Missouri
Soil Fertility and Fertilizers
Research Update
2015

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Agronomy Department
College of Agriculture, Food and Natural Resources
University of Missouri

Thank You
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

<u>Progress Reports</u>

2014

(Report received after publication of last Fertility Update)

Additional "quarter minus" materials research

David Dunn and Gene Stevens
MU-Delta Center, Portageville, MO,

Objective: Building on work previously funded by this body, this study will continue to investigate the possibilities of using "quarter minus" materials as lime sources by using laboratory incubation techniques to compare determine the relative rates of acid neutralization for standard ag-lime and "quarter minus" materials obtained from different source quarries. To this end two different 3-year incubation experiments were begun in 2013.

Procedure:

Experiment 1: This experiment was designed to compare the effectiveness of oversized nonstandard limes to their traditional ag lime equivalents. Limes from four different quarries which produce both traditional and "quarter minus" materials are being incubated with a low pH sandy soil over three-year period. Two of the limes are calcitic, the other two dolomitic. The ENM/ton of each material is presented in Table 1. The amount of each lime in terms of ENM/acre required by a standard soil test was mixed with the soil, water added to reach field capacity, sealed in a water tight container and allowed to react for a three-year period. One day following establishment and then every six months the container has been opened and a representative sample collected. This sample was then tested for soil pH and plant extractable Ca & Mg. The resulting data is presented in Table 2.

Table 1. Liming properties for materials used in EXP 1.

Treatment	Lime	ENM/ton	Emg/ton	8	8-40	40-60	-60%	Fineness Factor	Application rate
					% material passing sieve				ton/a
2	Rolla 5/16 minus	240	75	44	28	4.2	23.8	33.3	5.3
3	Rolla ag-lime	581	183	5.3	9.3	8.6	76.8	84.3	2.2
4	Holts Summit 5/16 minus	268	8	26.6	29.8	7.6	36.6	48	4.7
5	Holts Summit ag-lime	326	9	6.8	42.2	9.2	41.8	57.9	3.9
6	Boone 1/8 minus	205	34	32.3	50.4	3.6	13.7	28.5	6.2
7	Boone ag-lime	596	112	1.6	14.7	12.6	71.1	82.4	2.1
8	Delta 1/4 minus	284							4.5
9	Delta ag-lime	495							2.6

Table 2. Average pH, Ca, Mg levels for ag lime and oversized nonstandard limes.

		pH salt (units)			
		3/5/13	9/5/13	3/11/14	9/24/14
	Treatment				
1	Check	5.3 d	4.2 b	4.8 c	3.8 d
2	Rolla 5/16 minus	5.5 c	5.3 b	5.7 ab	4.6 b
3	Rolla ag-lime	5.5 c	4.9 c	5.3 bc	4.4 c
4	Holts Summit 5/16 minus	5.7 b	5.5 ab	6.0 ab	4.8 b
5	Holts Summit ag-lime	5.8 b	5.5 ab	5.9 ab	4.7 b
6	Boone 1/8 minus	5.7 b	5.9 a	6.2 a	5.3 a
7	Boone ag-lime	5.9 b	5.6 ab	6.0 ab	4.7 b
8	Delta 1/4 minus	5.7 b	5.5 ab	5.8 ab	4.8 b
9	Delta ag-lime	5.6 bc	5.8 ab	5.8 ab	4.9 b
LSD (P=.05)		0.11	0.31	0.51	0.19
CV		1.4	3.8	6	2.8

		Ca (lb/acre)				Mg (lb/acre)			
		3/5/13	9/5/13	3/11/14	9/24/14	3/5/13	9/5/13	3/11/14	9/24/14
	Treatment								
1	Check	1135 b	1305 d	1185 c	1332 e	198 e	183 c	179 d	180 e
2	Rolla 5/16 minus	1242 b	1752 c	1510 b	1667 d	473 b	198 bc	390 b	436 c
3	Rolla ag-lime	1177 b	1685 c	1395 b	1785 cd	408 c	200 bc	348 b	434 c
4	Holts Summit 5/16 minus	1645 a	2267 ab	2077 a	2317 a	228 e	203 bc	176 d	207 e
5	Holts Summit ag-lime	1652 a	2312 a	1902 a	2387 a	214 e	200 bc	171 d	212 e
6	Boone 1/8 minus	1330 b	2005 b	1805 a	1997 bc	645 a	234 a	569 a	633 a
7	Boone ag-lime	1667 a	2265 ab	1987 a	2040 bc	407 c	230 a	351 b	345 d
8	Delta 1/4 minus	1517 a	2222 ab	1845 a	2257 ab	322 d	224 ab	266 c	329 d
9	Delta ag-lime	1287 b	2060 ab	1855 a	1927 cd	629 a	239 a	505 a	546 b
LSD (P=.05)		160	202	198	220	50	20	62	60
CV		7.8	7	7.9	7.7	8.8	6.5	2	11.1

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

Experiment 2: This experiment was designed to compare the effectiveness of the screened size consists of two different oversized nonstandard lime sources. One of the lime is calcitic (Boone), the other dolomitic (Delta). Material from both of these sources was screened using a standard set of nested screens. From each resulting size consist 20 grams was mixed with the soil, water added to reach field capacity, sealed in a water tight container and allowed to react for a three-year period. One day following establishment and then every six months the container has been opened and a representative sample collected. This sample was then tested for soil pH and plant extractable Ca & Mg. The resulting data is presented in Table 3.

Table 3 Average pH, Ca, Mg levels for lime treatments derived from size consists of two different oversized nonstandard lime sources.

		pH salt (units)			
		3/5/13	9/5/13	3/11/14	9/24/14
	Treatment				
1	Check	4.9 d	4.8 d	4.8 f	4.9 f
2	Boone 8	5.1 cd	5.0 d	5.2 e	5.2 e
3	Boone 40	5.4 c	5.7 c	6.1 d	6.1 d
4	Boone 60	5.9 b	6.2 b	6.7 c	6.9 c
5	Boone pan	6.3 a	6.7 a	6.8 bc	6.9 c
6	Delta 8	5.1 cd	4.9 d	5.2 e	5.2 e
7	Delta 40	5.2 cd	5.6 c	5.9 d	6.0 d
8	Delta 60	5.8 b	6.6 ab	7.0 ab	7.1 b
9	Delta pan	6.4 a	7.0 a	7.2 a	7.3 a
LSD (P=.05)		0.27	0.46	0.22	0.13
CV		2.8	5.4	2.4	8

		Ca (lb/acre)				Mg (lb/acre)			
		3/5/13	9/5/13	3/11/14	9/24/14	3/5/13	9/5/13	3/11/14	9/24/14
	Treatment								
1	Check	1460 c	1785 c	1526 de	1512 e	200 a	197 f	223 d	229 g
2	Boone 8	1567 c	2100 b	1784 cd	1965 d	200 a	220 ef	237 d	286 f
3	Boone 40	1572 c	3180 a	2279 b	2465 b	187 a	273 de	330 c	383 e
4	Boone 60	1962 b	3565 a	3058 a	3415 a	216 a	471 b	449 b	561 bc
5	Boone pan	2390 a	3645 a	3193 a	2397 a	223 a	568 a	552 a	625 a
6	Delta 8	1440 c	1782 c	1617 de	1592 e	195 a	277 de	293 cd	335 ef
7	Delta 40	1570 c	2242 b	1942 c	2127 c	205 a	418 c	463 b	594 ab
8	Delta 60	1895 b	2390 b	2400 b	2400 b	156 a	329 d	403 b	482 d
9	Delta pan	1960 b	2485 b	2583 b	2417 b	229 a	413 c	455 b	524 cd
LSD (P=.05)		142	196	243	151	26	48	65	50
CV		6.4	5.9	3.7	4.9	9	9.3	11.8	7.7

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

Proposed budget:

Expenses	2013	2014	2015
Labor	$6,000	$6,255	$6,518
Fringe benefits	$1,500	$1,564	$1,630
Supplies	$2,000	$2,000	$2,000
Travel	$550	$550	$550
Lab analysis	$1,500	$1,500	$1,500
Total	**$11,550**	**$11,869**	**$12,198**

2015
February 4, 2015

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.

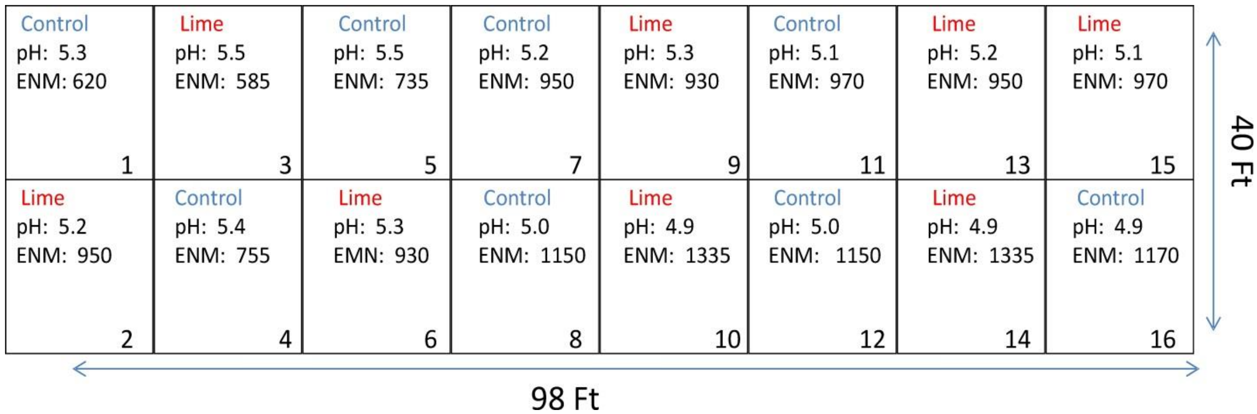

Figure 1. Plot layout of liming study located near Alton, MO with lime and pH data shown. The plots are 10 x 20 feet with 2-foot buffer strips (not shown).

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.

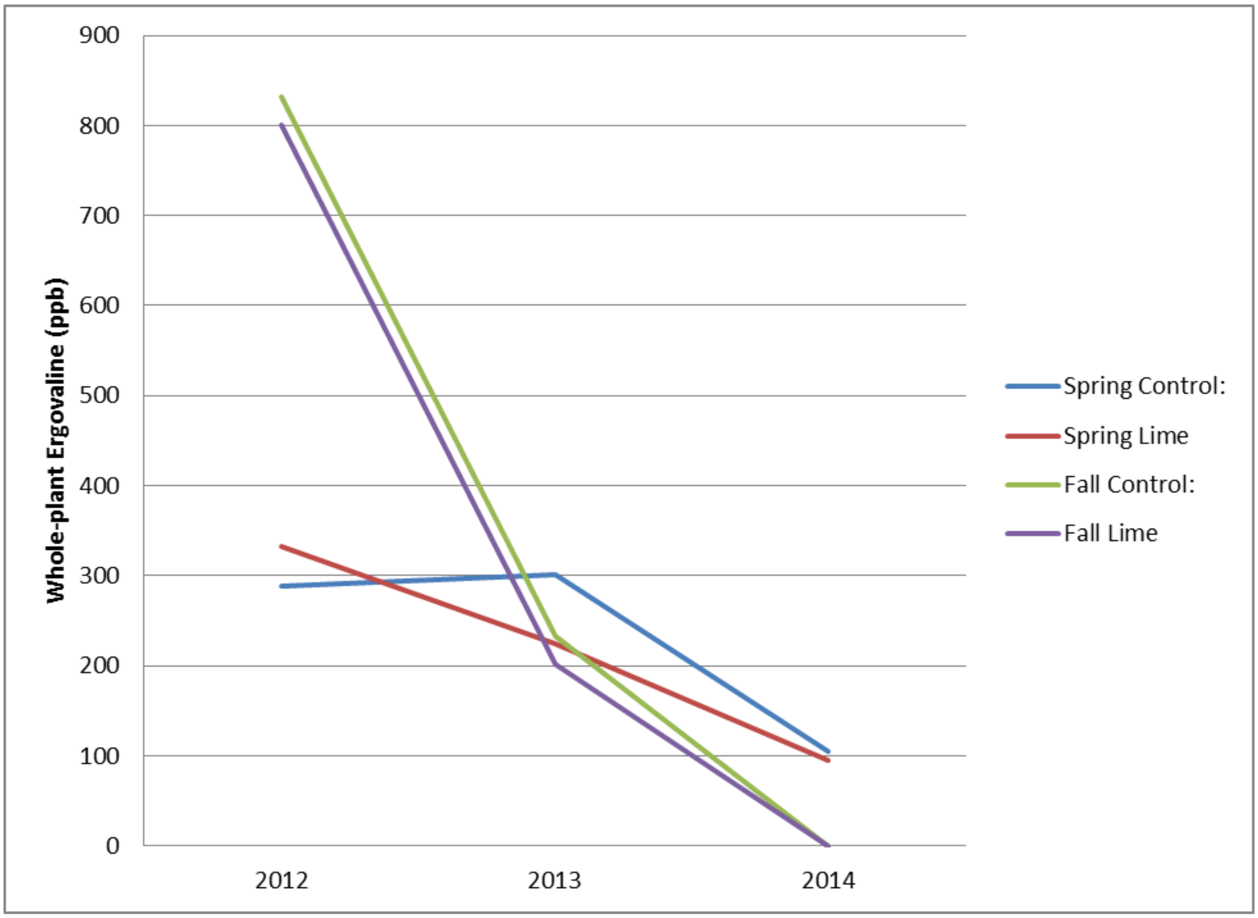

Figure 3. Ergovaline concentration of whole-plant samples subjected to treatment with limestone.

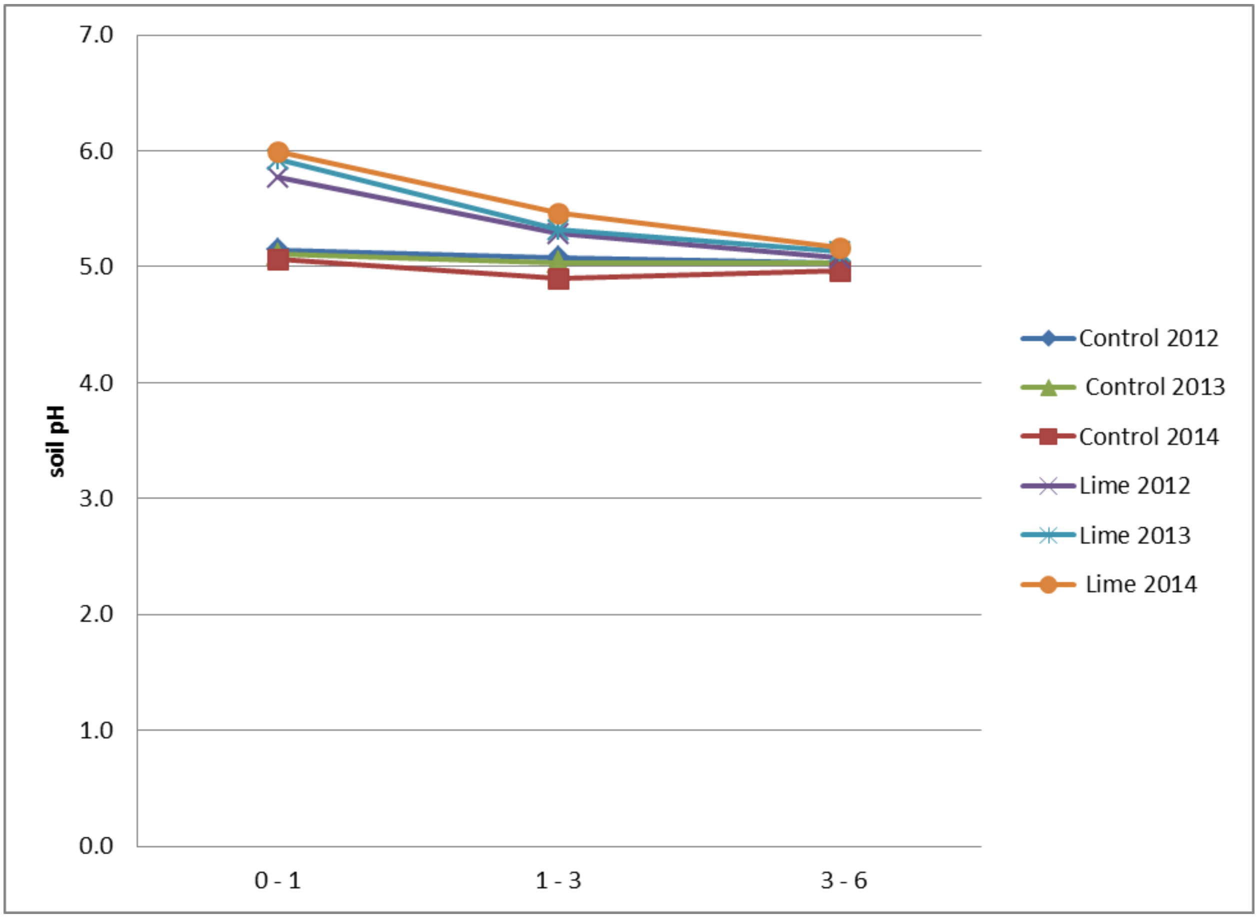

Figure 4. Changes in soil pH, soil core samples were divided into increments from the soil surface.

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.

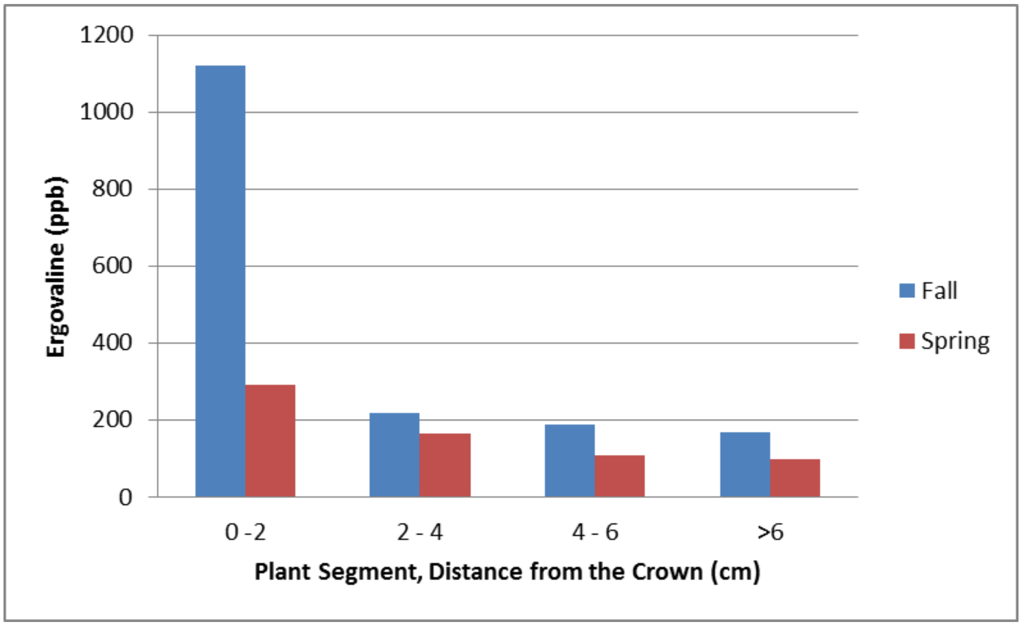

Figure 5. Ergovaline in segments of the tall fescue canopy in the spring and fall.

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*.

Final Report
2015

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 considered to be 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 methods being studied to 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). Si may compete with As ions for root entry points (Seyfferth and Fendorf, 2012). Increasing soil pH by liming could 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).

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 and lime 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 Dewitt 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 alkaline (pH 12 mixed with water). 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 intermittent (aerobic, flushed) 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

Applying calcium silicate fertilizer did not reduce total arsenic levels in brown rice grain in any of the locations (Table 1). This indicates that applying Si fertilizer probably does not limit As root uptake by rice roots. However, irrigation management significantly impacted As levels in rice grain. The lowest levels of arsenic were found in grain grown under center pivot irrigation (11 ppb As). At Portageville on Sharkey clay soil, arsenic levels were higher in rice grain harvested from continuous flood rice (77 ppb As) than internment flood irrigated rice (27 ppb As). The highest amount of arsenic was found in flood irrigated rice grown on Dewitt silt loam soil (210 ppb).

Rice yield response to silicate fertilizer and lime was not consistent. Rice grown under center pivot irrigation (not flooded) was Si deficient based on tissue testing (Korndorfer, et al., 2001). This may be the reason why non-flooded rice is more prone to diseases such as blast. In center pivot irrigated plots, grain yields were increased (39 bushels per acre in 2013 and 35 bushels per acre in 2014) with an application of 54 lb Si acre^{-1} (450 lb calcium silicate) compared to untreated checks (Figure 1). Applying higher rates of silicate did not show the same yield increase. No yield increases were found from applying calcitic or dolomitic lime (Table 2). Under intermittent and continuous flood soil conditions on Sharkey clay and Dewitt silt loam, soil amendments did not increase grain yield compared to untreated plots (Figure 2-4). Soils with reduced conditions from flooding may provide enough Si through the reduction of iron under anaerobic conditions.

Rice under center pivot irrigation averaged 145 bu acre^{-1}. Averaged across years, rice grown on Sharkey clay averaged 166 bu acre^{-1} with intermittent flood and 168 bu acre^{-1} with continuous flood. Flooded rice on Dewitt silt loam averaged 210 bu acre^{-1}. Although yield differences were found between CLXL745, CL151, and Jupiter, interaction in response to Si fertilizer within test locations were not found.

Conclusions

Aerobic rice grown with center pivot irrigations may benefit from applications of calcium silicate by reducing diseases such as blast. But applying Si fertilizer did not reduce arsenic levels in any of the trials in this study. Non-flooded rice contained less As in grains but yields were lower compared to flooded rice. Rice grown with center pivot irrigation produced lower yields than intermediate or continuous flooded rice.

Table 1. Total grain arsenic in brown rice planted on different locations and irrigation programs with a hybrid and cultivars receiving silicate fertilizer in 2013 and 2014.

Location	Hybrid or Cultivar	Si Fertilizer	2013	2014	2-yr Mean	Site Mean
		lb Si acre^{-1}	-------------------Total As, ppb------------------			
Pivot Irrigated	CLXL745	0	16	7	12	11
University of Missouri		54	15	10	13	
Marsh Farm		108	14	9	12	
Tiptonville silt loam		162	14	11	12	
Portageville, MO		216	16	9	13	
		270	16	11	14	
Intermittent Flood	CLXL745	0	13	30	21	27
University of Missouri		108	49	33	41	
Lee Farm		216	18	34	26	
Sharkey clay	CL151	0	16	32	24	
Hayward, MO		108	16	30	23	
		216	20	28	24	
	Jupiter	0	31	23	27	
		108	21	22	21	
		216	23	39	31	
Continuous Flood	CLXL745	0	48	114	81	77
University of Missouri		108	62	101	81	
Lee Farm		216	67	113	90	
Sharkey clay	CL151	0	54	83	69	
Hayward, MO		108	45	107	76	
		216	47	105	76	
	Jupiter	0	55	85	70	
		108	66	94	80	
		216	54	94	74	
Continuous Flood	CLXL745	0	205	204	204	210
Missouri Rice Farm		108	203	199	201	
Dewitt silt loam		216	176	247	211	
Glennonville, MO	CL151	0	209	244	226	
		108	170	210	190	
		216	191	260	226	

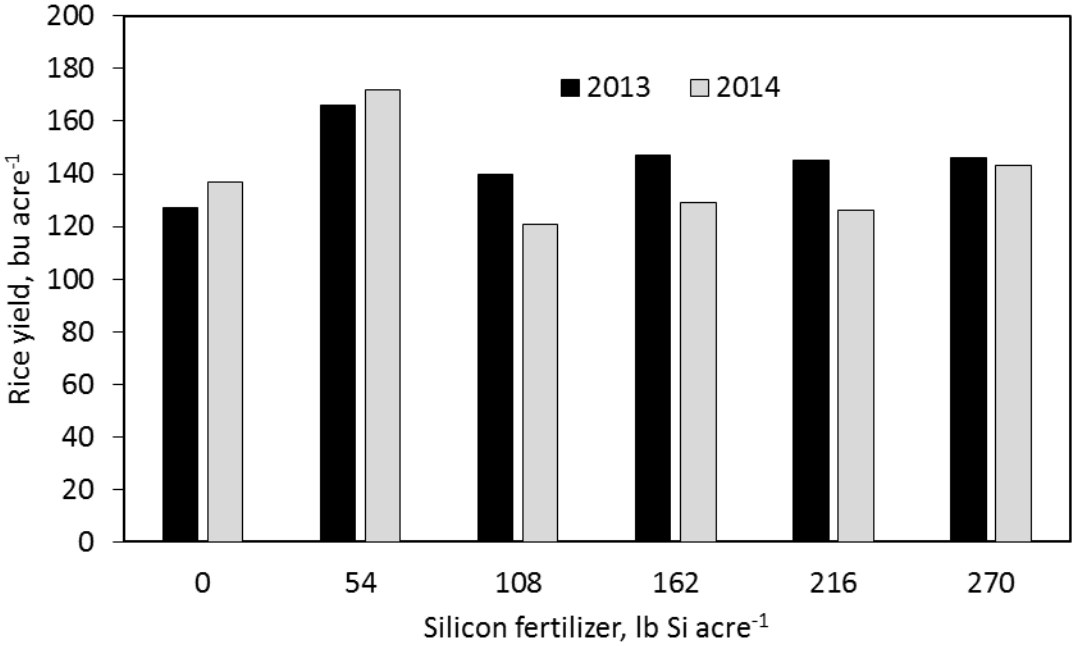

Figure 1. Grain yields from center pivot irrigated rice with CLXL745 receiving silicon fertilizer on Tiptonville silt loam soil at Portageville, MO in 2013 and 2014.

