the soil test recommendation rating system.

Implementing recommendation changes has been limited by the ability to include the revisions in the MU Soil Testing Database Program that benefits thousands and thousands of growers who receive the fertilizer and lime recommendations from the MU soil testing labs each year. The soil test database program that we currently use is a client based system that was written in VB6. Within the code for this system is where all of our calculations and recommendations are stored.

The main objective of this proposal is to provide support for a 0.5 FTE of programmer's salary for three years. We estimated that it will take three years to design a new system, launch the new system, convert the old data, test the new system, and to support the system in its beginning stages to work out any issues. However, the project is taking longer than the anticipated time for completion. The programmer will ensure that the future recommendation changes to the MU soil test and fertilizer and lime recommendations can be made in the database. This will allow us to make the change as soon as it goes into effect and make the recommendations available online to be accessed by all citizens of Missouri.

Procedures:

It is estimated that we will need a total of three years to design and launch a new system, convert the old data, test the new system, and to support the system in its beginning stages to work out any issues. The new system will have a table in the database for soil calculations, and soil recommendations, this is critical for future updating of the soil recommendations. The new system will be a web based system that is independent of operating systems, office systems, and web browsers. Updating the soil test data base programs will include managing lab data with sample identification, developing soil test based recommendation using current revisions, creating soil test reports in user friendly formats, enabling queries of the databases, and generating annual reports. The MU soil testing labs will fund 0.5 FTE of the position and request the fertilizer and lime advisory committee to fund the other 0.5 FTE of the programmer's salary to re-write the MU soil test database program. I am currently working with the programmer in updating the soil test database fertilizer and lime recommendation program with inputs from Dr. John Lory and CO-PIs and members of the MU Soil Fertility Working Group.

Status Report:

A contract has been signed with Center of applied Research and Environmental Systems (CARES), University of Missouri to develop the web-based data base for soil test and recommendations. Mr. James Cutts, Computer Project Manager, CARES has been contracted to develop the database. The project is taking longer than the estimated time of completion due to the broad needs of the soil test database program. The progress update on the project provided by the programmer is provided below:

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As of December of 2013, the Soils Lab rewrite could successfully collect data for soil samples of field crops, lawn and garden, and commercial horticultural crops. The results for each sample could be displayed, edited and saved. The recommendation engine was in place waiting for the definition of all the various rules. The screens and reports for the accounting system have been developed and are waiting for review. The assistance of Dr. John Lory for significantly organizing the progress of the Soils Lab rewrite needs to be recognized and appreciated.

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Due to the broad scopes of the program, the project is behind schedule in getting completed. We haven't completed all parts of the soil testing database and recommendation program to be tested yet. Additional funding is crucial to complete the project so that web-based soil testing database and recommendation program can be implemented. Additional work needs to be done to include the plant, water, manure, compost and research samples entered into the database and reports has to be generated with interpretations and recommendations. Additional support from the Lime and Fertilizer Grants to complete the project is essential for successful completion of the project and implementation.

Budget:

Category	**2014**
Salaries and benefits	
Salaries	$35,000 (0.5FTE)
Benefits	$10,500
Operating	
Equipment	
Total	$45,500

2014

Updating University of Missouri Soil Test Recommendations

Investigators:
John A. Lory — Peter Scharf — Manjula Nathan
Peter Motavalli — Gene Stevens — Newell Kitchen

Objective:
Update and revise University of Missouri Soil Test Recommendations and the supporting publication "Soil Test Interpretations and Recommendations Handbook."

Progress report:
This goal of the project was to provide supplemental research specialist support to facilitate faculty working on changes in the University of Missouri soil test recommendations. Table 1 outlines the current status of the update to our recommendation system.

Table 1. Status of components of University of Missouri soil test recommendations update.

Recommendation component	Literature review	Changes proposed	Changes approved
Review and update crop removal values for all crops	Completed	Completed	Completed
Review and update forage crop selections	Completed	Completed	
Review and update forage crop recommendations to include new crop selections	Completed	Completed	
New buildup equations for P and K	Completed	Completed	Completed
Review and update magnesium recommendations	Completed	Completed	
Review and update lime recommendations	Completed	Completed	
Review and update critical soil test P levels	Completed		
Review and update critical soil test K levels			
Review and update row crop N recommendations			

Work continues on this project.

