

**Missouri  
Soil Fertility and Fertilizers  
Research Update  
2006**

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

## **Thank You**

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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 the one's 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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# **Sanborn Field Update**

# Historic Sanborn Field: 2006 Growing Season

**Steven Troesser and Randall J. Miles**  
**Soil, Environmental, and Atmospheric Sciences Department**

## Introduction

Since the fall of 1888 researchers on Sanborn Field have explored the affects that different management schemes have on the properties of the soil. The longevity of the research on Sanborn Field has made it the third oldest research field in the world. Sanborn Field is located on the University of Missouri campus in Columbia, MO and consists of 44 separate plots with each plot's area (except plot 24) consisting of approximately 1/14 of an acre (.29ha) and measures 100.5ft by 31 ft (30.55 meters by 9.42 meter). Plot 24 is half as long as the other plots because the north half contains an automated weather station. A layout of the field can be seen on the plot plan diagram on the next page of the report. Plots numbered 1-7 and 9-39 are managed in an ongoing either monocrop or rotation crop scheme. Plots 40-44 are used for other research projects, teaching, and demonstration projects. Plot 45 was established to native warm season grass in 1990 and continues presently in this management scheme to assess carbon sequestration.

Sanborn Field is used for four primary uses: 1. Research, 2. Demonstration, 3. Documentation of the Past, and 4. Teaching. The following objectives reflect these uses:

- A. Document soil changes, crop response and nutrient balance under selected crop sequences.
- B. Collect and properly store soil and plant samples for use in the future as a means of identifying effects of environmental changes.
- C. To continue to measure soil changes and crop performance in plots uniformly managed since 1888.
- D. To demonstrate results of interaction that occurs through differential management of the soil-plant-environment continuum.
- E. To serve as an on-campus laboratory for teaching where varied crops grown under different management schemes provide living examples to students.

## Soil Sampling, Fertility Recommendation, and Fertility Applications

Soil sampling procedures set forth by the Second Century Plan call for the collection of soil testing samples every 5 years with the most recent set of samples being pulled in the fall of 2003. Every 25 years (1938, 1962, 1988), deep core samples have been taken from each plot. In 1962 and 1988, these samples were taken according to a systematic plan with the location of each core accurately measured from the permanent plot markers. The next set of deep cores is scheduled to be taken in 2013. All fertility and lime recommendations are made based on guidelines set forth in the Missouri program.

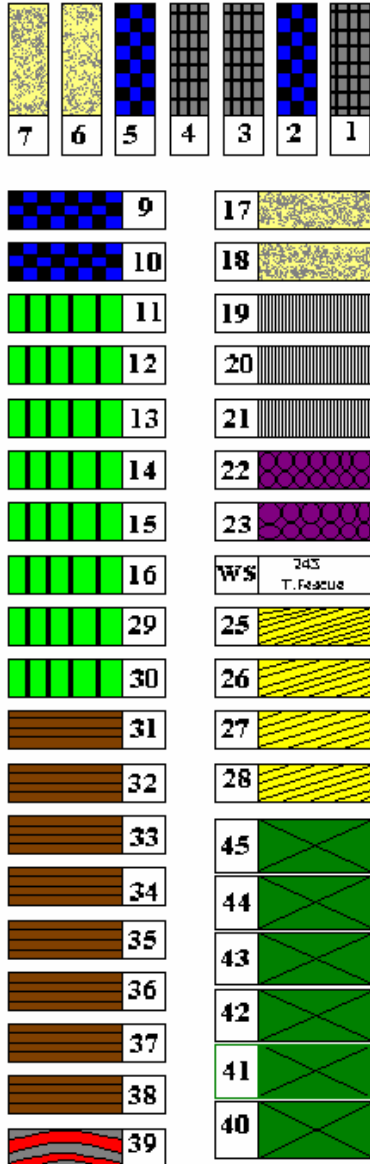
The manure applied to selected plots is sampled and analyzed. The manure used on Sanborn Field is collected from the Foremost Dairy Farm manure solids separated stockpile. Soil moisture of the plots and temperature determines the timing of the manure application. Due to the aroma of the manure and the proximity of the field to residential housing, manure is applied in the winter to forage plots and in tilled plots the manure is applied just prior to a tillage operation.

# Sanborn Field





## 2nd Century Plot Plan

Initiated 1990-1991







← North



### Historical Cropping Systems

-  Continuous Corn  
plot 6 Full Fertility Conventional Tillage  
7 Full Fertility No-tillage  
17 No Fertility  
18 6 Tons Manure/acre per year
-  Continuous Timothy  
plot 22 6 Tons Manure/acre per year  
23 No Fertility
-  Continuous Wheat  
plot 2 Full Fertility  
5 6 Tons Manure/acre per year + Nitrogen  
9 No Fertility  
10 6 Tons Manure/acre per year
-  C-W-RC  
plot 25 6 Tons Manure/acre per year  
26 Full Fertility  
27 No Fertility  
28 Full Fertility minus Nitrogen