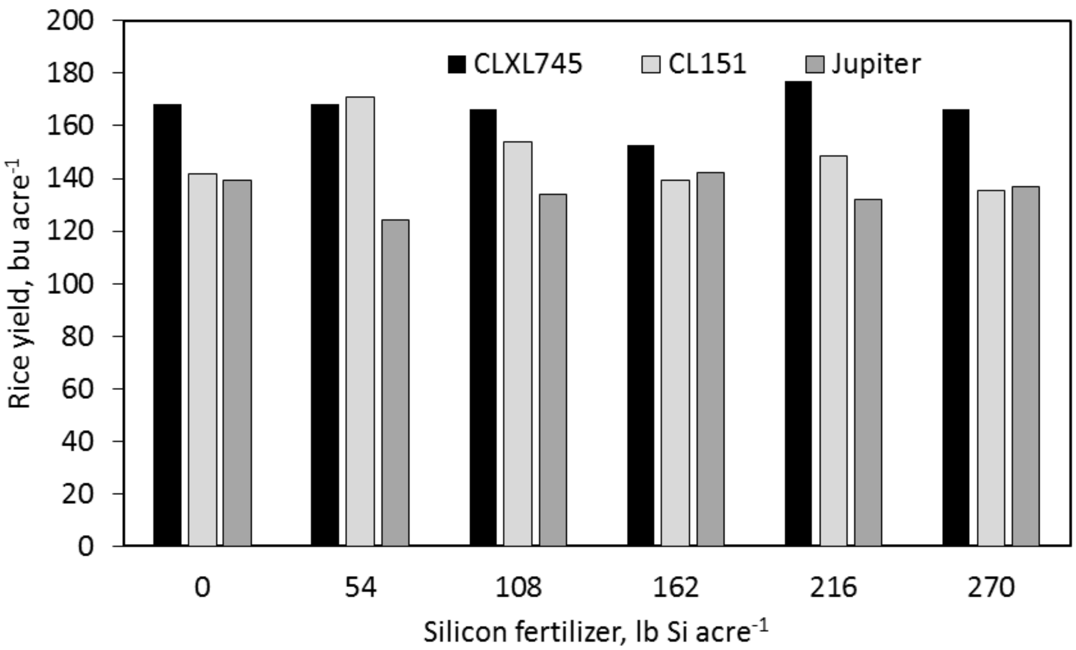

Figure 2. Grain yields from intermittent flood irrigated rice with CLXL745, CL151, and Jupiter receiving silicon fertilizer on Sharkey clay at Hayward, MO averaged across 2013 and 2014.

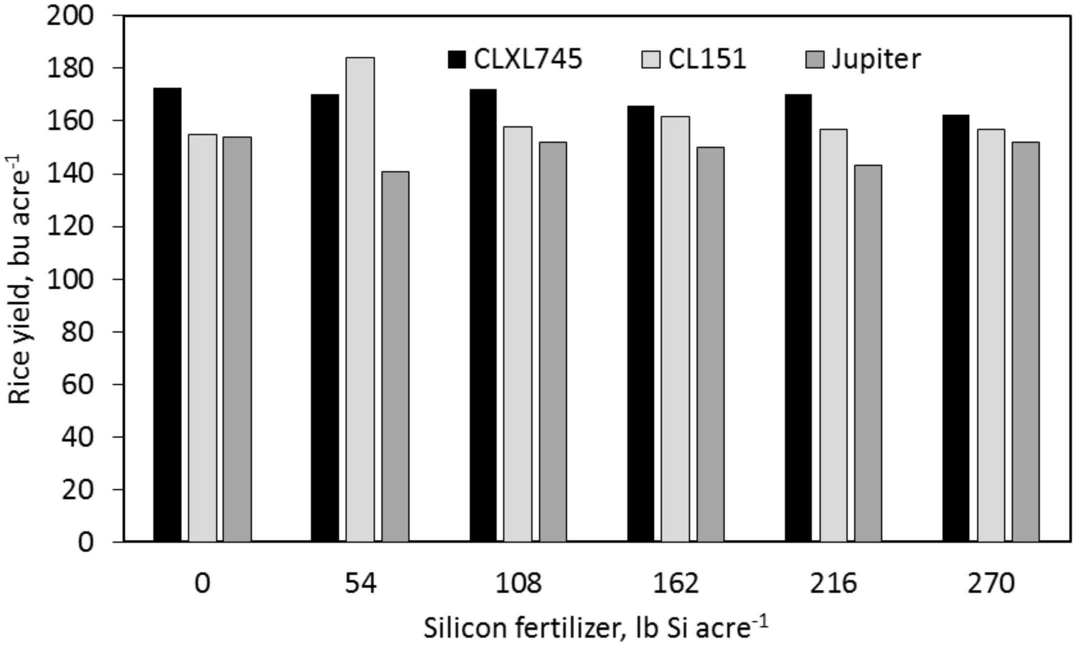

Figure 3. Grain yields from continuous flood irrigated rice with CLXL745, CL151, and Jupiter receiving silicon fertilizer on Sharkey clay at Hayward, MO averaged across 2013 and 2014.

Figure 5. Grain yields from continuous flood irrigated rice with CL151 receiving silicon fertilizer on Dewitt silt loam soil at Glennonville, MO in 2013, 2014, and 2015.

References

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Nitrogen Management

Progress Reports

2015

Optimal Placement of Nitrogen Fertilizer Sources to Improve Nitrogen Use Efficiency in Corn

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Accomplishments for First Year:

Research was initiated in 2015 with the objectives of determining the effectiveness of different N fertilizer placement practices including deep banding urea or urea plus a nitrification inhibitor on corn (*Zea mays* L.) yields and N use efficiency in a poorly-drained claypan soil, and assessing the differences in cumulative soil nitrous oxide gas emissions with deep banding and other N fertilizer placement strategies. The overall objective of the research is to develop N fertilizer management practices that enhance plant N availability at critical growth stages and to minimize overall environmental N losses.

Field Trial

A three-year field trial funded under this grant was initiated in 2015 with a previous test year in 2014 at the University of Missouri-Greenley Memorial Research Center in a poorly-drained claypan soil (Putnam silt loam, fine, smectitic, mesic Vertic Albaqualfs) to determine the effect N fertilizer placement has on corn growth and cumulative greenhouse gas flux over the growing season. The field trial was a randomized complete block design with five replications. Experimental plots were planted with corn hybrid, DeKalb 61-88, in fields that were grown with soybean the previous year. Plots were approximately 10 by 60 ft. Planting was done with a John Deere 7000 planter (Deere and Co, Moline, IL) with 30 in row spacing at 32,000 seeds/acre.

The treatments for this study were:

1. Non-treated control (NTC)
2. Pre-plant urea deep banded at a depth of 8 inches (UDB)
3. Pre-plant urea deep banded + nitrification inhibitor (UDB+NI)
4. Urea incorporated after application at a depth of 3 inches (UAA)
5. Urea surface applied (USA)

The fertilizer application rate for each N fertilizer treatment was 180 lb N/acre. The deep banded N fertilizer treatment was applied with a custom designed strip-till conservation C-jet unit (Advance, MO). Nitrogen fertilizers were banded to a depth of 8 inches below the planted row with fertilizer delivered using a Montag (Montag Manufacturing, Inc., Emmetsburg, IA) dry fertilizer air delivery system. After the banded fertilizer application, the entire soil surface was surface-tilled to remove the possible effects of strip tillage on crop response. The nitrification inhibitor (Instinct II®, Dow AgroSciences) was applied with urea at a rate of 37 oz/acre.

The initial soil properties for each year (Table 1) were determined from analysis of soil samples taken at 0-6, 6-12, and 12-18 in depths from the nontreated control plots in all the five replicates. Samples were taken using a stainless steel push probe with 10 to 15 subsamples per plot composited to make one sample. All soil samples were air-dried and ground to pass through a sieve with 2 mm openings. The initial soil samples were analyzed by the University of Missouri Soil and Plant Testing Laboratory using standard soil testing procedures (Nathan et al., 2006).

Stand counts for the center two rows of each plot were taken each year over a row length of 50 ft (data not shown). Corn silage was harvested at physiological maturity by cutting plants from 10 ft of one row length and obtaining the total weight of the plants using a hanging scale. These plants were then chopped using a brush chopper and subsamples taken to determine silage moisture for adjusting calculated silage yield on a dry weight basis and for tissue analysis. These yields are not shown in this report. Silage samples were dried at 70° C and ground to pass through a 1 mm sieve. Total N in the tissue was analyzed using the combustion method with a total carbon-nitrogen analyzer (LECO Corp., Township, Michigan). Tissue N concentration and silage yield were then used to calculate N uptake and subsequently the apparent N recovery useefficiency (NUE). Corn N uptake results are provided in this report.

Corn grain yields were determined using a plot combine (Wintersteiger, Salt Lake City, UT) that harvested the two center rows in each plot of 200 ft in length. All grain yields were adjusted to 15% moisture. Grain samples were collected from each plot for determination of test weight, grain moisture, and analysis of starch and protein concentration (Foss 1241 Infratec, Eden Prairie, MN).

Greenhouse Gas Sampling

Soil surface greenhouse gas (CO_2, N_2O, and CH_4) fluxes were determined during the growing season using vented PVC chambers based on the USDA GraceNet protocol (t=0 min, 30 min, 60 min) (see Fig. 1). Samples were taken frequently near the beginning of the growing season (roughly 3 times a week) and less frequently as the growing season progressed. During each gas sampling, soil samples were taken to measure gravimetric soil water content and soil temperature was measured at a 2 inch depth. The gas samples were analyzed using a Shimadzu Gas Chromatograph (Overland Park, KS) equipped with a methanizer, an electron capture detector (ECD), and a flame ionization detector (FID).

Results

Rainfall was relatively higher in 2015 compared to 2014 especially at the beginning of the growing season (see Fig. 2) but because of excessive rain in the 2015 season, corn grain yields were on average 47% lower in 2015 compared to those of 2014 (Fig. 3A&B). Deep banding of urea with (UDB + NI) and without NI (UDB) in 2014 had approximately a 16 to 19 bu/acre higher grain yield compared to the surface-applied urea treatment (USA), and the deep banded urea without NI (UDB) had a significantly higher grain yield than the shallow incorporated treatment (UAA) (Fig. 3A). In contrast, 2015 was extremely wet and yields were relatively lower. The UDB + NI and the USA fertilizer placement treatments had significantly higher grain yields compared to UAA and UDB (Fig. 3B). These results indicate that response to N fertilizer placement was affected by climatic conditions, the timing of rainfall events and soil moisture content, but additional research is required to examine these interactions. However, the UDB + NI treatment was the most consistent in obtaining relatively higher yields among the N placement practices evaluated in this study during 2014 and 2015.

Results for N uptake, which is a measure of the amount of N in the aboveground biomass of the corn crop, had similar results to that of the corn grain yields in response to N fertilizer placement in 2014 and 2015 (Fig. 4A&B). In 2014, the UDB + NI treatment had 31 to 33% higher N uptake than that of the USA and UAA treatments, respectively (Fig. 4A). However, the USA treatment had significantly higher N uptake compared to that of the UDP and UDP+NI treatments in 2015 (Fig. 4B). These results may indicate that the saturated soil conditions in the beginning of the growing season in 2015 may have limited the growth of corn roots with depth so that roots were unable to absorb the deep banded fertilizer N, but were able to obtain the surface and shallow-placed N fertilizer.

Cumulative soil nitrous oxide gaseous emissions were generally lower in 2014 compared to 2015 (Fig. 5 A&B). Saturated soils promoted nitrous oxide gas loss when nitrate was present in the soil. The deep-banded urea treatment had higher cumulative emissions in both years compared to that of other fertilizer placement treatments. In 2015, both the UDB and USA treatments had the highest gaseous N losses compared to the UAA and UDB+NI treatments (Fig. 5B). These results suggest that the nitrification inhibitor added in conjunction with the UDB treatment was effective at reducing nitrous oxide gas loss. Shallow incorporation of the urea was also effective at reducing gas loss.

Further research will be evaluating the interaction between climate and corn response to N fertilizer placement. Early results indicate that climatic conditions affected the fate of the applied N including gaseous losses as well as the growth of corn roots which influenced the availability of N whether it was placed on the surface, shallow incorporated or deep banded. Initial results indicate that addition of nitrification inhibitor helped to reduce cumulative soil nitrous oxide losses when urea was deep-banded.

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 published in the 2015 Greenley Center Field Day Report in Northeast Missouri.

Objectives for Year 2:

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

1. Determine the effectiveness of different N fertilizer placement practices including deep banding urea or urea plus a nitrification inhibitor on corn yields and N use efficiency in a poorly-drained claypan soil,
2. Assess the differences in cumulative soil nitrous oxide gas emissions with deep banding and other N fertilizer placement strategies.

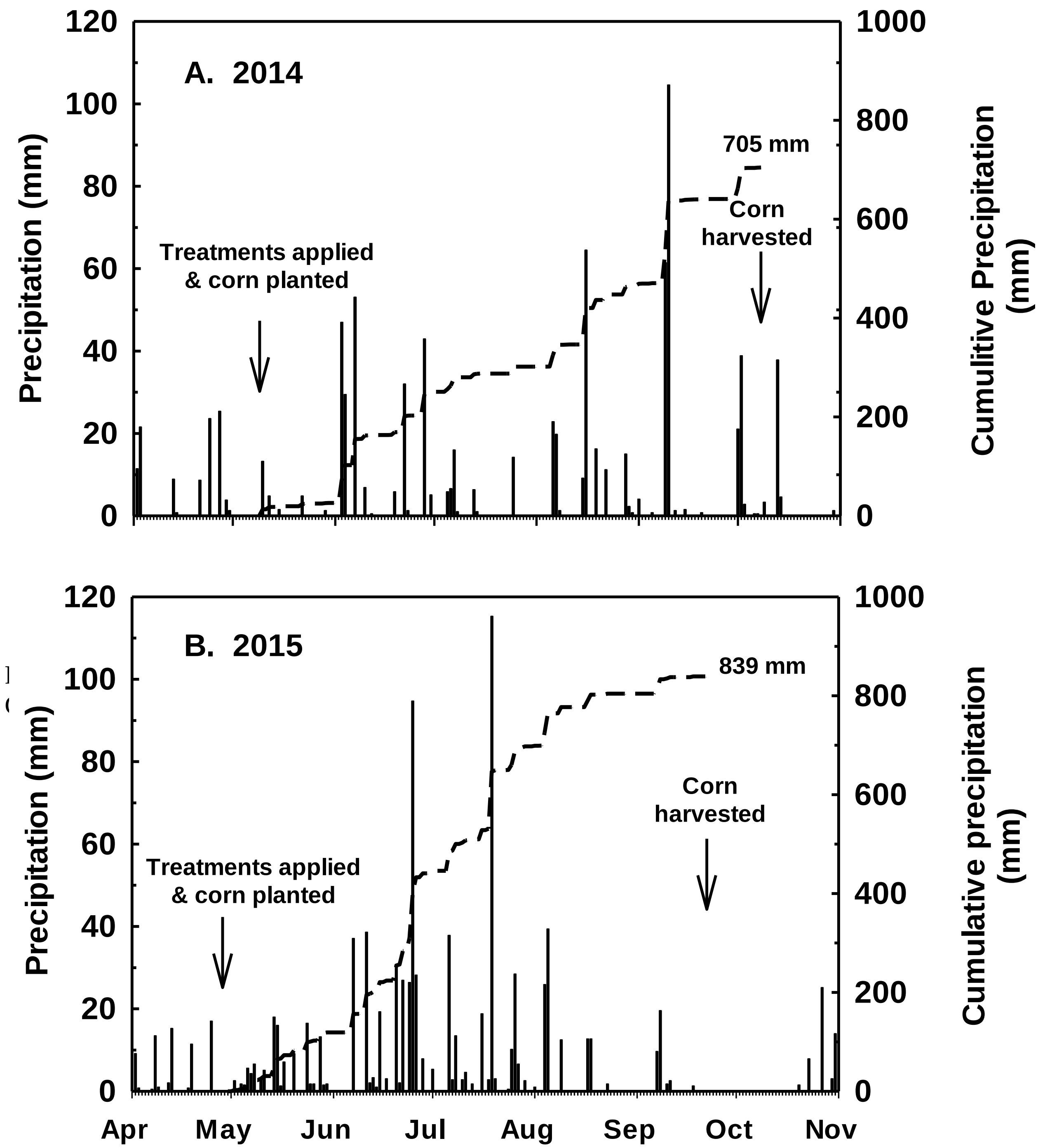
The field study will be repeated for a second year to assess variation in climate on corn response to N fertilizer placement and on soil nitrous oxide emissions.

Table 1. Selected means (± standard deviation) for initial soil properties in 2014 and 2015.

	Depth (in.)		
Soil properties†	0-6	6-12	12-18
2014			
pH (0.01 M $CaCl_2$)	6.7 ± 0.1	6.0 ± 0.4	5.0 ± 0.2
Neut. Acidity (meq/100g)	0.4 ± 0.2	2.4 ± 0.9	7.0 ± 1.5
Organic matter (%)	2.8 ± 0.3	2.1 ± 0.2	2.2 ± 0.2
Bray I P (lb/acre)	77 ± 12	15 ± 3	15 ± 11
Exc. Ca (lb/acre)	4919± 446	4452 ± 448	5520 ± 335
Exch. Mg (lb/acre)	361 ± 91	462 ± 169	1076 ± 184
Exch. K (lb/acre)	290± 37	149 ± 12	201 ± 20
CEC (meq/100g)	14.6 ± 1.5	15.6 ± 2.3	25.6 ± 2.9
2015			
pH (0.01 M $CaCl_2$)	6.1± 0.1	5.9 ± 0.2	4.8 ± 0.3
Neut. Acidity (meq/100g)	1.2 ± 0.3	1.8 ± 0.6	6.4 ± 2.0
Organic Matter (%)	2.6 ± 0.1	1.8 ± 0.3	2.1 ± 0.4
P Bray I (lb/acre)	70 ± 37	8 ± 4	7 ± 1
Exch. Ca (lb/acre)	3671 ± 2296	3772 ± 588	3439 ± 625
Exch. Mg (lb/acre)	332 ± 38	320 ± 102	465 ± 125
Exch. K (lb/acre)	273 ± 25	94 ± 14	93 ± 13
CEC (meq/100g)	12.1 ± 0.9	12.7 ± 2.4	17.1 ± 4.1

†Abbreviations: Neut. Acidity, Neutralizable Acidity; Bray I P, Bray-1 Phosphorus; Exch. Ca, Exchangeable Calcium; Exch Mg, Exchangeable Magnesium; Exch. K, Exchangeable Potassium; CEC, Cation Exchange Capacity.

Figure 1. M.S. graduate student from Missouri sampling to determine surface greenhouse gas emissions using PVC chambers in field site in northeast Missouri.


A. 2014
Precipitation (mm)
Cumulitive Precipitation (mm)
Treatments applied & corn planted
705 mm
Corn harvested
B. 2015
Precipitation (mm)
Cumulative precipitation (mm)
Treatments applied & corn planted
839 mm
Corn harvested
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov

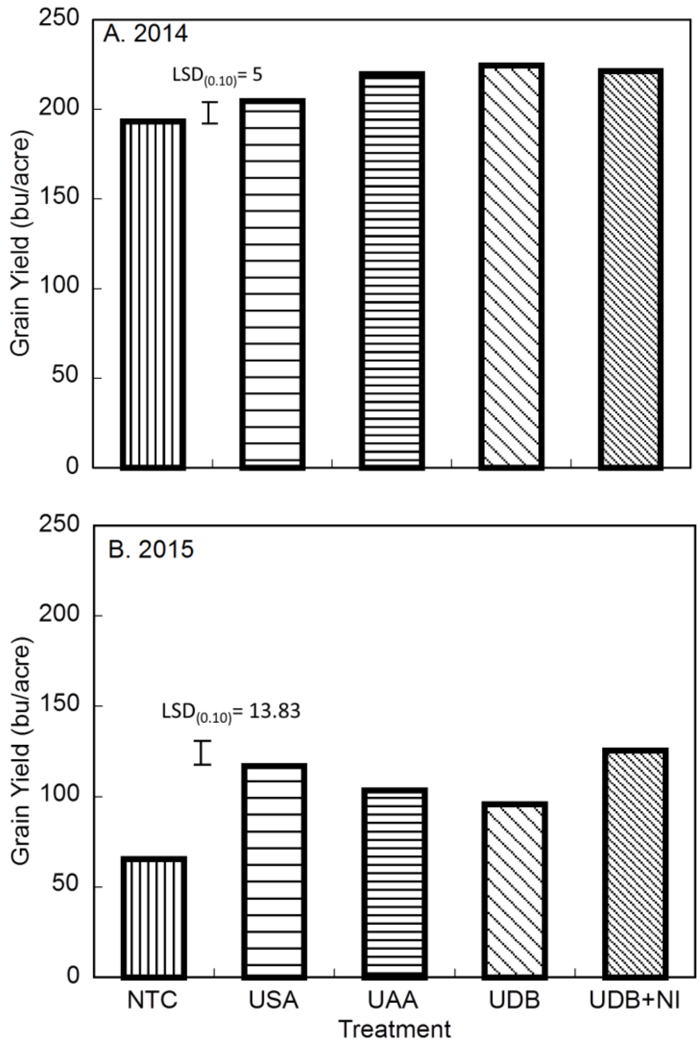
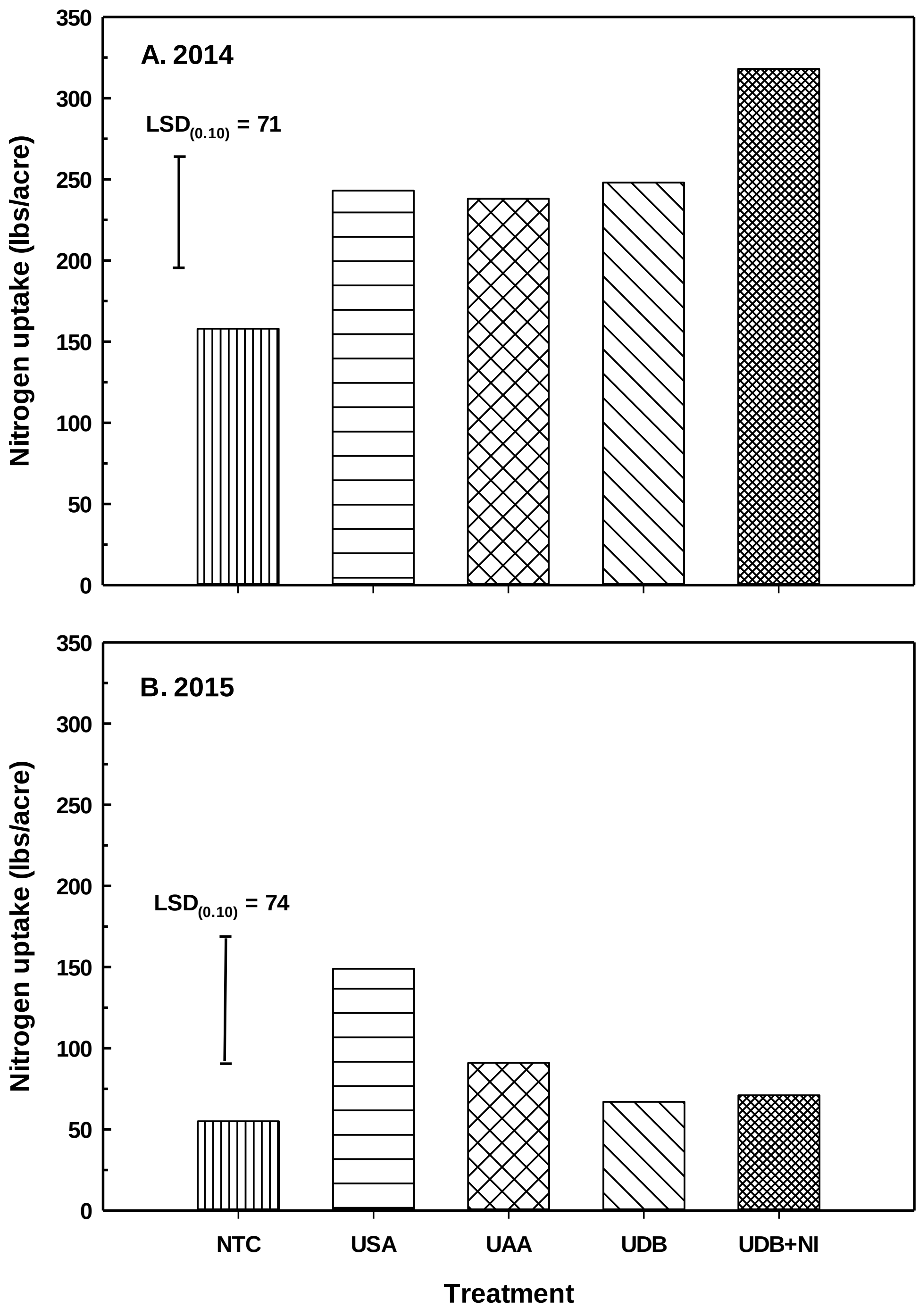


Figure 3 A & B. Corn grain yields in A) 2014 and B) 2015 as affected by N fertilizer placement. LSD = least significant difference at $p \leq 0.10$. Abbreviations: NTC = non-treated control; USA = urea surface applied; UAA = urea shallow incorporated; UDB = urea deep banded; UDB + NI = urea deep banded plus nitrification inhibitor.