- In 2014 a research fellow using funding from another source worked with John Lory to complete a comprehensive literature review of Midwest research correlating soil test levels to crop response to applied phosphorus.
- In late 2013 and early 2014 John Lory gave presentations at various Missouri workshops including the Missouri Crop Management Conference detailing possible changes in MU soil test phosphorus recommendations.
- Peter Scharf has been developing a proposal to have lower critical values for crops on fields with site-specific management strategies such as grid soil sampling, yield monitors and variable rate fertilizer applications.
- In 2014, Peter Scharf, John Lory and Brent Myers obtained support for on-farm strip trials to assess phosphorus response on farmer fields. John Lory, Brent Myers, Peter Scharf, Kent Shannon and Wayne Flanary will initiate a new Missouri strip-trail program that will help farmers to test and gain confidence in MU nitrogen and phosphorus recommendations.

Changes to the fertilizer recommendation system are meaningless unless they can be implemented in the software used to support the MU Soil Testing Laboratory. There is an on-going project to implement new software to support the lab. That software was designed to insure that new recommendations could easily be implemented without the need of a computer programmer. That project has had real issues delaying completion. Manjula Nathan, and in 2014, John Lory have worked extensively with computer programmers to complete this project. Successful completion of the lab software update will provide much more incentive to complete recommendation changes. It will also provide more time to focus on recommendation changes instead of focusing on lab software updates for key faculty in the process.

Budget:
We retain $7,399.75 (~30% of the funding) in the project account in anticipation of support needed when we work to finalize proposed changes.

Final Report

2013

Fertilizing Summer-Annual Grasses for Forage Production

Investigator: Robert L. Kallenbach

Objectives and relevance of project: Summer-annual grasses are becoming more popular each year, especially forage varieties of crabgrass and dwarf, brown mid-rib sorghum sudangrass. These grasses provide high-quality forage for summer grazing and/or stored forage. However, we have almost no information about how to fertilize these grasses for optimum economic production. This is especially true for nitrogen fertilizer. Although these grasses represent a great opportunity for forage/livestock producers at present, there is little data for solid agronomic recommendations.

The **overall objective** is to develop research-based recommendations that help industry personnel and farmers properly fertilize summer annual grasses. Specific objectives are:

Objective 1: Determine the optimum economic N rates for crabgrass, dwarf brown mid-rib (BMR) sorghum-sudangrass hybrids, non-dwarf sorghum-sudangrass hybrids and pearl millet.

Objective 2: Determine if split application of nitrogen fertilizers provides a significant advantage compared to larger single applications.

Objective 3: Determine the influence of N application rates on nitrate accumulation and/or prussic acid concentrations in forage.

Procedures:
Treatments: This experiment has 32 treatments; four forage entries and eight N rates x timing applications. The four forage entries are 'Big-n-Quick' crabgrass, dwarf BMR sorghum x sudangrass, BMR sorghum-sudangrass and pearl millet. The eight nitrogen treatments are described in the table below.

Table 1. Nitrogen rates and application timings tested on summer annual forages.

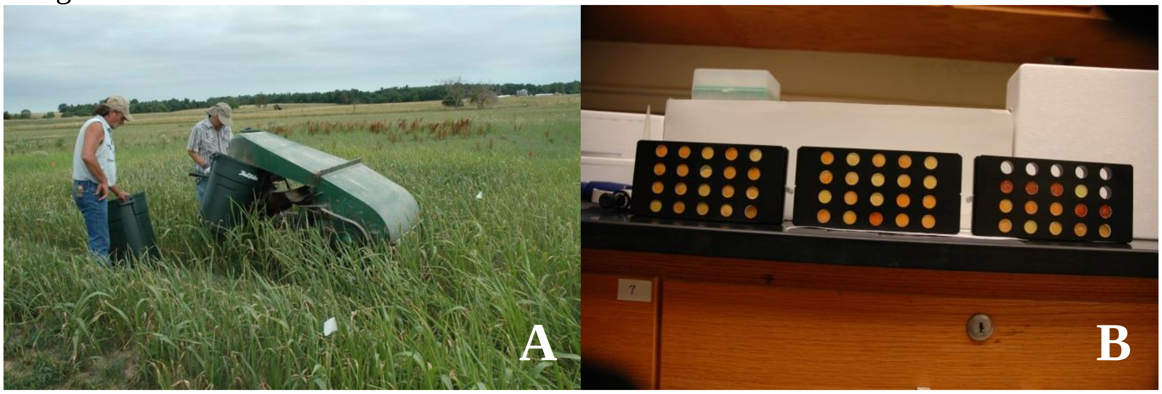
Treatment	Annual N rate	No. of Applications	Notes
	lb/acre	#	
1	300	3	1/3 late May, 1/3 late June, 1/3 late July
2	300	2	1/2 in late May, 1/2 late June
3	150	3	1/3 late May, 1/3 late June, 1/3 late July
4	150	1	Applied in late May
5	100	2	1/2 in late May, 1/2 late June
6	100	1	Applied in late May
7	50	1	Applied in late May
8	0	-	Control

Cultural practices: Stands of each annual forage were established in early May at the Southwest Center, near Mt. Vernon, MO and at the Forage Systems Research Center near Linneus, MO. Both

sites were planted using a Truax no-till drill. The seeding rates (PLS) for each species were as follows; crabgrass 4 lb/acre, sorghum-sudangrass 40 lb/acre, and pearl millet 30 lb/acre.
Design: Each treatment was replicated three times in a randomized complete block design in a split-block arrangement. Forage entries were main plots and nitrogen treatments sub-plots.