### Cropping Systems Initiated in 1990

-  Continuous Soybeans  
plot 39 Full Fertility
-  C-W-RC (since 1950)  
plots 1, 3, & 4
-  GS-SB-W(rc green manure)  
plots 19, 20, & 21-Full Fertility
-  C-SB-W-RC  
plots 11, 13, 16, & 29-Full Fertility  
plots 12, 14, 15, & 30-Full Fertility minus Nitrogen
-  C-SB-W(rc green manure)  
plot 31 Full Fertility  
32 Full Fertility minus Potassium  
33 Full Fertility minus Phosphorus  
34 6 Tons Manure/acre per year  
35 No Fertility  
36 Full Fertility (clover omitted)  
37 Full Fertility  
38 Full Fertility
-  Research, Teaching, and Demonstration  
plots 24S (tall fescue), 40, 41, 42, 43, & 44 -  
Full Fertility  
45 (warm season grass) - Burn Only

WS-Weather Station

### *Weather*

The effects of weather conditions on growth and development of non-irrigated agriculture crops in Missouri plays a major roll. The weather data that is presented in Table 1 was collected from a weather station located on Plot 24 on Sanborn Field. In 1994, an automatic weather station was placed on the north half of plot 24. In 2003 the weather station was updated to allow for real time weather information to be obtained. This information is feed back to computer on campus and is available for viewing on the web at [aes.missouri.edu/sanborn/weather/sanreal.stm](http://aes.missouri.edu/sanborn/weather/sanreal.stm).

**Table 1. Temperature and precipitation data measured on Sanborn Field in 2005-06.**

Month	Maximum Temp. Avg.		Minimum Temp. Avg.		Precipitation Totals	
	2005/06	30 year	2005/06	30 year	2005/06	30 year
2005	F	F	F	F	inches	inches
September	82.5	79.2	62.4	56.7	5.33	3.26
October	67.6	67.2	47.9	45.1	2.65	3.34
November	57.8	53.3	38.2	34.4	1.33	3.23
December	38.4	40.9	25	23.8	0.75	2.24
2006						
January	50.6	37.3	33.1	20.1	1.83	1.78
February	45.1	43.0	24.1	24.1	0.06	2.17
March	56.6	54.4	36.8	33.7	3.11	2.73
April	73.4	66.0	50.4	44.3	2.06	4.27
May	75.4	74.5	56.4	53.9	2.47	5.19
June	85	82.8	64.6	62.6	4.9	4.35
July	92	88.7	70.6	67.7	2.69	3.88
August	91	87.2	69.2	65.4	4.23	4.41
September	77.3	78.7	56	56.2	0.57	3.21
October	64.3	67.2	43.8	45.3	3.22	3.08
November	56.9	53.6	38.7	35.1	2.31	3.42
December	47.9	41.6	31.5	24.5	1.42	2.22
Total or avg.	68.0	64.6	47.9	44.4	28.9	40.7

## Cropping Systems

### Continuous Wheat: Plots 2, 5, 9, and 10

Continuous wheat has been grown on Sanborn Field since the fall of 1888. The management of each of these plots is the same except for differences in the fertility treatments. These treatment consist of plot 2 receiving full fertility treatments, plot 9 with no treatment, plot 10 with 6 tons/acre applied annually and plot 5 having manure applied at a rate of 6 tons/acre plus 40# of N to the acre with ammonia nitrate (34-0-0) being the source. Yield results for the continuous wheat plots can be seen in Table 2.

**Table 2-Harvest data of winter wheat from plots 2, 5, 9, and 10 on Sanborn Field in 2006.**

Plot	Treatments	2006 Yield	2006 Yield	Average Yields	Average Yields
		Bushels/ Acre	Kilograms/ Hectare	1976-2006 Bushels/Acre	1976-2006 Kg/Ha
2	Full Fertility	13.5	907	26.9	1807
5	Manure + N	13	873	26.5	1781
9	None	8.4	564	9.8	658
10	Manure	3.6	242	30.4	2043

### Continuous Corn: Plots 6, 7, 17, and 18

Historic plots 17 and 18 have been in continuous corn since 1889. The treatments for plots 17 and 18 are no fertility applications and 6 tons of manure per acre, respectively. Plots 6 and 7 have been in continuous corn since 1950 and both have received full fertility treatments based on yield goal and soil test. Plot 7 was established in 1971 as a no-till plot. Yield data from the continuous corn plots can be found in Table 3.

**Table 3-Harvest data of corn from plots 6, 7, 17, and 18 on Sanborn Field in 2006.**

Plot	Treatments	2006 Yield	2006 Yield	Average Yields	Average Yields
		Bushels/ Acre	Kilograms/ Hectare	1976-2006 Bushels/Acre	1976-2006 Kg/Ha
6	Full Fertility	96.6	3656	106.8	6654
7	Full Fertility	88.1	3512	91.8	5807
17	None	11.3	608	12.1	734
18	Manure	41.4	3129	53.9	3349

### Continuous Soybean: Plot 39

In 1990 the Second Century Plan outlined that plot 39 would be in continuous soybean production. The reasoning for looking at such a system is to assess the changes in weed, insect, and disease pressures compared to soybean production in a rotation. This plot does receive a full fertility treatment. This plot yielded 26.4 bushels per acre (1774 kg/ha) in 2006.