A. 2014
LSD(0.10) = 71
B. 2015
LSD(0.10) = 74
Nitrogen uptake (lbs/acre)
0
50
100
150
200
250
300
350
NTC
USA
UAA
UDB
UDB+NI
Treatment

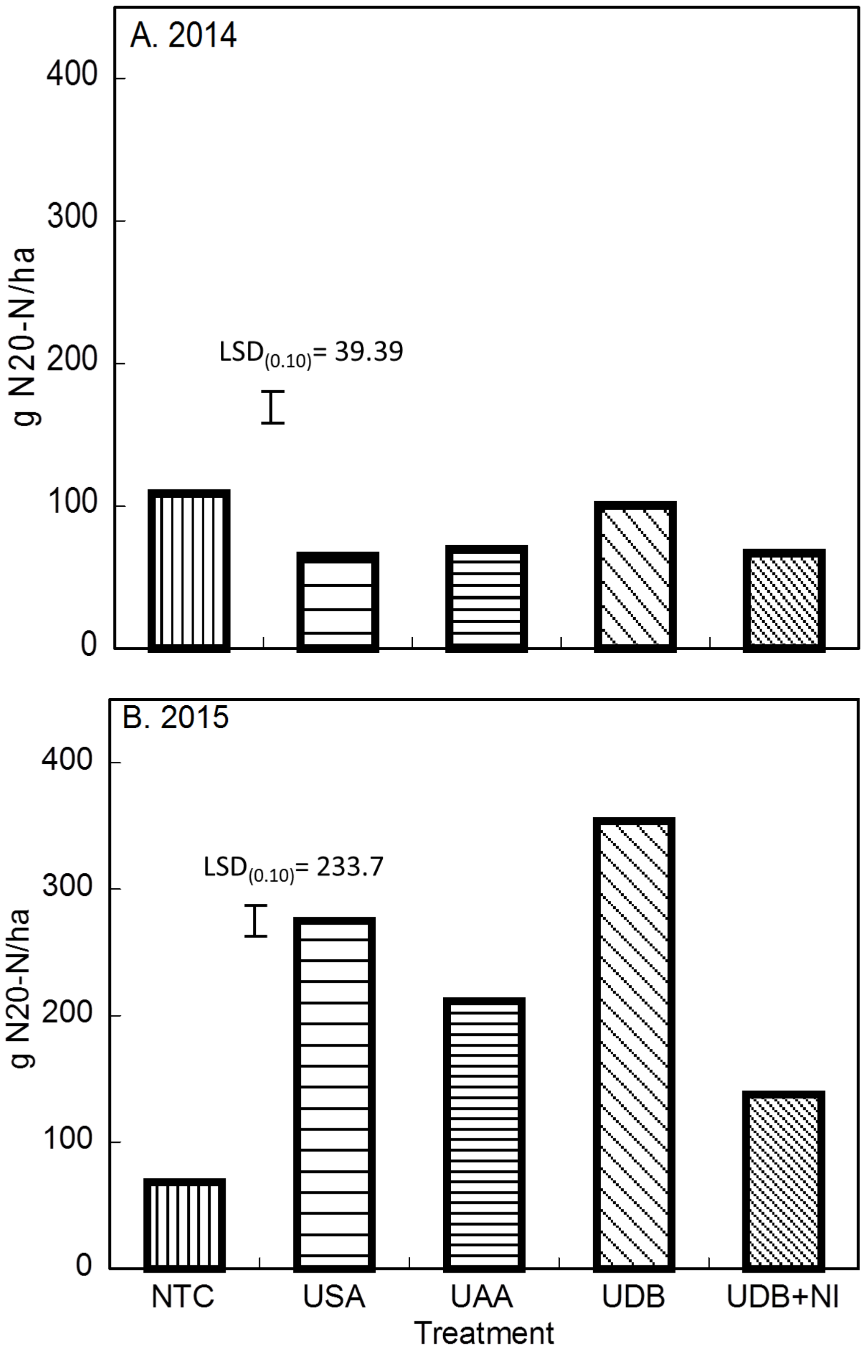


Figure 5 A&B. Cumulative soil nitrous oxide (N_2O) emissions over the growing season in A) 2014 and B) 2015 as affected by N fertilizer placement. LSD = least significant difference at $p \leq 0.10$. Abbreviations: NTC = non-treated control; USA = urea surface applied; UAA = urea shallow incorporated; UDB = urea deep banded; UDB + NI = urea deep banded plus nitrification inhibitor.

Proposed Budget for Year Two:

CATEGORIES	YEAR TWO
A. Salaries	
Ph.D. Graduate Research Assistant (50%)	$17,878
B. Fringe Benefits	
Fringe for graduate student	$3,140
TOTAL SALARIES AND FRINGE BENEFITS	$21,018
C. Travel	
Travel to field site	$672
Travel to professional meeting	$1,000
TOTAL TRAVEL COSTS	$1,672
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	$28,690

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 Farm 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.

Spread it and Forget it: Spoon-feeding Tall Fescue Pastures

Investigators: Robert L. Kallenbach and Brett T. Jones

Objectives and relevance of project:

Tall fescue is the predominant grass of Missouri's 11 million acres in pasture and hay. It provides forage for more than 3.5 million beef cattle in Missouri. About one-half of all tall fescue acres receive some nitrogen (N) fertilizer in spring. Most of these applications are made in March or early April. Other times in which tall fescue acres are fertilized with N are in late spring to stimulate summer regrowth and in late-summer for autumn stockpiling.

In past years, ammonium nitrate and urea have been the most popular sources of N for spring and late-summer fertilization. Ammonium nitrate is widely considered the most reliable source of N for forage production as the N in ammonium nitrate is much less likely to be lost to volatilization than that in urea. However, ammonium nitrate is being phased out in many areas due to security concerns.

Given the pricing structure and potential problems with ammonium nitrate, urea is commonly used as a N source for forage production. This is due to urea's wider availability and lower cost per N unit when compared to ammonium nitrate. In fact, in many rural areas the only source of N available for pastures is urea. While urea is a common source of N fertilizer for row crop applications in spring, its use for fertilization of pastures is problematic due to excessive nitrogen volatilization. Up to 40% of the N applied to pastures as urea can be lost due to volatilization if rainfall does not occur within 48 hours of an application. Given these problems, farmers are looking for a reliable and inexpensive source of N for pastures.

Environmentally Smart Nitrogen (ESN) is a polymer coated urea product from Agrium that offers protection from N volatilization. Additionally, N from ESN is released slowly over time and may provide a steady source of N throughout the growing season. We proposed to test an easy-management (*Spread-it-and –Forget-it*) protocol where a single application of ESN mixed with urea provides season-long N to the pasture. The ESN product has been an effective source of N for other crops, but research is needed to determine if the Spread-it-and-Forget-it program would be effective for pastures and if so, when is the ideal time(s) to apply it.

The **overall objective** is to test a simple N fertilization program that optimizes seasonal and annual production of tall fescue pasture. Specific objectives are:

Objective 1: Determine how the Spread-it-and-Forget-it program compares to fertilizing pasture with urea or ammonium nitrate.

Objective 2: Determine the best time to apply ESN/Urea mixture in the Spread-it-and-Forget-it program to optimize the slow-release characteristic of the product.

We are conducting a three-year experiment to evaluate forage production when N fertilization occurs at one of eight times. Fertilization timings start in mid-March and continue at 45-d intervals, to end in late January the following year. This spectrum of N fertilization dates encompasses most cultural practices that Missouri producers employ.

Procedures:

Treatments: Eight N fertilization dates and four N sources (total of 25 treatments per block; Table 1) were imposed on established tall fescue. The N rate was 100 lb./acre (annual total). Soil pH, P and K levels will be maintained at those recommended by the University of Missouri Soil Testing Laboratory.

Table 1. Nitrogen fertilizer sources and application timings (45 days apart) applied to tall fescue pastures at the Forage Systems Research Center near Linneus, Missouri.

N Application Date	N Fertilizer Source	N from ESN	Ammonium nitrate or Urea N
		---------------------lb/A---------------------	
Mid-Mar	Urea	-	75
Late Apr	Urea	-	75
Early Jun	Urea	-	75
Mid-Jul	Urea	-	75
Late Aug	Urea	-	75
Early Oct	Urea	-	75
Mid-Nov	Urea	-	75
Late Dec	Urea	-	75
Mid-Mar	Ammonium Nitrate	-	75
Late Apr	Ammonium Nitrate	-	75
Early Jun	Ammonium Nitrate	-	75
Mid-Jul	Ammonium Nitrate	-	75
Late Aug	Ammonium Nitrate	-	75
Early Oct	Ammonium Nitrate	-	75
Mid-Nov	Ammonium Nitrate	-	75
Late Dec	Ammonium Nitrate	-	75
Mid-Mar	75/25% ESN/Urea	56	19
Late Apr	75/25% ESN/Urea	56	19
Early Jun	75/25% ESN/Urea	56	19
Mid-Jul	75/25% ESN/Urea	56	19
Late Aug	75/25% ESN/Urea	56	19
Early Oct	75/25% ESN/Urea	56	19
Mid-Nov	75/25% ESN/Urea	56	19
Late Dec	75/25% ESN/Urea	56	19
---	Control	0	0

Location and Design: This study is being conducted on tall fescue at the Forage Systems Research Center near Linneus, MO. Each treatment is replicated six times in a randomized complete block design. Individual plots are 10 ft. x 25 ft. Plots will not be relocated when a new year starts and plots will receive the same N fertilization date and source each year. The repeated measures allow detection of cumulative and residual effects of treatments.

Measurements: Grass height was measured weekly in each plot with an ultrasonic sensor mounted to an ATV. Week-over-week measurements will allow us to determine weekly growth rates. At 6 times during the growing season, the ultrasonic sensor heights will be calibrated to dry matter yield by harvesting and weighing forage. This growth monitoring system allows us to determine 1) seasonal and annual forage production, 2) how quickly pastures respond to a fertilizer application, and 3) the dynamics of the best time to apply N fertilizer to optimize forage production

Cultural practices: Forage growth accumulated until grass height reached approximately 10 inches. At that time, all plots were clipped with a flail chopper and the mulched residue was returned to the plots. We reset the plot heights 6 times in 2015 with the grass height measured before and after each clipping event to document forage mass.

Timetable for proposed research: This study began in spring of 2015 and will continue until December of 2018 (three years of study). The table below gives a brief summary of the project's activities. (* indicates task to be done on an annual basis throughout the three-year study).

Locate and layout plot areas; take initial soil samples	2/15/2015
Apply nitrogen containing fertilizer products	*Eight times per year (45 days apart)
Measure grass height in plots with ultrasonic sensor	*Weekly all year long
Calibrate ultrasonic sensor to mechanical harvest	*April, May, June, August, October
Clip plots with flail mower; determine forage mass and accumulation	*Variable based on plant growth (expect 3 to 5 harvests per year)
Prepare report to Fertilizer/Ag Lime Advisory Council	*December
Incorporate results into soil testing reports, hay school materials and forage conferences. Work with press on articles.	October 2015 through December 2018
Submit manuscript to a peer-reviewed journal	July 2019

Application/transfer of knowledge: We will transfer our results in three ways. First, we will incorporate the results and recommendations from this study into the curriculum of the grazing schools and the annual Forage Conferences held across the state. Second, we will work with the Soil Fertility Working Group and the Soil Testing Laboratory to refine the recommendations printed on soil testing results. Finally, we will prepare articles to be published in statewide and national magazines such as Missouri Ruralist, Stockman Grass Farmer and scientific (peer-reviewed) journals.

Report on activity: The timing of N treatments is one important aspect of this study (Fig. 1). To date, the final application time has not been applied; it will occur in late December. We harvested accumulated forage in late April, early June, mid July, late August, early October, mid November. These harvests allow us to compute growth rates over time. We have not analyzed any forage production or growth rate data yet.

Figure 1. Plots have been imposed at the Forage Systems Research Center near Linneus, MO. This satellite imagery from 11 May 2015 shows plots that had responded in color to N fertilizer in mid-March or late-April. Weekly height measurements are being recorded by ultrasonic sensor and growth rates can be calculated over time after calibration to mechanical harvest. From these measurements, we can recommend the optimum time for N fertilizer to be applied in pasture systems and determine if some N products are more effective than others during these application periods.

Budget:

YEAR 2

Salary and Benefits	
Research Specialist (20% of $59,740)	$11,948
Benefits for Research Specialist	$4,062
Total Salary and Benefits	$16,010
Operating Expenses	
Fertilizer, bags, repair parts for harvester and other field supplies	$3,740
Travel to research location (mileage, lodging, and meals for 8 trips/yr)	$1,600
Total Operating Expenses	$5,340
Equipment	
None	$0
Total Equipment	$0
Total Proposal Request for Year #2	$21,350

On-Farm Rescue Nitrogen Applications for Corn

Year 1 report
Peter Scharf, University of Missouri, Plant Sciences Division

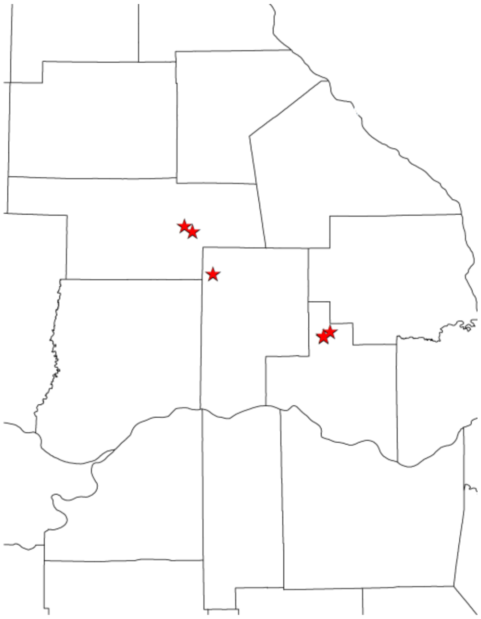
Accomplishments in 2015:
The intention of this project is to use normal production equipment to apply rescue N applications to corn when wet weather has caused N loss.

There was some risk of not getting enough rain anywhere in Missouri to cause substantial N loss. This was not a problem in 2015. In fact, it was so wet that our attempts to apply rescue N with normal production equipment were almost a complete failure.

There were very few days when high-clearance N applicators could run, and on the days that they could run everyone wanted them to cover the maximum possible acres, not fiddle around doing tests to measure the effect of the extra N. We were not able to get any tests put out with ground-based equipment.
Because there were many days when ground equipment couldn't run, more N was applied with airplanes this year than ever before in Missouri. With a handful of phone calls, I have documented around 100,000 acres of corn in Missouri that received aerial N in 2015. This is probably well short of what was actually done. The most I was able to document in any past year was 20,000 acres in 2010. I was proud of Missouri farmers for moving aggressively into aerial application to get their corn taken care of. Unfortunately, there were some planes/pilots available that didn't get much N applied. At least part of this was due to inefficiencies in finding fields and loading planes that I witnessed. A number of farmers who ordered aerial N did not receive it because ag aviators moved to fungicide applications before getting those N orders applied.

1. Aerial rescue N application map

<u>2015 rescue N trials</u>
We did get one rescue N trial applied with production equipment near Mexico. This trial consisted of a whole field that was fertilized with 100 lb/acre urea by plane, with two strips left unfertilized. Nitrogen application was made in early July. An aerial photo with the pilot's application paths is shown in the figure to the right. We do not yet have the yield map for this field, and so we don't yet know whether corn yield responded to rescue N, or how much.



2. Locations of fields with hand-applied rescue N experiments in Audrain, Montgomery, and Warren Counties.

We also were able to get permission in 6 fields to hand-apply rescue N on small plots. These 6 fields were in Audrain, Montgomery, and Warren Counties (Figure 2). In each field, we created 15 small plots with hand-applied N rates of 0 (6 plots), 50 (6 plots), and 200 lb N/acre (3 plots). The plots with the 200 lb N rate were included to identify cases where 50 lb N was not enough, and to establish the largest yield response possible at that location.

I heard from many sources this year that they did not believe that the most pitiful corn could respond profitably to extra N. Although this does not agree with my past research, I began to wonder if there is some combination of pitiful and late that would result in rescue N not being profitable. We waited until corn was tasseling and then searched for corn with a range of N stress, from moderately stressed to absolutely terrible looking. Our goal was to find 'the line' at which corn looks so bad that it should no longer be rescued with more N.

We selected areas with decent stands. This was not hard to do, because most fields we looked at had decent stands over most or all of the field.

Rescue N was applied in these fields on July 10 to 14. Fields were 20% to 80% tasseled on the day of N application. Chlorophyll meter measurements ranged from 34 (absolutely terrible) to 47 (not so great for tasseling corn). Average height ranged from 51 inches to 74 inches, all of which are short for tasseling corn.

Yield outcomes are shown in the table below. Rescue N at 50 lb N/acre was profitable averaged over all fields, giving an average yield response of 18 bushels/acre. However, no yield response to 50 lb N was found in the 2 best-looking (darkest leaves) fields. All yield response was concentrated in the worst-looking fields. This is similar to what I have always found before–the worst-looking corn gives the biggest response. We failed to find corn that was so late and so pitiful that rescue N was unprofitable. For the 4 worst-looking fields, yield response to 50 lb/acre of rescue N was 28 bushels. In these 4 fields, 50 lb N/acre was not enough, leaving them 17 bu/acre short of their yield potential.

Fields	Yield with:			Yield response to:	
	0 N	50 N	200 N	50 N	200 N
All 6	151	169	184	18	33

4 worst-looking (yellowest corn)	131	159	176	28	45

Another thing that I heard many times this year is that farmers were not applying rescue N to their corn because they felt that even if they got a yield increase, their yield would still come out below insurance level. In that case, the money they invested in N would just reduce their insurance payment dollar-for-dollar. This fear may have been correct in fields with serious stand issues, but it was not correct in the fields we studied. In all 6 fields where we did tests, the farmer had decided not to apply insurance N for reasons along this line. Given that average yield with no rescue N was 151 bu/acre, and in the 4 worst-looking fields was 131 bu/acre, the yield response to rescue N would have been mainly or completely above the insurance level in these fields.

Summary

We managed to get only one trial with rescue N established with field-scale equipment in 2015 because demands on that equipment were so great. We do not yet have the yield results for this field.

In the six fields where we set up small-plot, hand-applied rescue N experiments, we found that:

- despite searching for fields that were so late and so pitiful that they would not respond to rescue N, we found that the worst-looking fields gave the largest yield responses in the 4 worst-looking fields, average yield response to 50 lb rescue N was 28 bu/acre, and that this rate left the fields 17 bu/acre short of their potential–50 lb N/acre was not enough yield levels were generally good, so that yield responses to rescue N were above insurance yield levels and would contribute to the bottom line.

Other key findings were that:

- it was too wet to solve N limitations with high-clearance N applicators in 2015, and we saw about 5 times as much N go on by plane this year as in any past year.

Budget year 2:

Fertilizer and application costs	$10,000
Aerial photos	2,000
Research specialist salary	15,000
Benefits	5,000
Total year	**$32,000**

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 2015:
- 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.
- The small-plot corn experiment planned for the Delta Center did not work this year due to equipment issues. We will plan to run this experiment an extra year at the end of the project.
- The corn experiment at Columbia has had the same plots receiving the same N management systems since 2007.
- The cotton experiment has had the same plots receiving the same N management systems in 2010, 2011, and 2013, with uniformly managed cotton planted in this area in 2012 and 2014.
- The cumulative long-term performance of sensor-based variable-rate N can be compared to other N management systems for both corn and cotton. Part of the motivation for setting the experiment up this way was the possibility that using the sensors to apply 'just enough' N every year could negatively affect productivity in the long run.

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

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

- 2015 is the 9th 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.

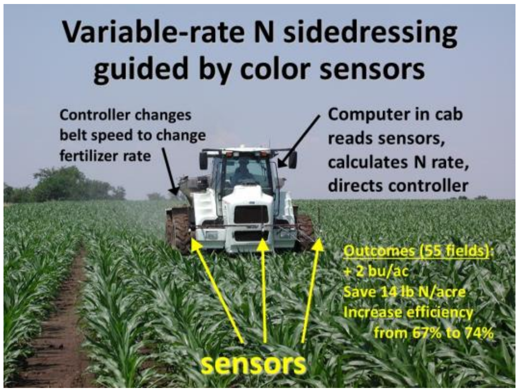
- This experiment received average rainfall in April, but then higher than average rainfall in May, June, and the first half of July.
- The experiment was planted on May 3.
- Many barren ears were observed in the plots. The reason for the barren ears is unknown.
- An August 27 photo showed strong color differences between plots, with the sidedress N plots having a darker color. However, this did not translate into a yield advantage. Yields seemed to be limited to about 70 bushels/acre, but the limiting factor is not clear. Rainfall from July 20 to August 20 was on the low side (2 inches) but should not have limited yield this drastically. Whatever caused the barren ears may have been an important yield-limiting factor.

- Because yields did not exceed 76 bu/acre, N management was not the yield-limiting factor. Only the check (zero N) and low (100N) treatments had yields different than the rest of the N treatments, which were all statistically the same. The other six treatments were all capable of supporting the observed yield levels.
- Despite the lack of yield differences, the aerial photo shows clearly that the sidedress treatments were superior at delivering N to the plants, resulting in darker green leaves (photo above). It's just that the darker green leaves didn't improve yield because yield was limited by some other factor that interfered with ear development.

Nitrogen Recommendation System	N timing Stage	2015 N Rates lb/ac	2015 Yield bu/ac	2015[2] Yield value Minus N cost $/ac	2007-15 Cumulative N rate lb/ac	2007-15 Cumulative Yield bu/ac	2007-15[3] Cumulative Yield value Minus N cost $/ac
Chlorophyll meter	V7[1]	220	74	126	1494	1154	4053
Crop Circle sensor	V7	220, 200, 174, 220, 161, 220 **avg rate = 199**	76	147	1323	1120	4013
Sidedress soil test	V7	144	73	169	1107	1042	3810
High	Preplant	180	75	154	1620	854	2756
Yield goal/ MRTN	Preplant	140	69	158	1260	770	2630
Preplant soil test	Preplant	140	65	144	1233	758	2614
Low	Preplant	100	53	127	900	658	2374
Check	Preplant	0	23	80	0	343	1488
Least significant difference (95% confidence)			10	36			

[1] Growth stage V7 is about knee high corn
[2] Partial profit analysis based on early-Dec. 2015 prices. Corn - $ 3.50/bu. Nitrogen cost - $ 0.60/lb
[3] Prevailing prices in individual years were used

- **Sensor-based variable-rate N has performed very well in this experiment**. The fear that applying just enough N might reduce soil productivity was unfounded.
- **The two systems based on crop color to guide sidedress N rate have out-performed all other systems.**
- **Canopy sensors are far more practical than the hand-held chlorophyll meter for farm-scale N management.**
  - There is too much labor required to get good field-average values with the hand-held meter. Using it to support variable-rate management is even more labor-prohibitive.
  - The whole process can be automated with the canopy sensors mounted on a fertilizer applicator. Rates are changed second by second in response to crop color.