Measurements:
Forage yield and growth rates. Growth rate of forage was measured weekly using a rising plate meter for crabgrass and by measuring the natural height with a meter stick for the other forage species. Mechanical forage harvest for an individual treatment occurred when forage reached the following threshholds:18 rising plate meter units for crabgrass, 30 inches for the other species. For those unfamiliar with rising plate meter measurements, this would equate to approximately 8 inches in height for crabgrass. Subsamples for forage nutritive value, prussic acid, and plant nitrates were also collected at the time of a mechanical harvest.

Figure 1. (A) Forage being harvested in field plots near Mt. Vernon, MO.
(B) Laboratory assay showing the variation in prussic acid toxicity potential of forage harvested from the plots. The brick red color indicates a large concentration of cyanide gas was released and forage was toxic.



Results:

2011

At Mt. Vernon, summer precipitation was 59% less than the 30 year average in 2011. As a result, dry matter yields of all 4 species were lower than expected (Table 2). For instance, the sorghum x sudangrass hybrids, which commonly yield 4 to 6 tons per acre, produced less than 1 ton per acre. Additionally, pearl millet, which is known as a drought-tolerant species, was the only species of forage that showed a response to N applications, but that response was not economical by most standards. The greatest summer forage production at Mt. Vernon occurred when crabgrass was seeded and no benefit resulted from N fertilization.

At Linneus, dry matter yields were greater than those at Mt. Vernon (Table 3). However, lack of late summer precipitation limited yields. The pearl millet did not establish well at this site and is not included in the 2011 data analysis. Neither crabgrass nor dwarf sorghum-sudangrass responded to N applications while BMR sorghum x sudangrass did. The data show that 100 lb/A of N in a single early summer application were more favorable than the greater rates of 150 and 300 lb/A of N. Dry matter yields were often no better if N was spread out over the summer in 2 or 3 applications. This result was likely influenced by the precipitation shortage in late summer; we expect the later N applications to stimulate more growth when summer precipitation is more evenly distributed.

2012

The extreme drought experienced across the Midwest in 2012 limited forage yields at both locations. The impact of the drought was most severe at Mt. Vernon, where the only forage species that showed a response to N fertilization was pearl millet (Table 2). The pearl millet control plots yielded poorly (almost 1,000 lb/acre less) compared to unfertilized plots of the other species. This unusual drought-related response likely led to the N yield response shown for pearl millet at Mt. Vernon.

At Linneus, dry matter yields were generally greater than those at Mt. Vernon for the 3 species that established well (Table 3). Crabgrass did not respond to N applications but the BMR sorghum x sudangrass and the pearl millet did. As an aside, the dwarf sorghum-sudangrass in 2012 was a victim of spotty germination; only 3 out of 8 N treatments were able to be harvested. The data show that early applications of 100 or 150 lb/A of N were more favorable than 300 lb/A of N spread into late-summer applications.

2013

More favorable precipitation in 2013 at Mt. Vernon, led to slightly greater yields. However, only 2 of the 4 species responded to the N fertilization treatments. For the third consecutive year, crabgrass forage production was not influenced by N fertilization. Pearl millet produced the most forage when 300 lb/A of N was applied in 2 or 3 applications. However, the return in forage production was only 13 lb of forage per N unit. For pearl millet, 100 lb/A of N was the most cost effective fertilization rate. For the sorghum-sudangrass hybrids, the dwarf variety responded best to N fertilization, although applying more than 50 lb/A of N was not cost effective.

At Linneus, crabgrass was not affected by N fertilization, however, its yields were higher than the other three species at each N fertilization rate. Although BMR sorghum-sudangrass and pearl millet each responded to N fertilization, their yields were not great enough to justify the cost of N. The best approach at Linneus was to seed crabgrass and forego the N fertilizer.

3-Year summary

At Mt. Vernon, across 3 years, 8 of the 12 species x year combinations were not affected by N fertilization. Pearl millet almost always responded to N fertilization although in only 1 of the 3 years was the response economic. In that year, 100 lb/A of N was the best rate when applied as a single application in early summer. Crabgrass consistently yielded about as well as or better than the other species when left unfertilized.