- Although there were few yield differences due to N management in 2015, over the 9 years that we have run this experiment, **the effect of N timing has been huge**. The worst sidedress treatment (rate based on soil nitrate test) has produced 188 bu/acre more grain than the best preplant treatment (the high rate, 180 lb N/acre) while using 513 lb/acre less N. The economic advantage is over $1050/acre over the 9 years. This is because a string of wet years (2008-2010, 2013-2015) has caused loss of preplant N and low yields with preplant N treatments.
- The best sidedress N treatment, with N rate based on readings from a hand-held chlorophyll

meter, is $243/acre ahead of the soil-test-based sidedress treatment, showing that **choosing the right N rate is also important**. The soil-test-based treatment has under-recommended N (2007, 2010, 2013), limiting yields.

- Using N rates based on the hand-held chlorophyll meter is $1297/acre ahead of the best preplant N treatment (180 lb N/acre).
- Lower preplant N rates produced significantly lower yields and partial profits than the 180 lb N/acre preplant rate.
- 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.
    - 2015 is the sixth 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 early N stress experienced with the sidedress-only sensor-based treatments will not occur in this treatment.
- 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.
- **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 true both for 2015 and for the whole 6-year span.
    - In a number of these years (2010, 2013, 2014, 2015) early season weather has been wet, depleting soil N in the early season. The sidedress-only N treatment thus went through substantial early N stress in these years without it causing yield loss.
- Yields were low in 2015, similar to experiment 1 which is immediately adjacent.
- Also similar to experiment 1, sidedress N at rates based on sensor readings resulted in corn with much greener leaves in August (photo 2 pages above), but this did not translate into yields that were statistically higher than the 180 preplant N rate. Something other than N limited yield.

- As with experiment 1, **sensor-based N has produced more corn with less N than preplant N management.**
    - After 6 years, sensor-based N management is more than 90 bushels ahead of 180 lb N preplant, and achieved these higher yields with about 180 lb/ac less N. This translates into an economic advantage of $480/acre (see table below)

- This is due to loss of preplant N in wet years (2010, 2013, 2014, 2015).
- Compared to 140 lb N/acre applied preplant, sensor-based N management produced about 170 extra bushels/acre, and used about 70 lb extra N.

Nitrogen Recommendation System	N timing Stage	2015 N Rates lb/ac	2015 Yield bu/ac	2015[2] Yield value Minus N cost $/ac	2010-15 Cumulative N rate lb/ac	2010-15 Cumulative Yield bu/ac	2010-15[3] Cumulative Yield value Minus N cost $/ac
Crop Circle sensor 0 N preplant	V7[1]	220, 176, 220, 201, 220, 179 **avg rate = 203**	97	216	863	755	2858
Crop Circle sensor 50 N preplant	V7	153, 269, 197, 242, 270, 171 **avg rate = 217**	94	199	954	748	2772
High	Preplant	180	88	201	1080	659	2333
Yield goal/ MRTN	Preplant	140	73	171	840	580	2126
Least significant difference (95% confidence)			13	57			

[1] Growth stage V7 is about knee high corn
[2] Partial profit analysis based on early-Dec. 2015 prices. Corn - $ 3.50/bu. Nitrogen cost - $ 0.60/lb.
[3] Prevailing prices in individual years were used

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

- The experiment was carried out in the same plots as in 2010, 2011, and 2013.
- Treatments and where they are located is also the same as in those years.
- We have seed cotton yields but the cotton is not yet ginned (scheduled for December 21), so we don’t have lint yields yet which is the yield we report.
- Results from previous years are in the table below. We will add 2015 results to this table and do statistics on them once the yields are available.

[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 A	80	1285	1108 A
Sensor[5]	0	0	20, 34, 27 22, 22, 10 Avg. rate = 23	23	1136	1014 A	24	1238	1100 A
Sensor with Pre-plant N[5]	30	0	21, 24, 19 34, 28, 8 Avg. rate = 22	52	1200	1045 A	52	1243	1088 A
Petiole nitrate test	50	0	0	50	1173	1032 A	51	1224	1071 AB
Standard	50	50	0	100	1060	914 B	100	1249	1064 AB
Low	20	50	0	70	1127	989 A	70	1223	1059 AB
Check	0	0	0	0	1202	1063 A	0	1187	1058 AB
High	50	80	0	130	1081	872 B	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] Gross calculated using $0.90/lb cotton lint, $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.

Final Report
2014

(Report received after the last Soil Fertility Update was published)

AMMONIA VOLATILIZATION FROM SURFACE APPLICATIONS OF UREA:

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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; Koch 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

2015

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

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Summary:

Research was conducted for three years from 2013 to 2015 at the University of Missouri's Greenley Research Center in Northeast Missouri 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. The main findings of this experiment are:

- Screening of eight hybrids for flood tolerance in a greenhouse experiment showed that all hybrids were significantly different in their response to saturated soil conditions. This experiment helped in the selection of two hybrids that were used for field experimentation. One hybrid was selected that showed flood tolerance and another that was less tolerant to flooded soil conditions. The growth of adventitious surface roots was a physiological response that corn exhibits under flood stress.

- Soil conditions were changed due to waterlogging. Soil redox potential decreases with each day of soil waterlogging showing the depletion of oxygen and occurrence of reducing soil conditions with time. Significant differences were obtained for soil temperature, stomatal conductance and chlorophyll meter readings with flooding, but no significant changes in soil bulk density were observed. Soil temperature and leaf stomatal conductance were also affected by climatic conditions, but showed no consistent trend during the three years of this research.

- Soil waterlogging resulted in lower plant populations and lower corn yields compared to non-flooded treatments. Application of pre-plant fertilizer treatments resulted in higher yields compared to the non-treated control.

- Response to a rescue N fertilizer application was dependent on rainfall after application. Rescue N application resulted in higher yields in 2014 and 2015 compared to treatments not receiving a rescue N application. No consistent yield responses to rescue N fertilizer applications were observed in this study possibly due to dry conditions experienced after rescue N application in 2013, and to residual N in the soil from the previous year.

- These results suggest that changes in climatic conditions will have an effect on corn response to both pre-plant and rescue N applications prior to and after flooding.

Materials and Methods:

A greenhouse experiment was conducted prior to the field season in 2013 to determine the relative waterlogging tolerance of eight corn hybrids recommended by agronomists and breeders. The hybrids were planted in pots containing bulk soil (Putnam silt loam) collected from a field site at the Greenley Memorial Research Center in Novelty, Missouri and then allowed to grow at field capacity until the V2 growth stage. At that point, one set of hybrids was waterlogged continuously in trays for up to 21 days, another set was waterlogged for 14 days and then the soil allowed to return to field capacity and a third set was maintained at field capacity for the duration of the experiment. All treatments had four replications. Soil redox potential and pH was recorded during waterlogging. Plant growth was assessed by measurements of plant health and by harvest of the aboveground dry matter at the end of the experiment. Plant N uptake was determined from the harvested plant tissue and chlorophyll readings of leaf tissue during the experiment were determined using a SPAD meter. Leaf stomatal conductance was determined using a leaf porometer (Decagon Devices, Pullman, WA) to assess plant stress during waterlogging.

A field experiment was conducted for three years from 2013 to 2015 at the University of Missouri Greenley Research Center in Northeast Missouri. The fields chosen for the experiment each year were adjacent to each other. 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 for determining initial soil properties (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 development. The subplots consisted of N fertilizer treatments including a control or N at 150 lb N/acre as pre-plant-applied urea (NCU), polymer-coated urea (PCU; ESN®, Agrium, Inc), or 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. The 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.

Soil conditions during flooding were measured by determination of changes in soil redox potential (E_h), soil surface pH, soil temperature and bulk density at the soil surface. Soil surface pH, redox potential (E_h) and soil temperature at the soil surface were measured using hand-held meters (Cole Palmer ORP/pH 3 submersible, Vernon Hills, IL). Soil E_h was converted to the standard hydrogen reference electrode values (Vepraskas, 2002). Chlorophyll content of leaf tissue during the experiment was determined using a SPAD meter. Leaf stomatal conductance was measured using a leaf porometer (Decagon Devices, Pullman, WA) to assess plant stress during waterlogging. Soil samples were collected from all N treatments before and after flooding as well as after harvest at the end of the season. These samples were taken from 0-4, 4-8 and 8-12 inch depths and were analyzed for soil inorganic N (ammonium and nitrate N). 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. 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. Corn was harvested on 18 September, 29 September and 16 September in 2013, 2014 and 2015 respectively, for determining grain yield.

Results:

The initial greenhouse screening trial for flood tolerance showed marked differences among the eight corn hybrids selected for this study in response to saturated soil conditions (Fig. 1). Some of the corn hybrids exhibited a proliferation of surface roots as a response and possible tolerance mechanism to the extended soil saturation (Fig. 1). All of the hybrids, among the five corn leaves on the plant measured, showed a decrease in chlorophyll meter readings with an increased period of flooding (Fig. 2A&B). The chlorophyll meter readings corresponded to the greenness of the leaf which is often affected by the N status of the plant. The decrease in leaf chlorophyll meter readings occurred rapidly after approximately five days of flooding for the first and second leaves.

Plant growth, as measured by plant height, also showed differences among the hybrids when flooding was imposed (Fig. 3A). Plants were able to grow more rapidly after flooding was ended after 14 days of flooding; however, hybrids #1 and #5 were among the slowest to recover after flooding (Fig. 3B). To compare the performance of the corn hybrids under flooded versus optimal soil moisture conditions, the ratio of plant height and chlorophyll meter readings were determined for flooded versus optimal moisture conditions (Fig. 4A &B). Ratios under 1 indicate that plant height or the chlorophyll meter readings under flooded conditions were lower than under optimal soil moisture conditions. When saturated soil conditions were initiated, both plant height and chlorophyll meter readings generally decreased under flooding compared to optimal soil moisture. With plant height, hybrid #8 had the lowest plant height with flooding compared to optimal soil moisture and hybrid #3 had the highest relative plant height under flooding. When stressed, some plants drop their lower leaves which may have affected the relative chlorophyll readings among the different leaves that were measured under flooded versus non-flooded conditions. (Fig. 4B).

In the field experiment, soil redox potential (E_h) decreased with each day of soil waterlogging showing the development of reduced and anaerobic conditions with time (Fig. 5). Soil surface pH measured during waterlogging increased significantly in 2014 from 5.6 to 6.0 after 3 days of waterlogging and then decreased to its initial pre-flood value at the end of the flooding treatment. No significant differences were observed for soil pH during 2013 and 2015 (Table 3). Similar results for soil pH and redox potential were observed by Unger et al. (2009)

under waterlogged soil conditions. The soil temperature also varied significantly with each day of flooding. No significant changes in soil bulk density to a depth of 30 cm were observed due to waterlogging in all three years (Table 2). 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. Soil temperature was higher in waterlogged compared to non-waterlogged treatments in 2013 and 2015 (Fig. 6). The non-flooded treatments had 1.8^0F higher temperatures than the flooded treatments in 2014. In 2014 and 2015, plant populations were significantly decreased by 19 and 29% due to soil waterlogging (data not shown). In 2013 and 2015, all three pre-plant fertilizer applications resulted in significantly higher leaf chlorophyll content compared to the non-treated control (Fig. 7). Leaf chlorophyll content was decreased due to waterlogging in 2015. Stomatal conductance varied depending upon the weather conditions each day during waterlogging (Fig. 8).

No significant differences were found in pre-flood nitrate and ammonium-N among both hybrids in 2013 and 2014 (Figures 9 & 10). Both pre-flood and post-flood nitrate and ammonium N were significantly higher at the 0-4 inch depth compared to the 4-8 and 8-12 inch depth. At a depth of 0-4 inches, NCU+NI had higher ammonium N than the other fertilizer treatments in 2013 (Figure 9). All pre-plant fertilizer treatments had higher pre-flood and post-flood soil NO_3^--N compared to the control during 2013, but pre-flood soil NH_4^+-N was higher in the NCU+NI treatment compared to other fertilizer treatments. The post-flood ammonium N was significantly affected by different N treatments and soil depth, but no effect of flooding duration was observed in 2014 (Figure 9). The PCU treatment had higher soil ammonium N than that of the NCU+NI and control treatments. The control treatment had lower nitrate N contents than the remaining fertilizer treatments in 2013 (Figure 10). In 2014, the pre-flood soil nitrate N was not affected by different N treatments (Figure 10) whereas 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 in 2014.

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 Figures 11 and 12. The urea release was significantly affected by the flooding duration. The flooded treatments had 5% higher release of urea compared to non-flooded treatments (Figure 11). At times, the urea release from PCU was greater in flooded plots compared to non-flooded treatments, with >60% release two weeks after flooding (Figure 12).

Corn silage was collected from 10 feet of one corn row and used for determining total aboveground dry biomass weight and total N uptake. In treatments having 7 day flooding without rescue N, Hybrid #1 had an increase of 2.11 tons/acre in silage yields with the NCU+NI treatment compared to the control treatment in 2013 (Table 4). In contrast, an application of NCU+NI resulted in reduced silage yield of 2.51 tons/acre as compared to that of PCU due to flooding in treatments with a rescue N application. No significant differences in silage yield between hybrids were observed except for treatments having NCU and rescue N application with 7 days of flood in 2013 (Table 4). Corn N uptake among the different fertilizer treatments was not significantly different overall. However, there was a significant increase in N uptake when PCU was applied compared to application of NCU for Hybrid #1 with the 7 day flood treatment (Table 5).

In 2013, both hybrids under 7 day flooding treatment resulted in significantly lower grain yields than the non-flooded control. Hybrid #1, control treatment and 7 day flooding, had losses of 26 and 29 bu/acre compared to no-flood without and with rescue nitrogen application, respectively. Hybrid #2 showed a reduction in yield ranging from 18 to 33 bu/acre due to a 7 day flood among the different fertilizer treatments (Figure 13). 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; therefore, the results that are shown are averaged over the two hybrids for 2014 (Figure 14). Corn yield was significantly affected by N fertilizer treatments in both years.

In 2013, rescue N treatments did not show a grain yield response probably due to low rainfall after application, but in 2014 adequate rainfall did occur after application. Hybrid #1 had no significant losses in grain yield due to flooding in treatments with PCU, NCU, or NCU+NI fertilizer applications in 2013 (Figure 13). Hybrid #1 had a significant increase in yield among NCU, PCU and NCU+NI compared to the control with 7 day flooding in the presence or absence of rescue N application treatments. In contrast, a significant increase in grain yield was obtained with Hybrid #2 with NCU, PCU and NCU+NI in the non-flooded treatment and with the 7 day flood duration which was also applied with rescue N application.

The average grain yields for hybrid #1 and #2 were 208 and 215 bu/acre in 2014, respectively. In 2014, 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 decreased with a rescue N application to treatments receiving NCU+NI, whereas rescue N increased yield of the other pre-plant N treatments. The high yields observed in the control treatment may be due to residual soil N from the previous year. In 2015, flooded treatments had lower average grain yields compared to the non-flooded treatments by 62 bu/acre (Table 6). Rescue N application resulted in significantly higher yields compared to treatments not receiving rescue N in 2015.

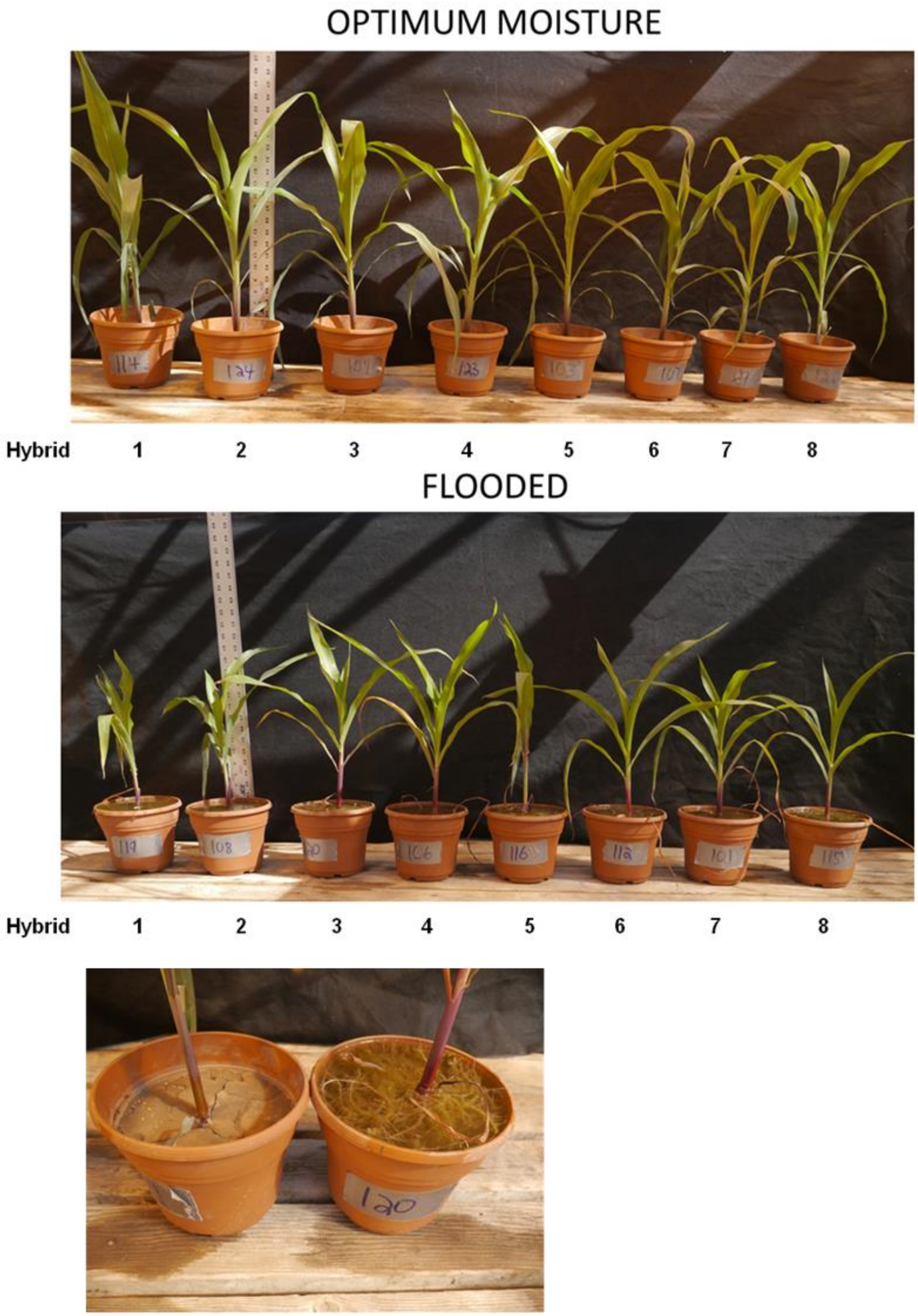
Outreach and Training:

A Ph.D. student in soil science is being trained under this project for her dissertation research. The results from the first year field trial were presented as an oral presentation to growers and agricultural professionals at the 2014 Greenley Center Field Day in Northeast Missouri. Results from all three years were presented at the American Society of Agronomy (ASA) National Meetings held in Long Beach, California in 2014 and Minneapolis, MN in 2015. The Ph.D. student won a prize for her poster presentation of this research at the ASA Meetings in the S4 Soil Fertility Division in 2014 and 2015. The research was also presented at the 2014 North Central Extension-Industry Soil Fertility Conference in Des Moines, Iowa and Agrium field day at Greenley Center in 2015. The student was honored at the North Central Extension Conference as the outstanding soil fertility graduate student from the state of Missouri in 2014.

References:

Unger, I.M., P.P. Motavalli, and R.M. Muzika. 2009. Changes in soil chemical properties with flooding: A field laboratory approach. Agric. Ecosys. and Environ. 131:105-110.

Vepraskas, M. J., and J. L. Cox. 2002. Redox potential measurements. NC State University.



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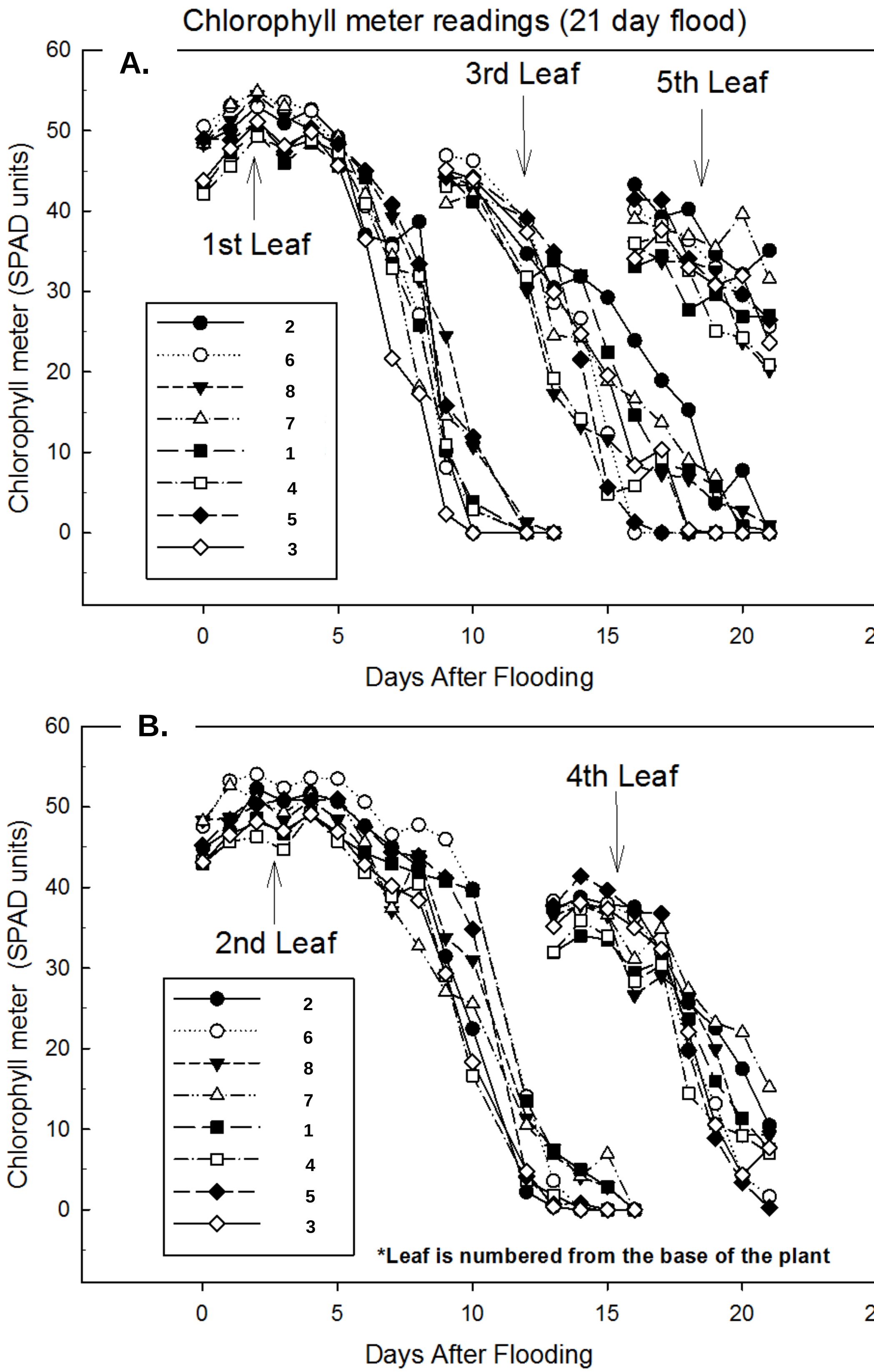


Figure 2 A & B. Differences in chlorophyll meter readings by corn hybrid with days of flooding and by corn leaf.

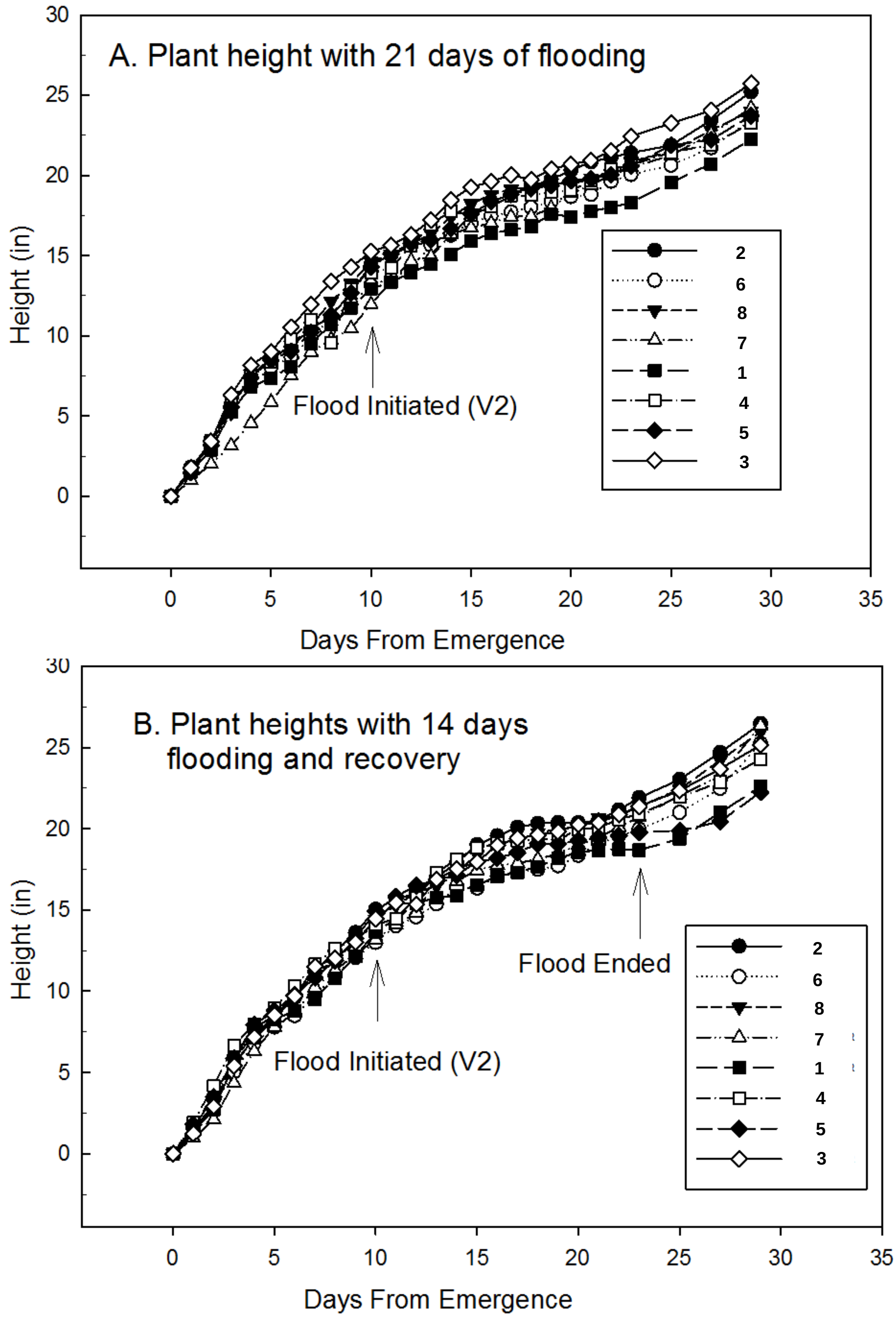
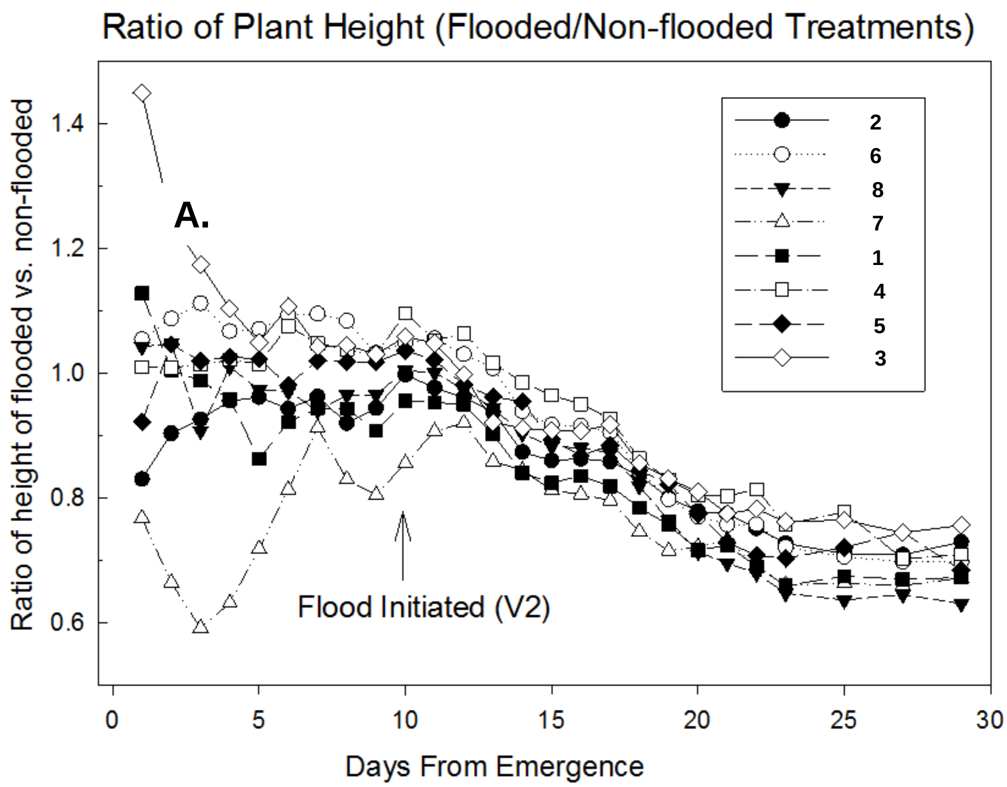


Figure 3 A & B. Differences in plant height among corn hybrids with (A) 21 days flooding and with (B) 14 days of flooding and 7 days of recovery.



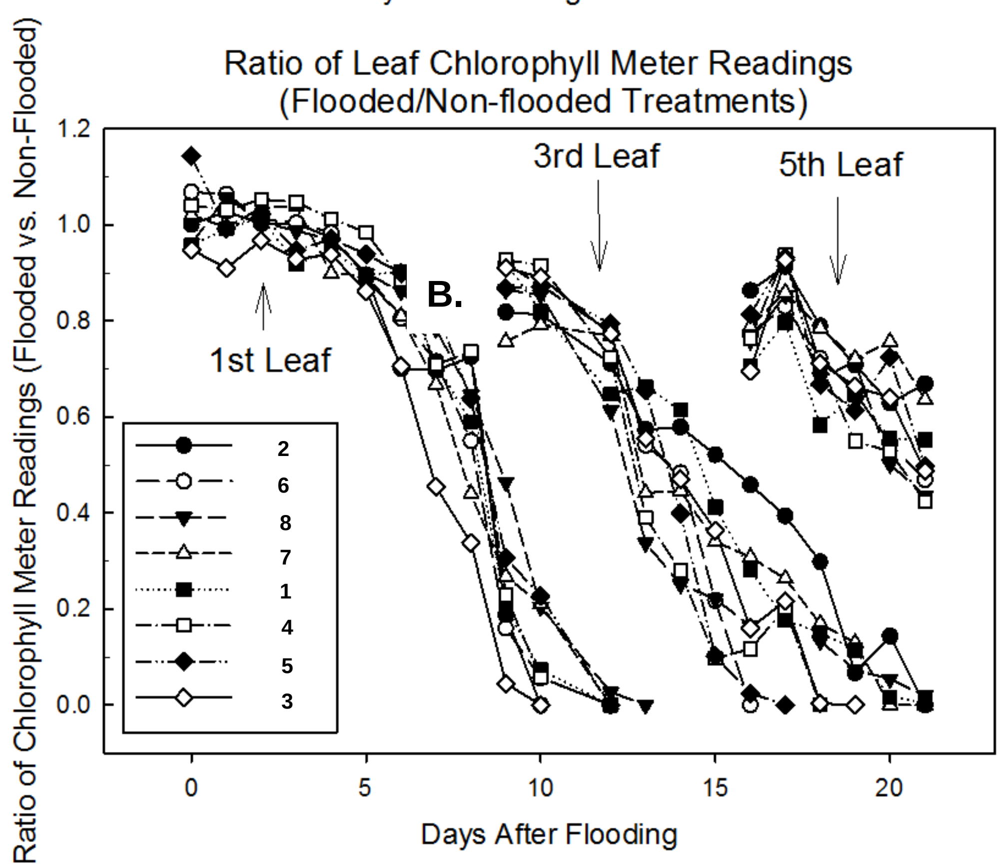


Figure 4 A & B. Ratio of flooded to non-flooded treatment by corn hybrid for (A) plant height and (B) chlorophyll meter readings by corn leaf.

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†
-- in --		meq/100 g	%	------------- lbs/acre			-------------	meq/100 g
2013								
0-4	6.0	2.0	2.8	70	3751	339	372	13
4-8	6.1	1.8	1.9	16	3831	263	123	13
8-12	5.4	4.0	1.8	14	3777	454	131	16
2014								
0-4	6.0	1.7	2.3	67	4322	445	228	15
4-8	5.7	2.7	1.6	14	3835	504	140	15
8-12	4.7	7.3	1.8	10	5226	1136	237	25
2015								
0-4	5.3	2.7	2.7	83	2632	312	325	11
4-8	5.9	1.5	1.9	13	2776	315	99	10
8-12	4.9	4.5	1.9	6	2843	503	80	14

†Abbreviations: CEC, Cation Exchange Capacity

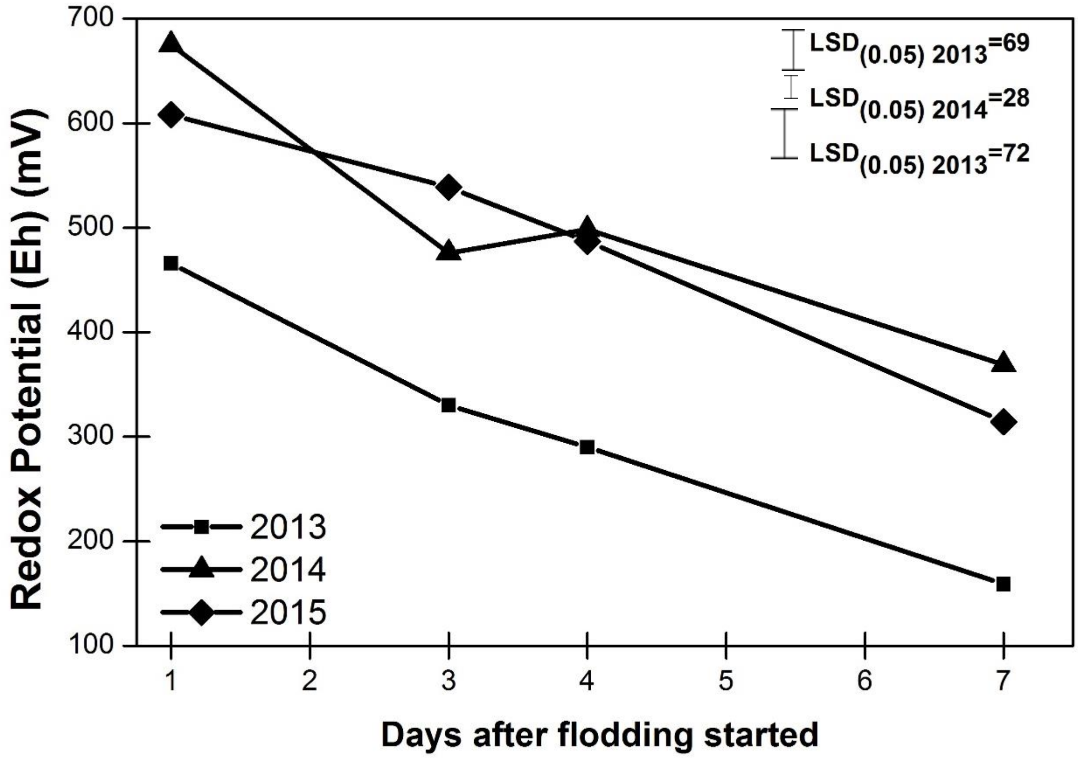


Figure 5. Changes in soil redox potential as affected by flooding duration from 2013 to 2015. $LSD_{(0.05)}$ values are presented for each year.

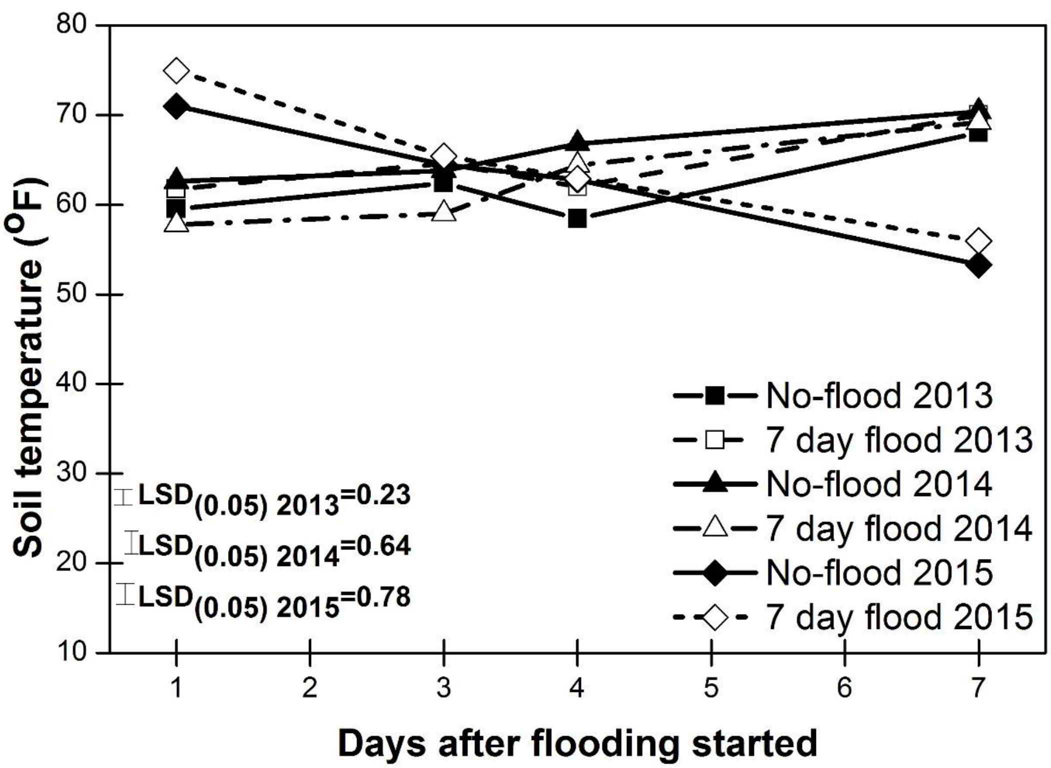


Figure 6. Soil temperature as affected by flooding and flood duration in 2013, 2014 and 2015. $LSD_{(0.05)}$ values are presented for each year.

Table 2. Soil bulk density at different depths among flood durations.

Depth (inch)	Bulk density		$LSD_{(0.05)}$ [‡]
	Pre-flood	Post-flood	
	--------------g/cm^3 --------------		
2013			
0-4	1.41	1.44	NS
4-8	1.38	1.42	NS
8-12	1.34	1.25	NS
$LSD_{(0.05)}$	NS	NS	
2014			
0-4	1.28	1.23	NS
4-8	1.40	1.41	NS
8-12	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.

Table 3. Soil surface pH during flooding

Days after flooding started	Soil pH		
	2013	2014	2015
1	6.2	5.6	5.2
3	6.1	6.1	5.3
4	6.2	6.0	5.4
6	6.1	5.9	5.8
$LSD_{(0.05)}$ [‡]	NS	0.4	NS

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

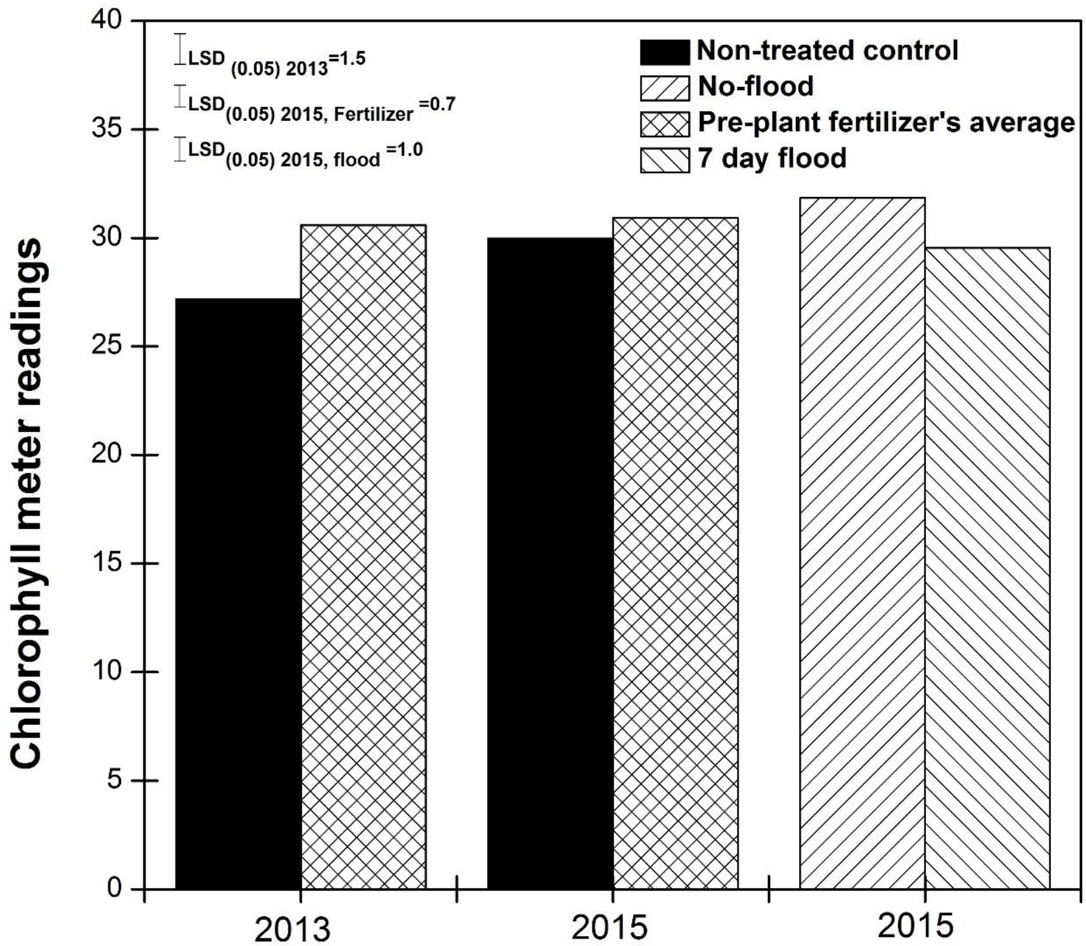


Figure 7. Chlorophyll meter readings as affected by pre-plant fertilizer treatments and soil waterlogging.

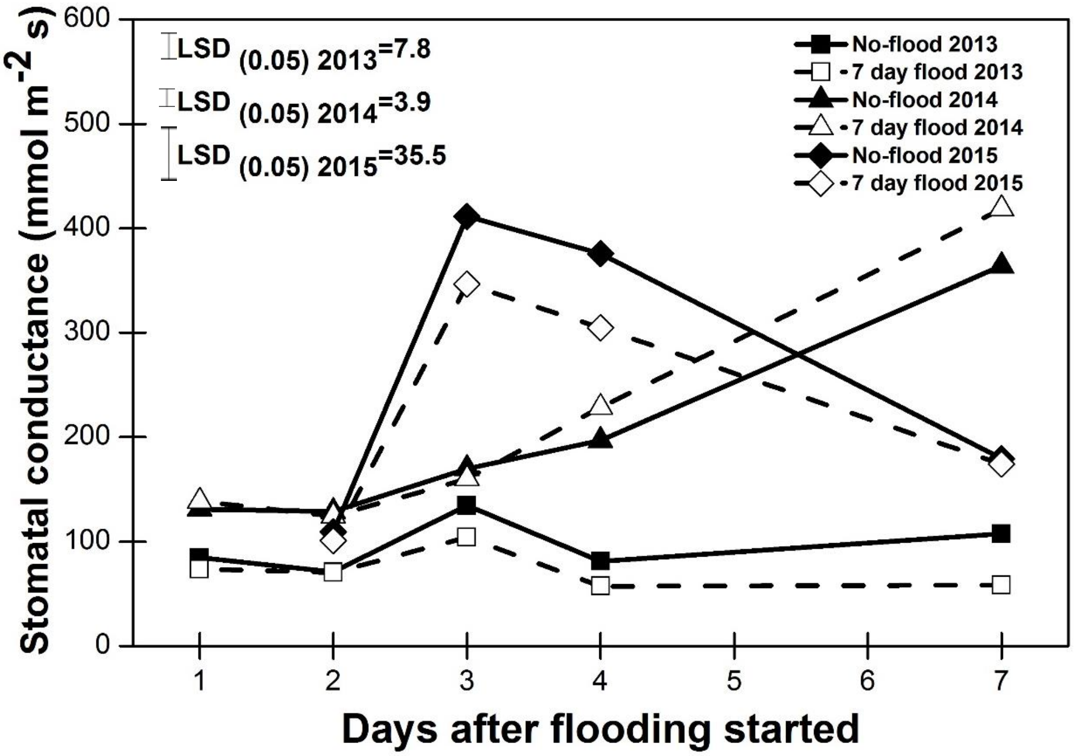


Figure 8. Changes in leaf stomatal conductance after initiation of soil waterlogging period. $LSD_{(0.05)}$ values are presented for each year.

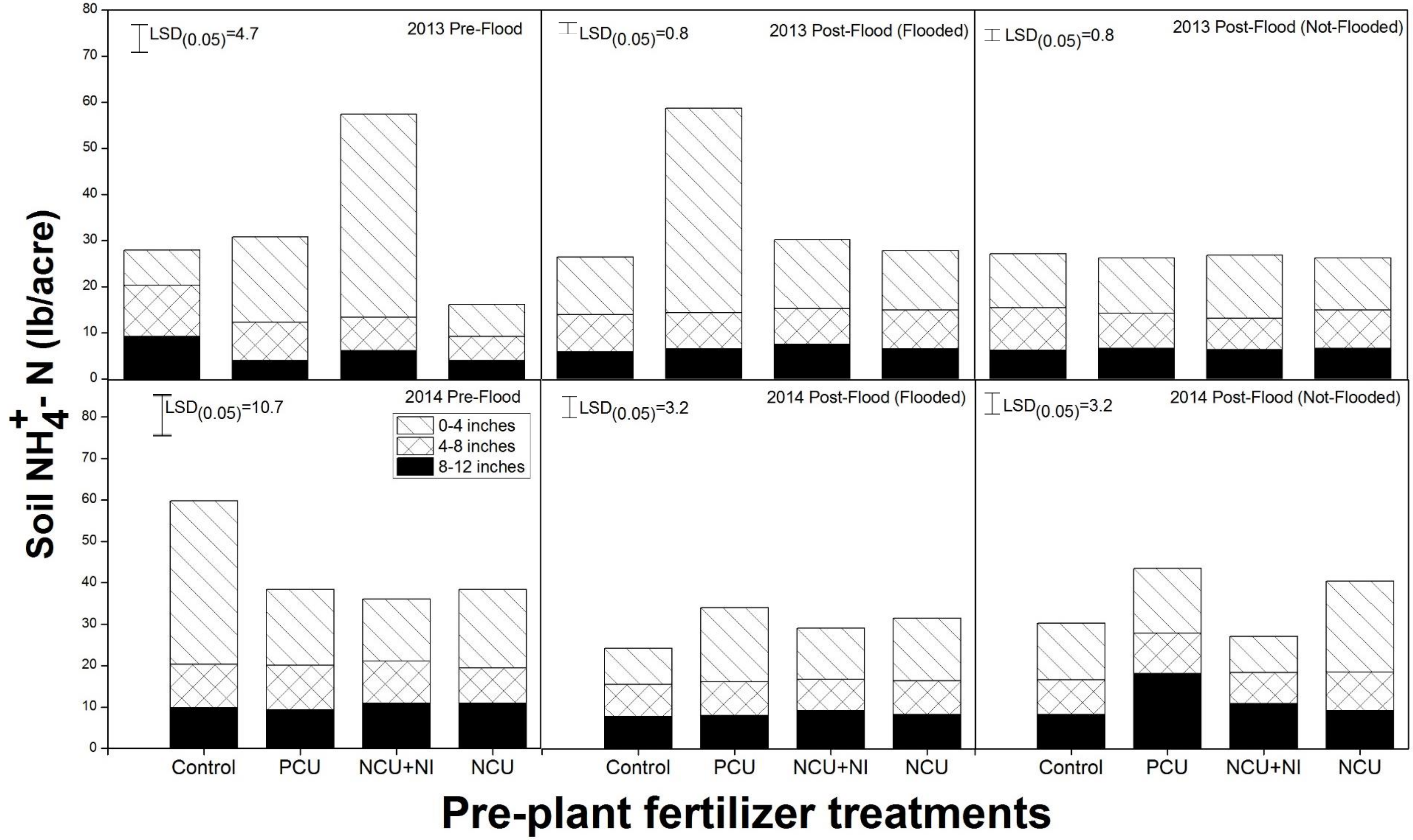


Figure 9. The effects of N fertilizer treatments on pre-flood and post-flood soil $NH4^{+}$-N concentrations by depth in 2013 and 2014.