At Linneus, there was no response to N fertilization in 50% of the species x year combinations. When there was a response to N fertilization, only twice did the return per N unit approach 20:1 (in 2011 with BMR sorghum-sudangrass and in 2012 with pearl millet). In general, crabgrass would have the lowest seed cost per acre for establishment, it can be managed for self-reseeding in subsequent years, does not produce prussic acid, and most often yielded as well as the other species even when no N fertilizer was applied. Crabgrass looks like the best choice for a summer annual forage.

Table 2. Annual yield of four species of summer annual grasses under eight different N fertilization regimes. Data were collected near Mt. Vernon, MO during the 2011, 2012, and 2013 growing seasons.

Year	Annual N rate	No. of Applications	Crabgrass	Dwarf Sorg x sudan	BMR Sorg x sudan	Pearl Millet
	lb/acre	#	---------------------------- lb/acre			----------------------------
2011	0	-	4352 ns	1483 ns	1529 ns	1261 d
	50	1	4825 ns	1835 ns	1873 ns	1977 cd
	100	1	4120 ns	1713 ns	1948 ns	2143 bc
	100	2	4936 ns	1982 ns	1638 ns	2148 bc
	150	1	4417 ns	1787 ns	1907 ns	2763 ab
	150	3	4477 ns	1684 ns	1787 ns	2681 abc
	300	2	4262 ns	2296 ns	1501 ns	2938 a
	300	3	4970 ns	2054 ns	1801 ns	2148 bc
2012	0	-	4337 ns	5150 ns	4815 ns	3426 c
	50	1	3983 ns	5996 ns	4708 ns	4333 b
	100	1	4233 ns	5182 ns	4790 ns	4929 ab
	100	2	4507 ns	6104 ns	5256 ns	4634 ab
	150	1	4064 ns	5815 ns	5448 ns	5026 a
	150	3	4049 ns	6174 ns	5403 ns	4664 ab
	300	2	4174 ns	5703 ns	5096 ns	5057 a
	300	3	4375 ns	5900 ns	5421 ns	4936 ab
2013	0	-	4424 ns	4484 b	5294 ns	4823 e
	50	1	4584 ns	5797 a	6293 ns	6418 d
	100	1	5347 ns	6510 a	6442 ns	6770 cd
	100	2	5221 ns	6874 a	6833 ns	7067 bcd
	150	1	5086 ns	6170 a	6349 ns	7784 abc
	150	3	4661 ns	6366 a	7000 ns	8035 ab
	300	2	4496 ns	6666 a	7084 ns	8617 a
	300	3	4716 ns	6847 a	6971 ns	8693 a

Table 3. Annual yield of four species of summer annual grasses under eight different N fertilization regimes. Data were collected near Linneus, MO during the 2011, 2012, and 2013 growing seasons.

Year	Annual N rate	No. of Applications	Crabgrass	Dwarf Sorg x sudan	BMR Sorg x sudan	Pearl Millet
	lb/acre	#	----------------------------	lb/acre	----------------------------	
2011	0	-	4624 ns	5412 ns	4821 d	
	50	1	5783 ns	6153 ns	5446 d	
	100	1	5585 ns	5888 ns	6718 c	
	100	2	4729 ns	5855 ns	6885 bc	
	150	1	6418 ns	7645 ns	7242 bc	
	150	3	6043 ns	5894 ns	6748 c	
	300	2	6501 ns	7815 ns	8463 a	
	300	3	6441 ns	6171 ns	7958 ab	
2012	0	-	6534 ns	858 ns	4715 b	5811 d
	50	1	8043 ns	431 ns	4996 b	5792 d
	100	1	7131 ns		6855 a	6511 cd
	100	2	7905 ns		6957 a	6541 cd
	150	1	7787 ns	426 ns	5135 b	7331 ab
	150	3	7631 ns		7399 a	6809 bc
	300	2	8349 ns		7519 a	7610 a
	300	3	6968 ns		7703 a	7528 ab
2013	0	-	4061 ns	3273 ns	3224 e	2348 d
	50	1	4628 ns	3987 ns	3292 de	2780 bc
	100	1	5006 ns	3790 ns	3735 ab	3211 a
	100	2	4599 ns	3283 ns	3628 bcd	2816 abc
	150	1	4559 ns	3675 ns	4013 a	2875 abc
	150	3	4675 ns	3629 ns	3329 cde	2706 cd
	300	2	4839 ns	3801 ns	3675 abc	3210 a
	300	3	4502 ns	3668 ns	3578 bcde	3115 ab

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