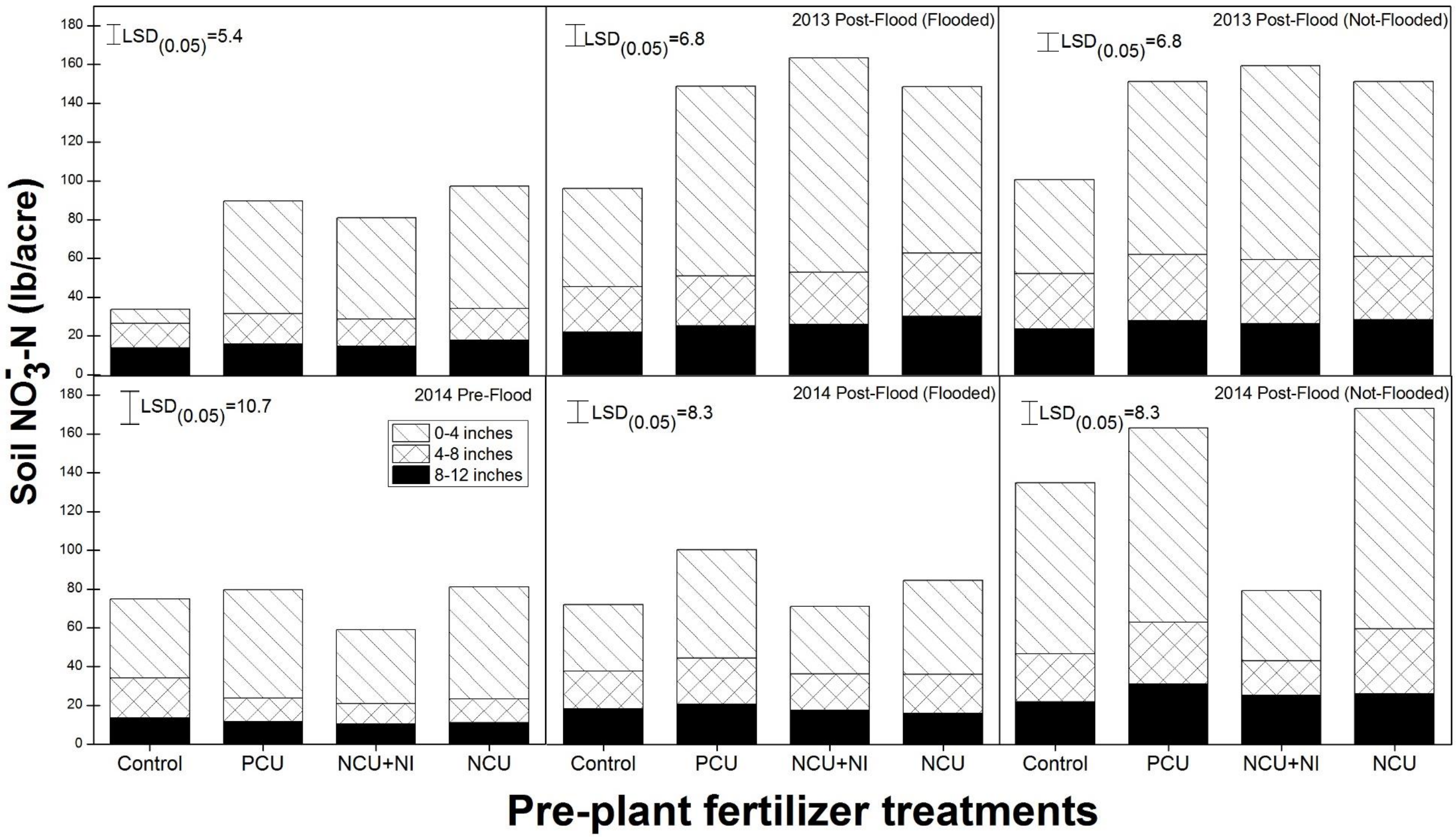


Figure 10. The effects of N fertilizer treatments on pre-flood and post-flood soil NO_3^--N concentrations by depth in 2013 and 2014.

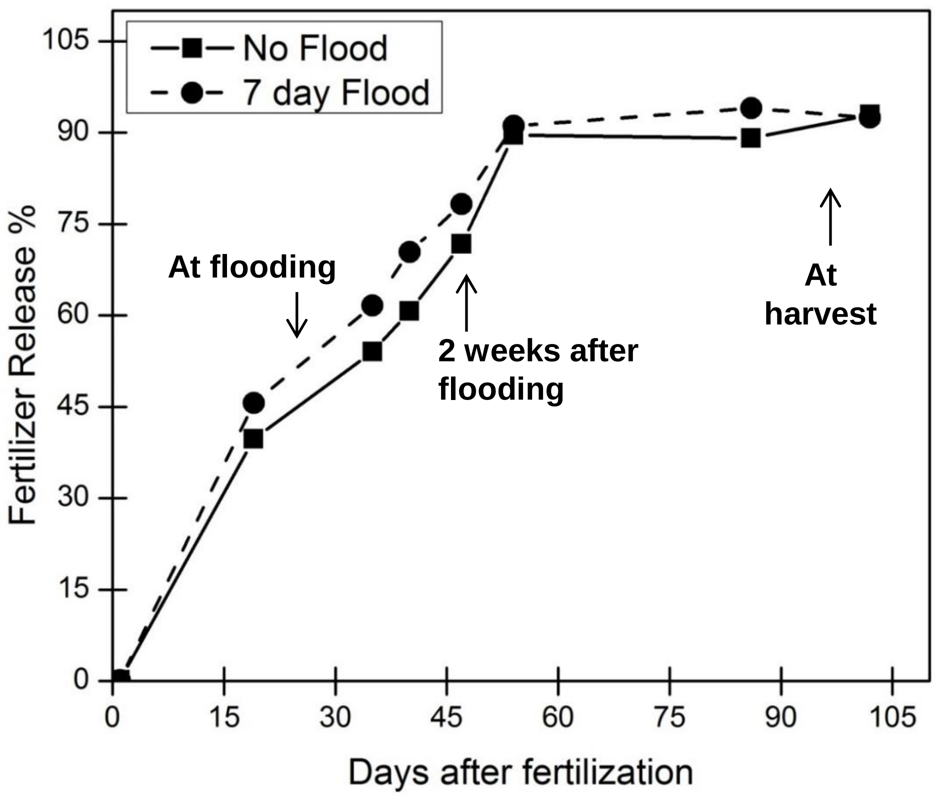


Figure 11. PCU fertilizer release at different times due to flooding in 2013.

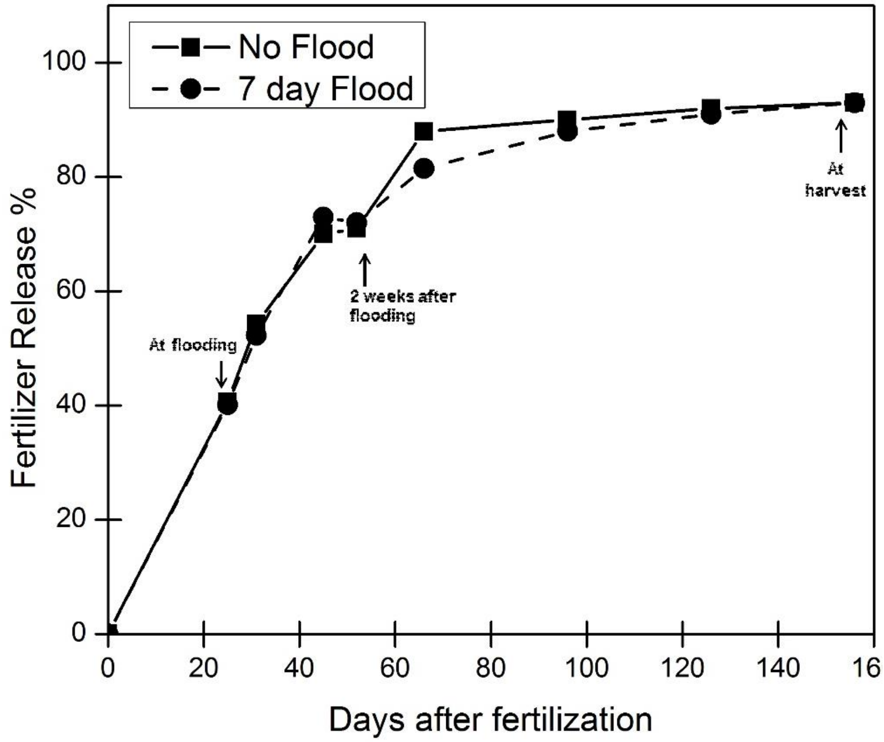


Figure 12. Release of polymer-coated urea over the growing season in 2014.

Table 4. Average silage yields with corresponding N treatments and flooding durations for corn hybrids in 2013.

N fertilizer treatment	Flooding duration (in days)					
	0			7		
	Corn hybrids			Corn hybrids		
	Hybrid #1	Hybrid #2	LSD $_{(0.05)}$	Hybrid #1	Hybrid #2	LSD $_{(0.05)}$
	---------- tons/acre ----------					
Without Rescue N						
Control	6.19	7.19	NS	4.72	6.21	NS
NCU[†]	7.70	7.38	NS	5.90	6.99	NS
NCU+NI	7.37	8.10	NS	6.83	6.52	NS
PCU	6.55	7.56	NS	6.35	6.16	NS
LSD $_{(0.05)}$ [‡]	NS	NS		1.95	NS	
Control	6.58	6.42	NS	5.68	5.92	NS
NCU	6.66	7.07	NS	4.62	7.57	1.88
NCU+NI	6.48	7.64	NS	4.75	5.90	NS
PCU	7.57	7.89	NS	7.26	7.41	NS
LSD $_{(0.05)}$	NS	NS		1.95	NS	

[†]Abbreviations: NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea. [‡]LSD, Fisher's least significant difference ($P \leq 0.05$); NS, not significant.

Table 5. Average corn hybrid N uptake resulting from different N fertilizer treatments and flooding durations in 2013.

N fertilizer treatment	Corn hybrids					
	Hybrid #1			Hybrid #2		
	Flooding duration (in days)			Flooding duration (in days)		
	0	7	LSD $_{(0.05)}$	0	7	LSD $_{(0.05)}$
Without Rescue N	---------- lbs N/acre ----------					
Control	126	112	NS	166	154	NS
NCU[†]	178	167	NS	180	157	NS
NCU+NI	176	169	NS	141	169	NS
PCU	161	148	NS	170	141	NS
LSD $_{(0.05)}$ [‡]	NS	NS		NS	NS	
With Rescue N						
Control	141	143	NS	111	140	NS
NCU	168	116	NS	160	172	NS
NCU+NI	153	123	NS	164	129	NS
PCU	172	195	NS	177	191	NS
LSD $_{(0.05)}$	NS	72		NS	NS	

[†]Abbreviations: NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea. [‡]LSD, Fisher's least significant difference ($P \leq 0.05$); NS, not significant.

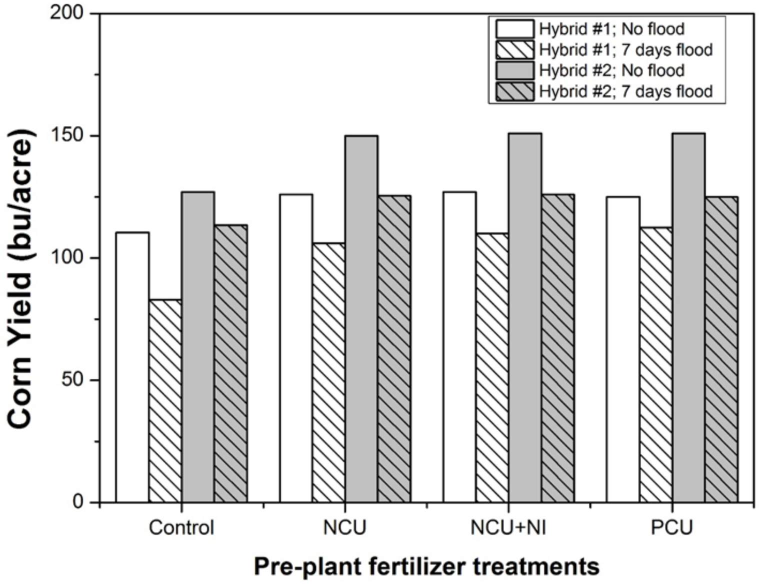


Figure 13. Average corn grain yields with corresponding N treatments and flooding durations for two hybrids in 2013. †Abbreviations: NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea.

LSD$_{(0.05)}$ =17

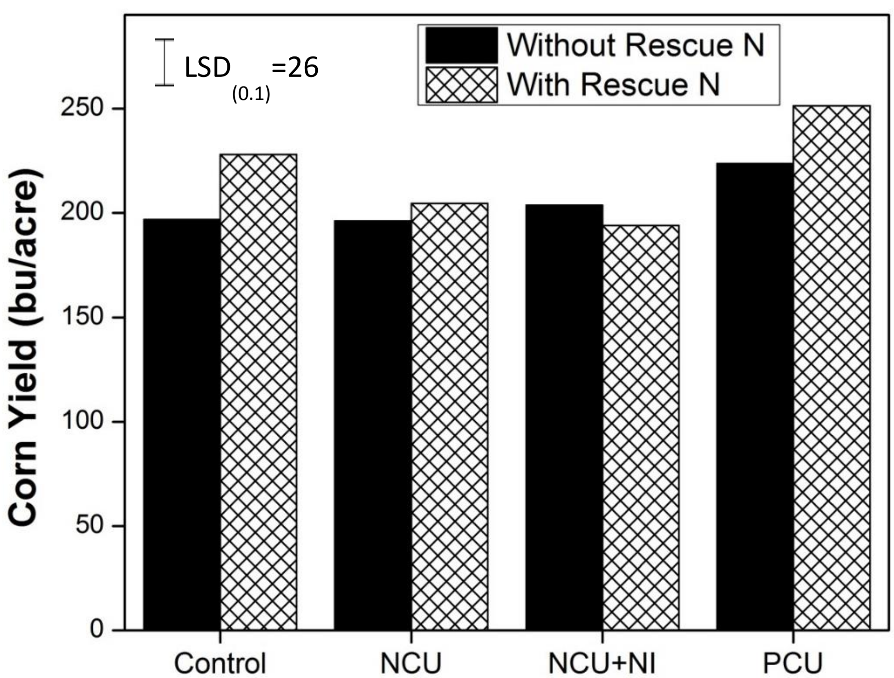


Figure 14. Corn grain yields among different N fertilizer treatments, with and without rescue N application in 2014. Yields were averaged over the two corn hybrids and flooding duration. †Abbreviations: NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea.

Table 6. Corn grain yields among different N fertilizer treatments under flooded and no-flood conditions in 2015.

N fertilizer treatment	Flood duration (in days) 0	7	LSD $_{(0.05)}$ ‡
	---bu/acre---		
Without Rescue N			
Control	77	63	NS
PCU	182	102	59
NCU†	118	69	NS
NCU+NI	147	120	NS
With Rescue N			
Control	129	68	59
PCU	223	130	59
NCU†	224	100	59
NCU+NI	187	139	NS
LSD $_{(0.05)}$ ‡	8	8	

†Abbreviations: NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated u

Phosphorus Management

Progress Report
2015

Managing Phosphorus for Maximum Cover Crop and Soil Health Benefit

Investigators: Timothy Reinbott, Superintendent of Bradford Research Center and Dr. Randall Miles, Associate Professor, Department of Soils, Environmental and Atmospheric Sciences.

Objectives/Relevance

The overall objective of this research is to compare cover crop production and root growth at two pH and eight phosphorus fertility applications for three years. Specific objectives are:

1. Determine if optimizing plant-available P through use of P fertilization and liming will enhance cover crop biomass and root growth.
2. Determine if enhanced cover crop biomass enhances the beneficial soil attributes of soil health and if a measurable improvement to soil health can be accelerated through improved fertility.
3. Examine effects of impacted soil health parameters on crop yields, soil water availability, runoff, soil organic carbon (SOC) sequestration and plant nutrient utilization.

In 2012, the USDA-NRCS began an initiative on soil health management systems that features cover crops as an integral component of good agricultural management practices. In addition, the NRCS EQIP cost share program provides funds for planting cover crops. As a result of these efforts, cover crop use is increasing in Missouri. The benefits are numerous; cover crops reduce erosion (Laloy et al., 2010) and promote microbial biomass and activities involved in decomposition, leading to increased carbon retention in soils (Drinkwater and Snapp, 2007). Cover crops can increase soil aggregate stability, total porosity, and plant available water compared with plots grown without cover crops (Villamil et al., 2006). They can increase hydraulic conductivity and water holding capacity and reduce bulk density (Keisling et al., 1994), and can reduce erosion and water runoff from agricultural fields by intercepting raindrops and increasing infiltration (Snapp et al., 2005). Cover crops can also sequester nitrogen that would instead be lost to leaching or denitrification (Reinbott et al, 2004). To gain maximum benefit from cover crops and their associated improvements to soil health, more needs to be known about fertility and liming enhancement for cover crop growth and development. Growing productive cover crops could require additional fertility inputs.

Timetable for proposed research

Date	Activity
March 2015	Take baseline soil tests, apply lime to achieve desired pH levels
May 2015	Plant soybean into plot area
Oct 2015	Harvest soybean, Apply P for fall treatments, Plant winter cover crops (CC)
March 2016	Apply P for spring treatments
April 2016	Collect roots and above ground biomass of CC, plant corn, collect soil samples
Sept 2016	Harvest corn, Apply P for fall treatments, Plant winter CC
March 2016	Apply P for spring treatments
April 2016	Collect roots and above ground biomass of CC, plant corn, collect soil samples
Sept 2016	Harvest corn, Apply P for fall treatments, Plant winter CC
March 2017	Apply P for spring treatments
April 2017	Collect roots and above ground biomass of CC, plant corn, collect soil samples
Sept 2017	Harvest corn, Apply P for fall treatments, plant winter CC

Update 2015:

Soil samples were taken from several plots at the MU Bradford Research Center to find an area that met the requirement of a pHs below 6.0 and medium in Bray 1 P (Table 1). The area was then divided into eight different whole plots, 80 ft wide x 50 ft long with four replications. The amount of lime needed to bring the pHs from 5.8 to 6.5 or above was calculated, and applied on May 19, 2015. Pell lime (ENM 640) was used since it is easy to broadcast by hand. Afterward the entire field was field cultivated in order to mix the lime. Soybeans (cv Pioneer 93Y92) were planted at a population of 180,000 seeds/acre with a Kinzee 15 inch row planter on June 5. Stand establishment was poor due to excessive rainfall but the decision was made not to replant because it would push soybean harvest past the optimum cover crop planting date.

Soybeans were harvested on October 13 and soil cores (6 inches) were taken from each whole plots. Afterward the eight 80 ft wide x 50 ft long whole plots (lime treatment) were split into sixteen 40 x 50 ft plots with eight planted to cover crops and eight not planted to cover crops. On October 15th 60 lb/acre of cereal rye and 15 lb/acre hairy vetch were mixed together and no-till planted with a Kinzee 15 inch row planter. The reason that cover crops were planted with a 15 inch row planter rather than a 7.5 inch spaced drill was for precision of planting and seed placement. Often drill planting rate is not uniform across the planter box and also seed depth varies greatly with a drill. Seeding rate was easily calibrated using soybean plates and cover crop seeds planted at 0.25" deep. Since it was extremely dry the entire plot was irrigated with 0.6 inch on October 16th and then an additional 0.5 inch on October 19th. Cover crops emerged approximately a week after planting. Mild temperatures in November and December along with abundant rainfall helped cover crops grow and become well established.

In late October each of the 40 x 50 ft subplots were divided into eight 20 x 25 ft split-split plots and monoammonium phosphate (MAP) was applied at rates of 0, 25, 50, and 75 lb P_2O_5/acre to half of the split-split plots and the other half no fertilizer was applied for a total of 128 plots. The recommended rate of phosphorus fertilizer was 60 lbs/acre. There were some differences within replications in soil nutrient values (Table 2) and it is obvious that the lime has not completely brought soil pH up to desired levels. However, we expect that pH will continue to rise throughout the fall, winter, and spring.

Base line soil quality data was not taken immediately in October due to the extreme dryness but were taken in November after rainfall occurred in order to take a more uniform sample. Soil samples were analyzed for active carbon, aggregate stability, and water infiltration on a whole plot basis (Table 3). There is some variability in these parameters across replications which will be used as base line information each autumn when additional samples are taken. Active carbon is an indicator of the amount of carbon that is available for soil microbial activity with the higher level better. These values, in the 300-400 ppm range, are very typical for a soil that has been tilled extensively without a cover crop. In other studies we have demonstrated that the active carbon level can approach 1000 ppm in pastures and other non-disturbed soils. We are extremely interested to see how this value changes with the addition of cover crops and the interaction with phosphorus on cover crop roots. The value that we provide for aggregate stability is based upon a percent basis and gives an indication of those aggregates that are between 1 and 2 mm which are considered large aggregates. Again the values that we are seeing in the 30 and 40% range are typical of soils that have been heavily tilled without cover crops. Data from studies in other states have shown that percent aggregate stability can change quite rapidly based upon cover crops and tillage. The interaction of increased microbial activity which should correlate to higher active carbon, available calcium from liming, and lack of tillage should result in higher aggregate stabilities. For the most part, active carbon and aggregate stability followed very similar trends across replications. The plot slopes downward with replications 1 and 2 being more on the summit and side slope and reps 3 and 4 on the toe slope. Typically higher active carbon values were found in replications having higher aggregate stability which is probably an indicator of more organic matter (Table 2). With the exception of replication 4, soil water infiltration was much greater in the unlimed treatments than limed treatments (higher numbers indicating a longer time before water ran off and more soaked into the soil profile). This is interesting since the lime treatments were randomized and there was little concern that the time of day would have played a role in the data. From the data taken water infiltration per minute can also be calculated and will be used as a comparison in subsequent years.

Plans for 2016:

A spring treatment of MAP (0, 25, 50, and 75 lbs/acre P_2O_5) will be applied in March before cover crops start rapid growth to those plots that were not treated in the fall. In April, cover crop dry matter yield will be estimated by harvesting 2 ft^2 areas will be taken from each for above ground and below ground measurements (6 inches deep) from each cover crop plot. Plant roots and shoots will be dried and weighed. In all treatments cover crops will be terminated and corn planted on the same day by applying glyphosate herbicide. After corn emergence but before the three leaf stage 160 lb N as Super U will be applied and herbicides. At corn silking, at least five ear leaves from each split-split plot will be taken and analyzed for nitrogen and other macronutrients. Corn will be harvested at maturity and cover crops planted and fall P applied as before. Soil measurements including soil nutrient content and soil quality will be made from each of the 128 plots.

These plots will be used as part of cover crop training at workshops and field days in the spring and during the summer. Data from these plots will be used at winter meetings and other extension venues.

Table 1. Initial soil test and recommendations for plot chosen for cover crop experiment at the MU Bradford Research Center.

	pHs	NA meq/100 g	OM %	Bray 1 lb/a	Ca lb/a	Mg lb/a	K lb/a	CEC meq/100g
F6	5.8	2.5	2.4	35	4581	490	262	16.3

Recommendations:
60 bushel soybeans: 0-60-0 ENM: 565

Table 2. Soil tests (October 2015) from plots treated with lime and controls. Lime was applied in May 2015 at a rate of 585 ENM as pelletized lime.

Rep	Trt	pHw	pHs	NA meq/100 g	OM %	Bray 1 P lb/acre	Bray 2 P lbs/acre	Ca lbs/acre	Mg lbs/acre	K lbs/acre	CEC meq/100g
1	no lime	6.5	5.9	2	2.7	28	171	2895	303	158	10.7
2	no lime	6.3	5.8	2.5	2.3	37	230	2988	363	191	11.7
3	no lime	6.6	6.0	2	2.9	46	231	3284	438	219	12.3
4	no lime	6.6	6.1	2	2.7	30	190	3606	499	190	13.3
1	lime	6.8	6.3	1.5	2.9	29	174	3527	406	175	12.2
2	lime	7.1	6.4	1	2.4	40	222	3188	310	180	10.5
3	lime	6.9	6.4	1	2.6	42	232	3445	394	196	11.5
4	lime	6.9	6.4	1.5	2.7	30	182	3484	423	198	12.2

Table 3. Soil quality factors tested on soils that were treated with lime (May 2015) and controls. Cover crops were planted afterward and changes in soil quality factors will be evaluated in October 2016. Also included in these factors will be soil phosphorus treatments. Active carbon and aggregate stability measurements were performed by the MU laboratory by standard practices. Water infiltration was determined by the Cornell Sprinkle Infiltrometer and indicates time before water began to run off.

		Active Carbon mg/kg	Aggregate Stability percent	Water Infiltration minutes
1	no lime	332	25	4.32
2	no lime	428	37	4.03
3	no lime	653	43	4.42
4	no lime	474	42	1.45
1	lime	323	34	3.37
2	lime	403	29	2.14
3	lime	303	26	1.09
4	lime	319	23	2.36

Final Report
2014

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

Investigator(s):
Kent Shannon, Todd Lorenz, Joni Harper, Peter Scharf, Brent Carpenter, Gene Schmitz, and Wendy Flatt

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 was 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 had 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 were initally grid soil sampled on a 1 acre grid. The three fields received final fertility treatments in the spring of 2014.

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. (See Appendix for details on the proposed P and K recommendations utilized).

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 spring of 2014. 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.

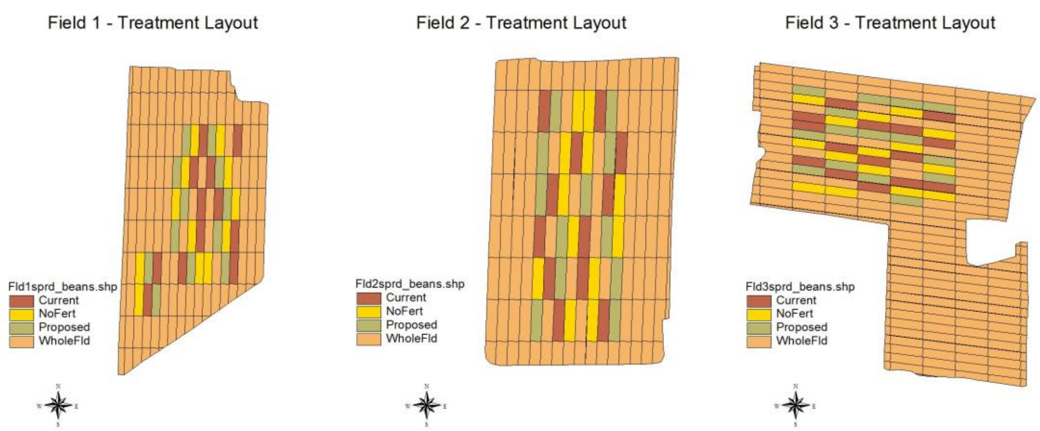


Figure 1. Plot Layout for Field 1, 2, and 3

<u>Results for 2014:</u>

Yield data was processed utilizing GIS software to analyze treatment differences.

Plot bean yields ranged from 44 to 77 bu/acre with the mean being 62 bu/acre for Field 1. Field 2 had plot corn yields ranging from 143 to 229 bu/acre with a mean of 186 bu/acre. Field 3 had plot corn yields ranging from 156 to 232 bu/acre with a mean of 198 bu/acre. There were no significant yield differences between treatments at the 5% probability level in Field 1 and 3. There were significant yield differences between the no fertilizer treatment and the other three treatments in Field 2 which indicates P and K soil test levels reached a critical point causing yield reduction at the end of the 5 year study. Plot yields in Field 2 do show the proposed P and K fertility recommendations have maintain yield levels while decreasing the amount of P and K applied.

A detailed summary of each field can be found in the following tables. It should be noted only 5 replications were analyzed for each of the three fields. This was due to the quality of as-applied fertilizer rate data and yield data.

Bean Yield Results for Field 1

	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Treatment Mean
Treatment	---- bu/acre ----					
No Fertilizer	54.7	55.9	61.1	66.3	58.9	59.4
Whole Field	74.4	61.7	65.1	60.2	58.6	64.0
Current Recommendations	76.9	60.8	54.3	60.3	61.5	62.8
Proposed Recommendations	64.0	64.6	43.9	68.7	62.4	60.7
Block Mean	67.5	60.8	56.1	63.9	60.4	61.7
No significant treatment differences (P=0.05)						LSD 9.8

Corn Yield Results for Field 2

	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Treatment Mean
Treatment	---- bu/acre ----					
No Fertilizer	157.0	148.4	142.9	160.1	165.3	154.7
Whole Field	228.5	174.8	176.9	196.4	193.4	194.0
Current Recommendations	198.5	185.1	202.8	196.2	196.4	195.8
Proposed Recommendations	221.3	189.8	196.3	202.7	188.1	199.6
Block Mean	201.3	174.5	179.7	188.9	185.8	186.0
Significant treatment differences (P=0.05)						LSD 15.0

Corn Yield Results for Field 3

	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Treatment Mean
Treatment	---- bu/acre ----					
No Fertilizer	206.5	155.5	195.6	192.8	219.0	193.9
Whole Field	205.3	172.5	205.7	193.7	208.7	197.2
Current Recommendations	207.0	179.8	231.8	190.6	228.9	207.6
Proposed Recommendations	204.0	174.8	178.2	188.9	217.8	192.7
Block Mean	51.8	49.7	45.6	47.5	47.5	48.4
No significant treatment differences (P=0.05)						LSD 14.8

Also included are tables summarizing fertilizer recommendations for P_2O_5 and K_2O for the three fields by treatment for the 2014 growing season. As in the past four 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 1950 lbs less and the K_2O recommendation was 4879 lbs less. Field 2 and 3 shows the same trend. The P_2O_5 recommendation was 6179 lbs less and the K_2O recommendation was 4147 lbs less for Field 2. In Field 3, the P_2O_5 recommendation was 2160 lbs less and the K_2O recommendation was 6802 lbs less.

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

Treatment	Total Pounds of P_2O_5	Total Pounds of K_2O
Whole Field	2494	9265
Current Recommendations	2790	8017
Proposed Recommendations	840	3138

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

Treatment	Total Pounds of P_2O_5	Total Pounds of K_2O
Whole Field	10766	5700
Current Recommendations	11099	6220
Proposed Recommendations	4920	2073

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

Treatment	Total Pounds of P_2O_5	Total Pounds of K_2O
Whole Field	2046	10742
Current Recommendations	2160	10505
Proposed Recommendations	0	3703

Over the total five years of the project the average rate of P_2O_5 was 81 lbs per acre for the whole field treatment, 83 lbs per acre for the variable rate treatment utilizing current University of Missouri recommendations, and 33 lbs per acre for the variable rate treatment utilizing proposed recommendations over all fields. For K_20 the average rates are as follows: 113 lbs per acre for the whole field treatment, 109 lbs per acre for the variable rate treatment utilizing current University of Missouri recommendations, and 42 lbs per acre for the variable rate treatment utilizing proposed recommendations.

Final soil sample analysis was conducted in the fall of 2014 soil sampling results and were compared to the original baseline soil sampling conducting in 2010 and the fall sampling in 2012. 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 2014 for Field 1 – Bray I P

Treatment	2010 – Bray I P (lbs/acre)	2012 – Bray I P (lbs/acre)	2014 – Bray I P (lbs/acre)
Whole Field	62	82	84
Current Recommendations	61	69	62
Proposed Recommendations	55	51	57
No Fertilizer	57	59	62

Soil Test Analysis Comparison from Spring 2010 to Fall 2014 for Field 2 – Bray I P

Treatment	2010 – Bray I P (lbs/acre)	2012 – Bray I P (lbs/acre)	2014 – Bray I P (lbs/acre)
Whole Field	16	45	61
Current Recommendations	16	53	75
Proposed Recommendations	14	34	32
No Fertilizer	18	36	11

Soil Test Analysis Comparison from Spring 2010 to Fall 2014 for Field 3 – Bray I P

Treatment	2010 – Bray I P (lbs/acre)	2012 – Bray I P (lbs/acre)	2014 – Bray I P (lbs/acre)
Whole Field	59	50	38
Current Recommendations	58	55	40
Proposed Recommendations	56	52	33
No Fertilizer	58	49	29

Soil Test Analysis Comparison from Spring 2010 to Fall 2014 for Field 1 – K

Treatment	2010 – K (lbs/acre)	2012 – K (lbs/acre)	2014 – K (lbs/acre)
Whole Field	232	236	271
Current Recommendations	247	253	252
Proposed Recommendations	229	157	193
No Fertilizer	230	187	192

Soil Test Analysis Comparison from Spring 2010 to Fall 2014 for Field 2 – K

Treatment	2010 – K (lbs/acre)	2012 – K (lbs/acre)	2014 – K (lbs/acre)
Whole Field	228	136	175
Current Recommendations	228	140	156
Proposed Recommendations	223	148	172
No Fertilizer	234	143	129

Soil Test Analysis Comparison from Spring 2010 to Fall 2014 for Field 3 – K

Treatment	2010 – K (lbs/acre)	2012 – K (lbs/acre)	2014 – K (lbs/acre)
Whole Field	183	216	230
Current Recommendations	176	223	234
Proposed Recommendations	185	207	199
No Fertilizer	182	195	156

In the summary of the data, it 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. Soil samples from 2012 and 2014 were collected in the same geo-referenced location. Two main observations were made: applying no fertilizer resulted in drawing down P and K levels over the five years of the study and the P and K levels in the proposed recommendation treatment were maintained over the life of the study.

Economic analysis was conducted utilizing 2010, 2011, and 2014 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	$427.05
Proposed Recommendations	$473.54
No Fertilizer	$477.67
Whole Field	$415.48

Analysis assumed P205 cost of $0.48/lb, K_2O cost of $0.40/lb, corn price of $3.75/bu, and soybean price of $7.00/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. Utilizing a cost of $10.00 per acre to cover the cost for soil testing, mapping and variable-rate application, the proposed University of Missouri recommendations net an extra $36.49 per acre.

In conclusion of the project, if only 25% of growers would adopt the proposed recommendations in a variable rate P and K fertility program an estimated the potential economic benefit of $25.00 per acre could by translated into a $8.0 million impact of fertilizer input costs saved to Missouri corn and soybean producers.

On behalf of the University of Missouri Extension faculty involved in this project, the generosity of the Missouri Fertilizer and Lime Board is greatly appreciated for funding this project.

APPENDIX

Soil Test P Recommendations

Current MU Rec

Equation Output : P Rec for Corn
If [Soil P1] < 45.00 Then

RESULT= ([Corn Yield Goal] * 0.450) + (110.00 * (45.00 ^ 0.500 - ([Soil P1] * 1.000) ^ 0.500)) / [Build Years]

Else If [Soil P1] >= 45.00 Then

RESULT= [Corn Yield Goal] * 0.450 * (1.000 - (2.000 * ((100.00 * (([Soil P1] * 1.000) / 45.00)) - 100.00)) / 100.00)

Proposed MU Rec

Equation Output : P Rec for Corn
If [Soil P1] < 30.00 Then

RESULT= ([Corn Yield Goal] * 0.320) + ((4.700 * (30.00 - [Soil P1])) / [Build Years])

Else If [Soil P1] >= 30.00 Then

RESULT= [Corn Yield Goal] * 0.320 * (1.000 - (2.000 * (([Soil P1] / 30.00) - 1.000)))

Soil Test K Recommendations

Current MU Rec

Equation Output : K Rec for Corn
If [Soil K] < (220.00 + (5.000 * [Soil CEC])) Then

RESULT= [Corn Yield Goal] * 0.300 + 75.50 * (((220.00 + (5.000 * [Soil CEC])) ^ 0.500) - (([Soil K] * 1.000) ^ 0.500)) / [Build Years]

Else If [Soil K] >= (220.00 + (5.000 * [Soil CEC])) Then

RESULT= [Corn Yield Goal] * 0.300 * (1.000 - (2.000 * ((100.00 * ([Soil K] * 1.000) / (220.00 + (5.000 * [Soil CEC]))) - 100.00)) / 100.00)

Proposed MU Rec

Equation Output : K Rec for Corn
If [Soil K] < (150.00 + (4.000 * [Soil CEC])) Then

RESULT= [Corn Yield Goal] * 0.250 + ((2.100 * ((150.00 + (4.000 * [Soil CEC])) - [Soil K])) / [Build Years])

Else If [Soil K] >= (150.00 + (4.000 * [Soil CEC])) Then

RESULT= [Corn Yield Goal] * 0.250 * (1.000 - (2.000 * (([Soil K] / (150.00 + (4.000 * [Soil CEC]))) - 1.000)))

Micronutrient Studies

Progress Reports
2015

Evaluation of Micronutrient Packages for Cool-season grass Pastures

Investigator: Robert L. Kallenbach

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 Table 1 below.

Table 1. Micronutrient products tested in the experiment.

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. On 11 March 2015, 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 200-112-300, according to soil test results with a yield goal of 3 tons per acre. Lime was applied at a rate of 1 T/acre to the plots in the high yield scenario. 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 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, plot readings were taken immediately before and after grazing by livestock. We can infer that more palatable treatments would be grazed to shorter residual heights than those not as palatable.

Preliminary Results:

Contrary to previous years, forage yield did not differ between the high and low soil fertility scenarios. The likely explanation is that timely rains in 2015 provided an environment conducive to exceptional forage growth regardless of the base soil fertility. Table 2 presents the season long forage yields for the micronutrient treatments averaged across the low and high yield scenarios. These treatments did not affect forage production in 2015, however, two sulfur containing products did result in about 10% more forage yield than the mean of all the other micronutrients. We want to stress our data are preliminary and that further long-term testing will be needed to confirm these results. Palatability response due to the treatments has not been analyzed but will be included in the final report.

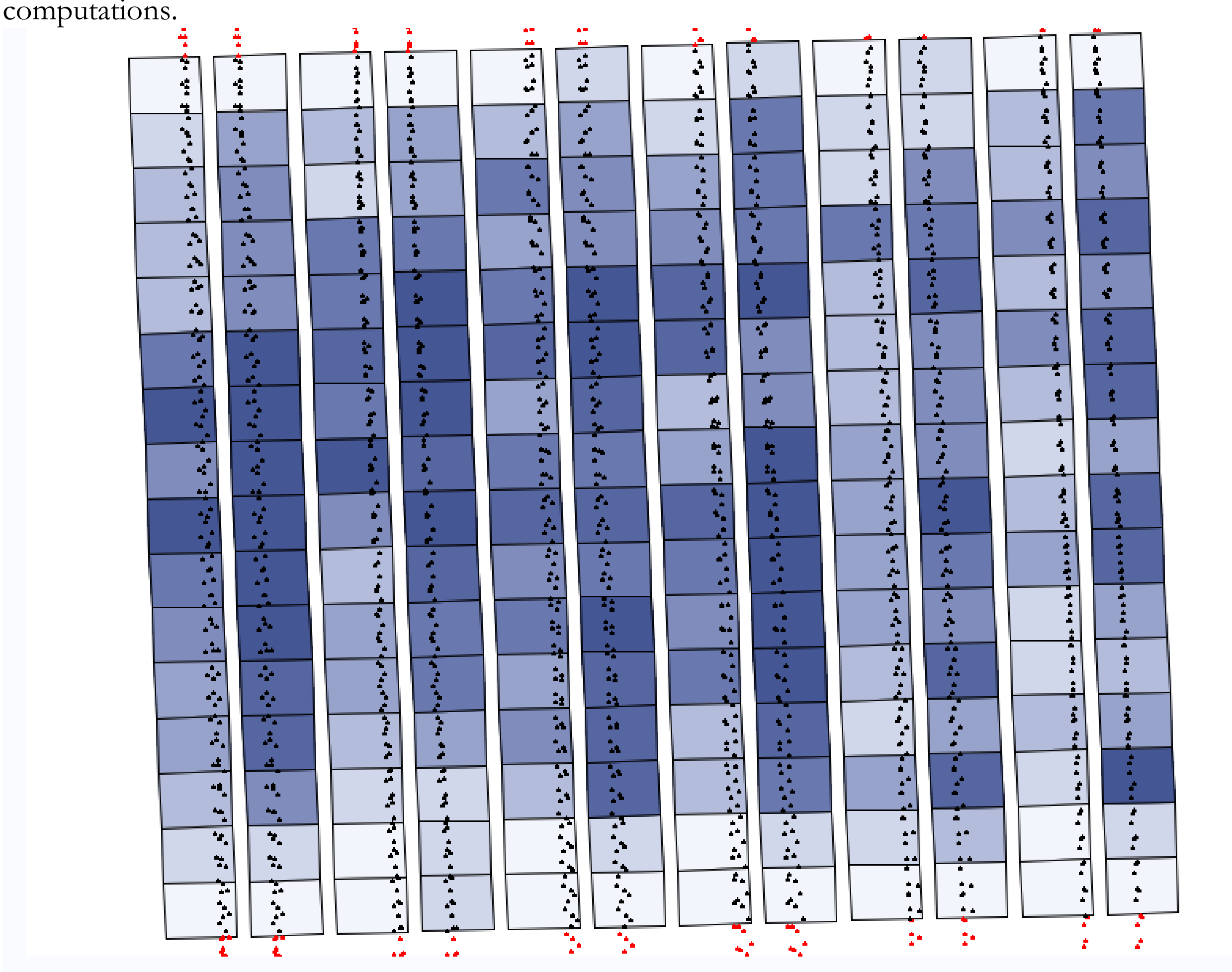
Table 2. Season-long yield of tall fescue treated with different micronutrient fertilizer products. Values were averaged across the low and high soil fertility scenarios.

Micronutrient	**Forage Yield, kg ha^{-1}**
MicroEssentials SZ	8935
MicroEssentials S15	8795
Versa Max	8710
Megafol	8600
Bio-Forge	8540
Black Label Zn	8510
Lignin Mg	8390
MicroScience	8280
Control	8220
LoKomotive	8055
Lignin Mn	7995
Humic 20	7960
Elemax	7905
LSD	n.s.

Figure 2. Forage height being measured with an ultrasonic reader.

Figure 3. Cows grazing tall fescue treated with different micronutrient products under high and low soil fertility scenarios.

Figure 4. Graphic output of innovative methods to calculate forage production with GPS, ultrasonic sensors, and computer code in SAS. Polygons of plots are identified, GPS records are stored with ultrasound sensor data on the bike reader, and finally an algorithm is used to calculate mean height of forage in plots. Red dots indicate that the sensor was not located in an identified plot when the measurement was recorded and thus the data is omitted by the algorithm and not included in the computations.



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:

1) Quantify the impact of pre-formulated micronutrient packages on corn yield.
2) Determine plant tissue concentration of applied micro- and macronutrients.
3) 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.

2015 ACCOMPLISHMENTS:

- This year was the third and final year for the project evaluating micronutrient applications on corn growth and yield.
- The following treatments were applied to Pioneer corn hybrid 32D79 in 2013 and Pioneer corn hybrid P0636AMX in 2014 & 2015 treated with and without glyphosate. In 2015, 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
- Treatments 1 and 2 were applied at recommended rates at planting using an 8 row John Deere 7000 Max Emerge planter with custom-built fluid injection system. AgXplore's MicroStarter (2qts/ac) (Trt 1) contains B, Mn, Mo, and Zn, and Agrisoulutions' Ultra-Che Corn Mix (2qts/ac) (Trt 2) contains Cu, Mn, and Zn.
- When the plants reached V5, the first round of foliar treatments were applied according to label recommendations. The treatments applied at this time included Agriguardian's MOLY (4oz/ac) (Trt 3) containing Mo only, Wuxall Top 3 (2qts/ac) (Trt

4) which contains N, S, B, Mn, and Zn, Winfield Max IN ZMB (1qt/ac) + Max-IN Boron (1pt/ac) (Trt 5) containing S, B, Mn, and Zn, and Inorganic Zn sulfate (150.18g/L), Mn sulfate (160.61g/L), and Molybdate (34.31g/L) (Trt 6). The same treatments and amounts were also applied at VT. The rates and timing of applications were all based on label recommendations for each product.

- Grain yield was determined at the end of the season.
- Tissue nutrient analyses from the 2013 and 2014 seasons have been completed. .
- Data from 2013 and 2014 were presented at the 2015 ASA-CSSA-SSSA annual international meeting and received a lot of attention from many attendees.

2015 PRELIMINARY RESULTS:

NOTE: Due to large amounts of precipitation throughout the beginning of the season many areas of the field suffered from severe flood stress which caused a lot of variation within plots. The extreme weather conditions should be considered when examining the 2015 yield data.

Table 1. Yield and yield components of corn after being treated with eight micronutrient products and treated with or without glyphosate as part of standard weed control.

	Yield		**Kernels per ear**†		**100 kernel wt.**	
Product	**no glyphosat**	**glyphosate**	**no glyphosate**	**glyphosate**	**no glyphosate**	**glyphosate**
	----------- bu/ac	--------	-------------- No.	--------	---------- grams	---------
AgXplore	70.1	97.7	-	-	-	-
Agrisolution Ultra-	80	57.5	-	-	-	-
Agriguardian	79.9	96.6	-	-	-	-
Wuxall Top 3	104.3	69	-	-	-	-
Winfield Max-IN Ultra ZMB + Max-	75.5	75.4	-	-	-	-
ZnSO4 +	123.6	81.2	-	-	-	-
Control (no product applied)	89	77.9	-	-	-	-
Pr>F	**ns**	**ns**	**-**	**-**	**-**	**-**
Mean	79.3	88.9	-	-	-	-

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

† Data analysis ongoing.

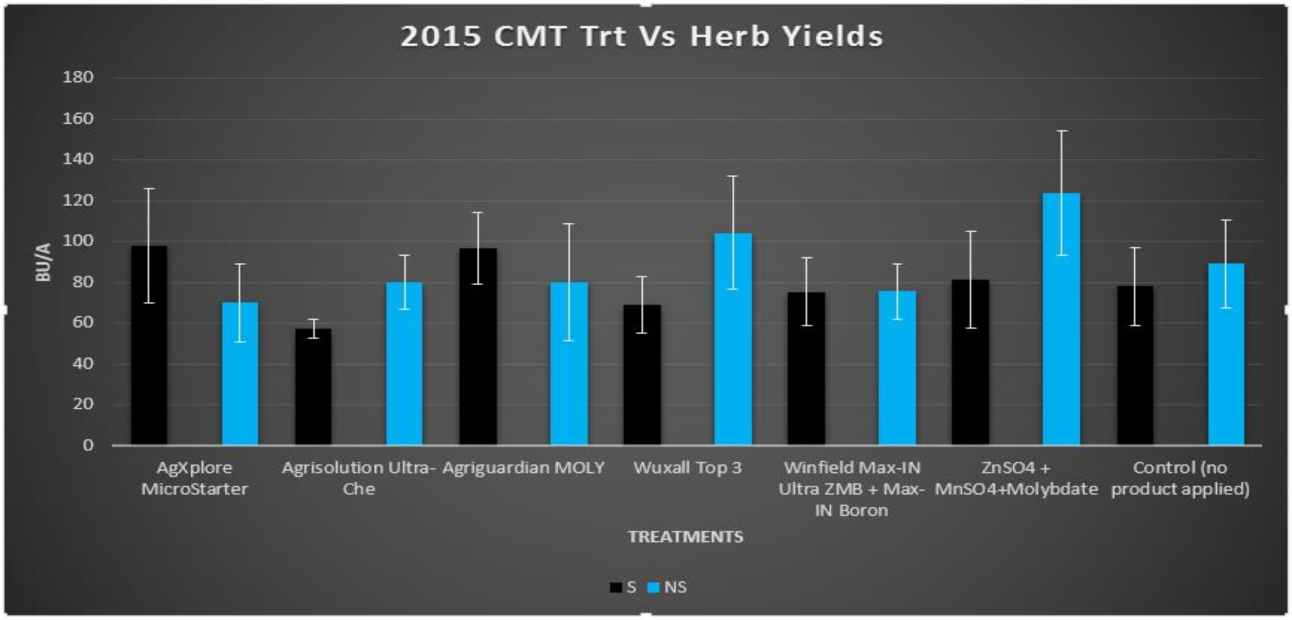


Figure 1. Grain yield of all fertilizer treatments treated with and without Glyphosate. (S) denotes treatments sprayed with glyphosate, (NS) denotes treatments not sprayed with glyphosate.

As noted earlier, yields and variability of yield within the field was dramatically influenced by 2015 precipitation pattern. Due to the conditions in 2015, no consistent statistical differences were observed and data are not considered representative.

Preliminary 3-year overview:
In general, no yield difference were observed as a function fertilizer treatment. Overall, the most consistent response observed to date was the response to glyphosate application. Glyphosate treated plots generally yielded less than treatments not sprayed with glyphosate. While not as consistent in 2015 as in 2014 and 2013, across the three years, yields of glyphosate treatments were approximately 10bu/ac lower than those of treatments not sprayed with glyphosate. Comprehensive analyses of all the data from this study are yet to be completed and additional research is needed to further characterize and confirm the observations from this study.

Evaluation of Commercial Micronutrient Fertilizer Packages for Corn, Soybeans, and Rice

Gene Stevens and Matthew Rhine

Essential plant nutrients for crops are divided into macronutrient and micronutrient categories. Carbon, hydrogen, and oxygen, are supplied from air and water. Other macronutrients are phosphorus, potassium, nitrogen, sulfur, calcium, magnesium and silicon. The micronutrients are iron, molybdenum, boron, copper, manganese, sodium, zinc, nickel, chlorine, cobalt, and aluminum. In most cases, enough micronutrients are supplied by organic matter to meet crop needs. The objective of this test is to compare micronutrients using label recommendations.

Procedure. Micronutrient labels were read for recommended rates and timings of applications. Plots were planted and micronutrients applied at the MU Delta Center in four replications.

Results. Tissue test collected from plants before foliar application were made showed that most nutrients were within or above the sufficiency range (Table 1). Manganese in rice was low and magnesium in corn was low. Non-irrigated corn yields were very low because of dry weather (Table 2).

Table 1. Tissue test results from soybean, rice, and corn before foliar fertilizers were applied.

	Soybean		Rice		Corn	
Nutrient	Sufficiency range †	Tested‡	Sufficiency range	Tested	Sufficiency range	Tested
	---------------------------------------%--- ----					
Calcium	0.5-2.0	2.3	0.15-0.30	0.6	0.25-1.0	0.8
Magnesium	0.30-0.70	0.4	0.15-0.30	0.2	0.25-0.50	0.1
	-------------------------------------ppm--- ---					
Zinc	25-50	46	25-50	48	30-60	38
Iron	55-750	1674	75-200	358	50-750	1636
Manganese	75-100	138	200-800	149	75-150	192
Copper	12-30	16	8-25	14	9-20	19
Sulfur	150-500	2876	150-500	1428	150-500	195
Boron	26-55	47	8-14	257	8-16	48

† H.A. Mills and J.B. Jones, Jr., 1991. Plant Analysis Handbook II, MicroMacro Publ., Athens, GA.

‡ Average from four replications.

Table 2. Soybean, rice, and corn yields following foliar application of micronutrient fertilizers.

Element	Formulation	Brand	Rate	Center pivot irrigated		Rainfed
				Soybean	Rice	Corn
	%		acre	------------bushels per acre†		-----------
Check	-	-	-	59	134	39
Boron	5.0	BorPak	1 pt	61	126	63
Boron	7.5	Boron Plus	6 oz	73	127	49
Copper	7.5	Copper 7.5	2 qt	69	137	58
Iron	4.5	GreenFlash	2 qt	73	‡	49
Zinc	9.0	Zinc9	1 pt	73	145	44
Moly.	0.001	MicroStarter	1 qt	56	130	66
Blend	19 K2O+13 S	Max-In Sulfur	2 qt	67	113	43
Blend	6 N+ 5 Mg	Max-In Mg	1 qt	56	130	66
Blend	3 S+0.1B+3Mn+4 Zn	Max-In UltraZMB	2 qt	74	141	60
Blend	10N+11Ca+1Mg+all micros except Ni, Cl	Wuxal Calcium	1.5 pt	70	128	51
Blend	4 N+1S+0.25B+2Mn+2Zn	Wuxal Top 3	1 qt	53	148	47
Blend	5.8S+10Mn	Manganese Plus	1 qt	57	144	57
Blend	4.9S+10Zn	Zinc Plus	1 qt	67	126	43
Blend	2Mg+5.7S+1Cu+1Mn+4Zn	MicroVite	1 qt	59	134	54

† Average from four replications. ‡ We are studying results from this treatment.

Final Report

2015

Comparison of Co-Granulated Dry Fertilizers with S and Zn to Blends for Corn: Soybean Response the Following Year

Investigators:
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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 using co-granulated formulations. Each prill was 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 can affect the uniformity of distribution when the blended fertilizer is applied in the field. Distribution of a 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.

Co-granulated fertilizers have S and Zn added in layers to the MAP prill which allows for a more uniform distribution of fertilizer and allows roots to have a higher probability of contact with the fertilizer granule which 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 were to 1) evaluate P rates of co-granulated MES10 and MESZ formulations compared to equivalent blends of MAP, Zn, and S, and 2) evaluate $ZnSO_4$ rates in a blend with MAP or DAP compared to co-granulated MES10 and MESZ formulations on grain yields and uptake of nutrients (P, S, and Zn) in a corn-soybean rotation. The corn portion of this research was summarized (Caldwell, 2015; Nelson et al., 2015). This report is focused on the soybean portion of this research.

Materials and Methods:

- Field research was conducted at Novelty in 2011 and 2012, and was expanded to include two locations (Novelty and Albany) in 2013 and 2014.
    - Corn plots were established at all six site-years. Initial soil characteristics 0-6 inches deep for objectives #1 and #2 were reported (Caldwell, 2015; Nelson et al., 2015).
    - All corn plots were followed by soybean at each site-year.
    - Protein and oil concentrations were determined using a near infrared (NIR) machine (Foss Infratec, Eden Prairie, MN).
    - The treatments at each site were arranged as randomized complete block designs with 4 and 5 replications at Albany and Novelty, respectively.
    - Field and management information for corn and soybean is available in Caldwell (2015).
- Objective 1: Evaluate P rates of MES10 and MESZ formulations compared to equivalent blends of MAP, Zn, and S. Treatments are listed in Table 1.
    - Soybean plots had no additional fertilizer application and were in the same location as the corn plots the previous year. Soybean plots were maintained weed-free and were no-till seeded.
    - Soybean 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 2.
    - Soybean plots were no-till planted, had no additional fertilizer applied, and were in the same location as the corn plots the previous year.
    - 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.
    - Soybean yields were adjusted to 13% moisture content prior to analysis.

<u>Results:</u>

All of the sites had very low to medium soil test P, except for the corn-soybean rotation site at Albany in objective 2 (Caldwell, 2015; Nelson et al., 2015). 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. Details on the corn results from this research for objectives 1 and 2 are available in Nelson et al. (2015) and Caldwell (2015). P, S, and Zn applications were reflected in the post-harvest soil test data following corn harvest (Caldwell, 2015).

- Objective 1: The carry-over effect of P fertilizer treatments from corn to soybean indicated no significant effect of the treatments on soybean plant population at harvest, grain yield, seed oil concentration, or seed protein concentration (Table 1).
- Objective 2: The carry-over effect of Zn fertilizer treatments from corn to soybean indicated no significant effect of the treatments on soybean plant population at harvest, grain yield, seed oil concentration, or seed protein concentration (Table 2).
- If S and/or Zn are applied, MicroEssentials MES10 or MESZ are advised for nutrient distribution purposes.

References:

Caldwell, M. 2015. Comparison of co-granulated fertilizers to equivalent blends of phosphorus, sulfur, and zinc in a corn-soybean rotation. pp. 120.

Nelson, K.A., M. Caldwell, C. Dudenhoeffer, B. Burdick, P. Motavalli, and M. Nathan. 2015. Comparison of Impregnated Dry Fertilizer with S and Zn to Blends for Corn. Agron. Misc. Publ. No. 15-01. pp. 183-18.

Table 1. Soybean response to phosphorus fertilizer treatments (Objective #1) applied the previous year to corn. Plant population and yield data were for all site-years. Grain oil and protein data were determined for all site-years except Albany in 2014. Data were combined over site-years (Novelty in 2012, 2013, 2014, 2015, and Albany in 2014 and 2015).

Phosphorus treatments	P_2O_5	Population	Yield	Oil	Protein
	lbs/A	plants/A	Bu/A	%	%
Non-treated control	0	109,000	40.9	19.3	34.8
MESZ	70	111,000	42.0	19.2	35.0
MES10	70	112,000	41.8	19.2	35.0
MAP	70	116,000	42.3	19.2	35.0
MAP +AMS	70	115,000	41.8	19.3	35.1
MAP +AMS+$ZnSO_4$	70	109,000	41.9	19.2	34.9
MESZ	110	110,000	43.5	19.2	34.9
MES10	110	107,000	43.1	19.2	35.0
MAP	110	113,000	42.0	19.1	35.0
MAP+AMS	110	109,000	41.7	19.1	35.1
MAP+AMS+$ZnSO_4$	110	112,000	42.3	19.1	35.1
14 lbs N/A[‡]	0	112,000	42.7	19.1	35.1
21 lbs N/A	0	112,000	42.9	19.1	35.1
28 lbs N/A	0	114,000	40.3	19.1	35.1
33 lbs N/A	0	109,000	43.0	19.1	36.4
46 lbs N/A	0	107,000	42.7	19.2	34.9
P-value		0.6 (NS)	0.74 (NS)	0.11 (NS)	0.26 (NS)

[†]Abbreviations: AMS, ammonium sulfate; MAP, monoammonium phosphate; MES10, MicroEssentials 10% Sulfur; MESZ, MicroEssentials 10% Sulfur and 1% Zinc; NS, Non-significant.
[‡]Additional N applied as urea.

Table 2**.** Soybean response to Zn fertilizer treatments (Objective #2) applied to corn the previous year. Population at harvest and yield data were for all years. Grain oil and protein data were determined for all site-years except Albany 2014. Data were combined over site-years (Novelty in 2012, 2013, 2014, 2015, and Albany in 2014 and 2015).

		Population		Yield		Oil		Protein	
Zinc treatments[†]		2012-13	2014-15	2012-13	2014-15	2012-13	2014-15	2012-13	2014-15
	lbsA	------- plants/A -------		----------- bu/A -----------		-------------------------- % --------------------------			
Non-treated	0	124,500	130,200	39.2	43.3	19.7	18.9	35.2	34.9
N-only	0	127,200	128,300	39.7	46.4	19.3	18.9	35.7	34.8
DAP	0	125,500	118,300	38.2	47.2	19.2	18.8	36.0	34.9
DAP+ ZnSO4	2	122,800	136,300	39.0	46.6	19.3	18.8	35.8	34.7
DAP+ ZnSO4	5	134,200	126,300	39.0	45.8	19.2	18.9	35.8	34.7
MAP	0	137,700	130,000	37.9	46.4	19.1	18.8	36.0	34.8
MAP+ ZnSO4	2	113,300	125,200	38.7	46.4	19.2	18.8	35.9	34.9
MAP+ ZnSO4	5	128,100	135,000	38.5	46.7	19.3	18.8	35.7	34.7
MESZ	2	135,000	134,800	39.0	46.7	19.1	18.9	36.0	34.9
MES10	0	137,700	126,100	39.4	46.6	19.0	18.8	35.7	34.6
MAP+ AMS	0	130,700	122,400	39.6	46.5	19.2	18.8	35.8	34.8
MAP+ SuperZn	2	-[‡]	128,500	-	47.8	-	18.9	-	34.7
MAP+ SuperZn	5	-	121,300	-	47.5	-	18.9	-	34.4
DAP+ AMS	0	-	121,300	-	48.1	-	18.9	-	34.6
DAP+ SuperZn	2	-	119,400	-	45.5	-	19.0	-	34.7
DAP+ SuperZn	5	-	134,800	-	46.5	-	18.9	-	34.8
P-value		0.5 (NS)	0.15 (NS)	0.85 (NS)	0.16 (NS)	0.42 (NS)	0.37 (NS)	0.33 (NS)	0.46 (NS)

[†]Abbreviations: AMS, ammonium sulfate; DAP, diammonium phosphate; MAP, monoammonium phosphate; NS, Non-significant.
[‡]Treatments were not applied during these two years (2012 and 2013).

Miscellaneous Studies

Progress Reports

2015

Fertilizer and Hormone Applications to Reduce Chalkiness in Rice Grains

Gene Stevens and Matthew Rhine

Rice marketability is dictated by two traits- proportion of broken grains after milling and amount of chalkiness (opaque spots) in whole grains. Both traits are the result of uneven packing of amyloplasts in the rice seed endosperm which causes weak and brittle grains. Broken grains in cooked rice detract from its aesthetic value and chalkiness hurts the taste. The most valuable rice grains are translucent. Typically, rice grains from the bottom of panicles (heads) mature latest in the season and have more chalk and broken grains than grains from the top.

In recent years, chalkiness has become an obstacle for selling USA rice in Turkey and Latin America countries. Research has shown that changes in plant hormones from stresses, such as potassium and silicon deficiency, high nighttime temperature, and water stress, can increase rice grain chalkiness. The objective of this study is to develop nutrient and hormone programs to reduce the proportion of broken grains and chalkiness in Missouri rice and increase it marketability to consumers in the United States and foreign countries.

Procedure. Field tests were conducted at the Missouri Rice Research Farm and University of Missouri-Lee Farm. Two varieties or hybrids were planted at each location in four replications. Each rice received management treatments with an untreated check, soil applied potassium, soil applied calcium silicate, and internode elongation applied potassium fertilizer. Foliar treatments were gibberellic acid and kinetin applied at 50% heading. Plots were harvested with a combine for yield and grain milling and chalkiness.

Results. Rice grain yields of CL151 were significantly higher than those of CL111 (Table 1). Across cultivars, yields were significantly reduced by applications of potash at internode elongation and foliar gibberellic acid at heading.

Panicles were separated into top, middle and bottom thirds to determine if location on the panicle affected rice transparency (Figure 1). Rice transparency is inversely related with chalk, and higher numbers indicate a lower chalk value. Rice grain located at the top of the panicle was found to have significantly higher transparency than those kernels located in the middle and bottom portions of the panicle (Figure 2). Rice kernels in the top mature earlier than lower portions, indicating that this difference could be affected by temperature or soil moisture.

Rice transparency was also affected by genotype. Cultivar CL111 produced significantly more grain transparency than CL151. Given the applied amendments, rice transparency was reduced by both potash applied preplant and foliar applications of gibberellic acid at heading (Figures 3 & 4). This was found across both cultivars used in the study. These two applications are also known to delay grain maturity, which may have cause kernels to mature when temperatures were higher late in the season.

These results indicate that those actions that delay maturity, whether it be due to physiological location on the panicle or an applied amendment, have the potential to increase rice chalk.

Table 1. Effect of potassium and silicon fertilizers and gibberellin and kinetin hormones on rough rice and milled rice yields and chalkiness at the Missouri Rice Research Farm in n 2015.

Variety	Fertilizer/Hormone	Timing	Rate	Rice yield	Unbroken kernels	Trans. factor†
			per acre	bu/ac	%	
CL151	untreated check	-	0	248	66	3.30
	potassium	planting	60 lb K2O	235	68	2.83
	calcium silicate	planting	54 lb Si	223	66	3.11
	potassium	midS (IE)	60 lb K2O	221	68	3.13
	gibberellin	50% Head	45 mg	226	67	3.04
	kinetin	50% Head	45 mg	232	71	3.14
CL111	Untreated check	-	0	227	66	3.50
	potassium	planting	60 lb K2O	212	69	3.14
	calcium silicate	planting	54 lb Si	228	70	3.22
	potassium	midS (IE)	60 lb K2O	218	68	3.40
	gibberellin	50% Head	45 mg	205	68	3.09
	kinetin hormone	50% Head	45 mg	227	70	3.47

† Measured with Whiteness Meter MBZ-1 by Agro-Indus. Higher numbers indicate less chalk.

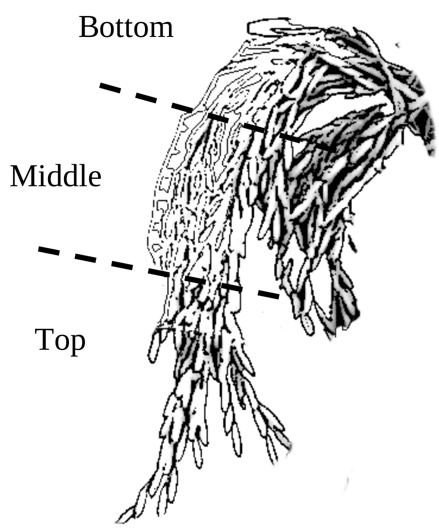

Figure 1. Dissection of panicles by top middle, and bottom locations for transparency testing.

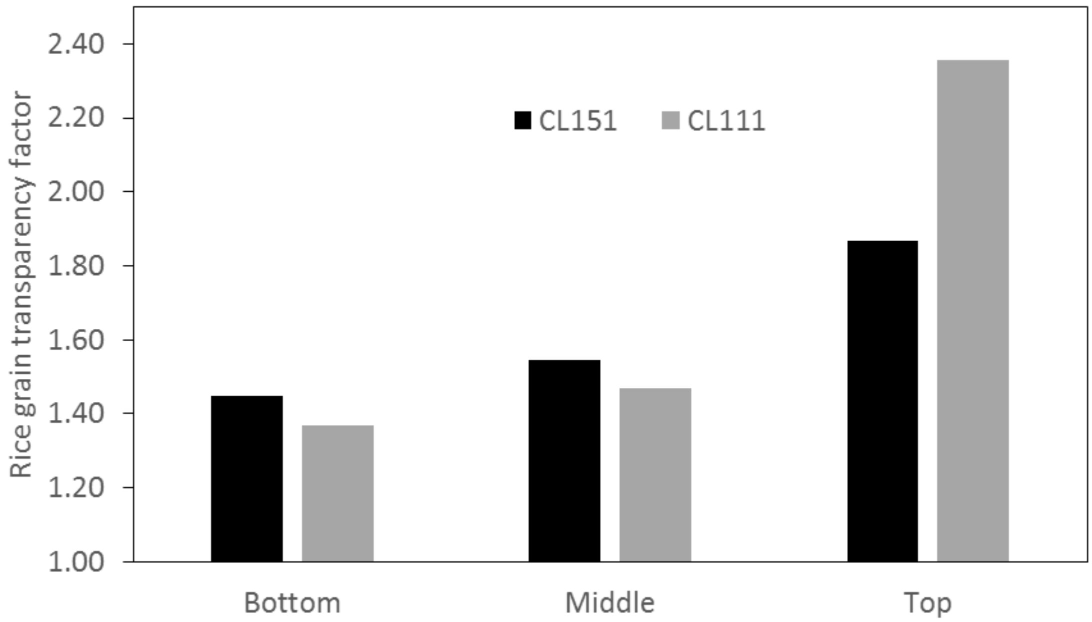

Figure 2. Effect of panicle location on rice grain transparency in rice cultivars CL151 & CL111.

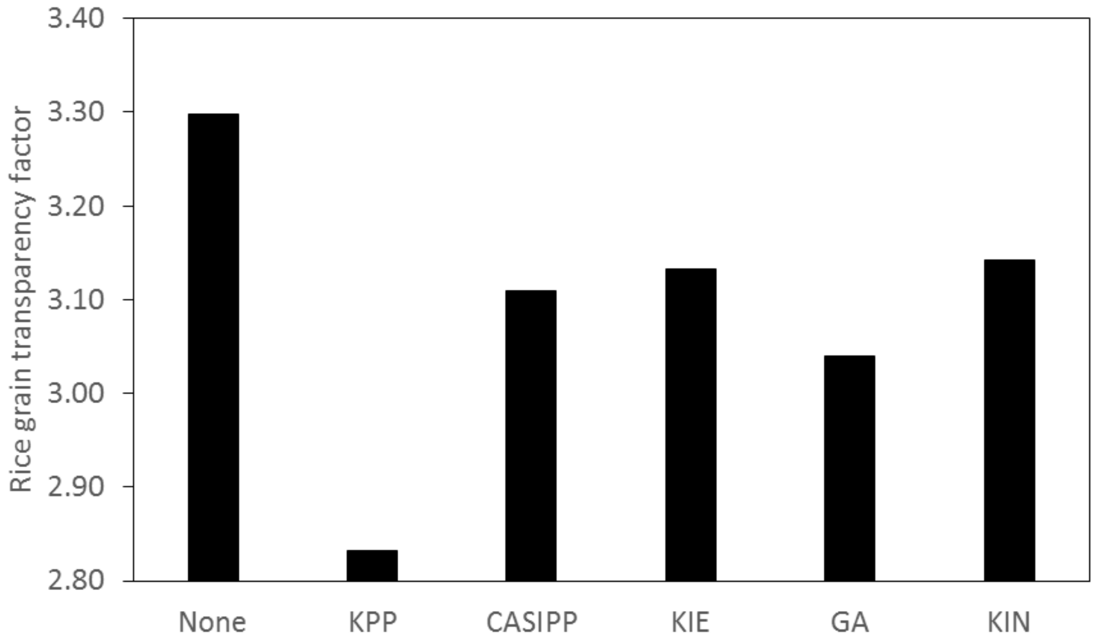

Figure 3. Effect of amendments on rice grain transparency of cultivar CL151. None= untreated check, KPP=potassium preplant, CASIPP=calcium silicate preplant, KIE=potassium internode elongation, GA= gibberellic acid at 50% heading, KIN=potassium at 50% heading.

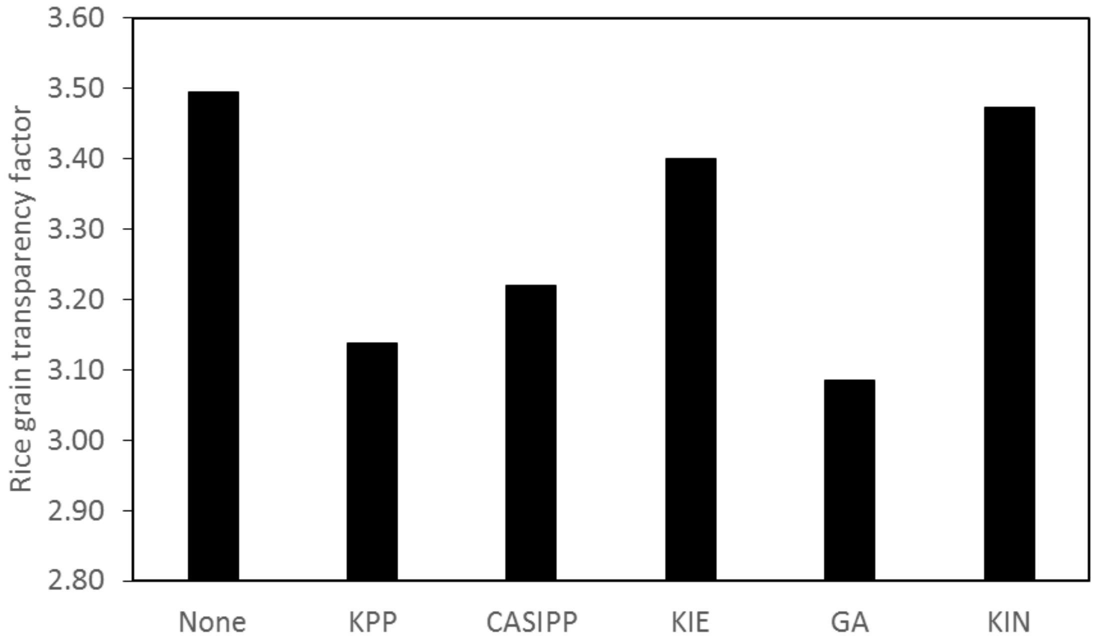

Figure 4. Effect of amendments on rice grain transparency of cultivar CL111. None= untreated check, KPP=potassium preplant, CASIPP=calcium silicate preplant, KIE=potassium internode elongation, GA= gibberellic acid at 50% heading, KIN=potassium at 50% heading.

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