### Continuous Forages: Plots 22, 23, 24, and 45

The objectives of the continuous forage crops were to continue the treatments and management of the historical timothy plots (22 and 23) and to demonstrate alternative forages for teaching purposes (24S and 45). Timothy has been grown continuously on plot 22 and 23 since 1888. Plot 22 has received 6-tons of manure per acre annually and plot 23 has received no additional fertilizer applications. Periodic reseeding is required on these historical plots due to stand decline and weed encroachment. The tall fescue in plot 24 south (24S) is used for demonstration purposes. The reason this plot is designated as south is because the north half of this plot contains the Sanborn Field weather station. Yield results for plots 23, 24, and 25 can be found in Table 4.

**Table 4. Harvest data from the continuous forage crops on Sanborn Field in 2006.**

Plot	Crop	Treatment	2006 Forage Yields	2006 Forage Yields	Average* Forage Yields	Average* Forage Yields
			Tons/Acre	Kg/Hectare	Tons/Acre	Kg/Hectare
22	Timothy	Manure	3.44	7705.6	3.11	6966.4
23	Timothy	None	2.93	6563.2	1.5	3360
24	Tall Fescue	Full Fertility	4.72	10572.8	4.21	9430.4
*Averages for plots 22, 23, 24 are based data from 1991-2006.						

### Three-Year Rotation (Corn-Wheat/rc-Red Clover): Plots 1, 3, 4, 25, 26, 27, and 28

The historic rotation plots 25, 26, 27, and 28 were initiated in 1888, whereas plots 1, 3, and 4 were started in 1950. The treatments for the plots is as follows: plots 1, 3, 4, and 26 receive full fertility, plot 25 receives 6 tons of manure per acre annually, plots 28 receives full fertility minus the additions of nitrogen, and plot 27 has no additional fertilizer added. The treatment on plot 28 was started in 1990 to evaluate the relative nitrogen contributions from the red clover in the rotation. Yield data for this three-year rotation can be seen in Table 5.

**Table 5. Harvest data from the corn-wheat/rc-red clover rotation on Sanborn Field in 2006.**

Plots	Treatment	2006 Crop	Yield							
			2006 Grain	2006 Grain	2006 Forage	2006 Forage	Average*			
			Bu/ acre	Kg/ ha	Tons/ acre	Kg/ ha	Grain		Forage	
						Bu/ acre	Kg/ ha	Tons/ acre	Kg/ ha	
1	Full	Red Clover			5.62	12589			3.6	8064
3	Full	Corn	88.3	5537			110.4	6923		
4	Full	Wheat/RC	45.7	3071	2.18	4883	49.8	3346	1.8	4032
25	Manure	Corn	96	6020			110.9	6955		
26	Full	Corn	59.8	3750			117.3	7356		
27	None	Corn	31.8	1994			73.3	4597		
28	Full-N	Corn	110	6911			97.4	6108		
*Average is based on the past 4 times that particular plot was in the same crop as the year 2003										
Bu/acre = Bushels/Acre    Full=Full Fertility Treatment    Full-N=Full Fertility minus Nitrogen Treatment										

**Three-Year Rotation (Grain Sorghum-Soybeans-Wheat (rc): Plots 19, 20, and 21**

This rotation was started in 1990 with the Second Century Plan. The objective of these plots is to obtain soil and crop data for a comparison to like rotations that use corn instead of grain sorghum.

Bird cages were built with chicken wire to keep the birds from the yield strips in the grain sorghum plot and in 2004 the cages were modified with a smaller mesh bird netting to remedy the problems that occurred in the past. Yields for this three year rotation can be found in Table 6.

**Table 6. Harvest data form the grain sorghum-soybean-wheat (rc) rotation on Sanborn Field in 2006.**

Plots	Treatment	2006 Crop	Yields			
			2006 Grain	2006 Grain	Average*	
			Bu/Acre	Kg/Ha	Bu/Acre	Kg/Ha
19	Full Fertility	Grain Sorghum			119.1	
20	Full Fertility	Wheat/(red clover)	63.8	4287	44.7	3003
21	Full Fertility	Soybeans	25.9	1740	44	2956
*Average is based on the past 4 times that the particular plot was in the same crop as it was in 2006.						
Bu/Acre=Bushels/Acre    (red clover) is plowed down and no harvest yields are taken						

### Three-Year Rotation (Corn-Soybeans-Wheat (rc): Plots 31, 32, 33, 34, 35, 36, 37, and 38

This set of plots provides many different treatments for comparisons. All plots in the rotation except for plot 36 utilize a frost seeded red clover/lespedeza mix as a fall plow-down to supply part of the nitrogen to the proceeding crop. A lay out of the plot design is as follows:

<u>Plot</u>	<u>Treatment</u>
31, 37, 38	Full fertility treatments
32	Full fertility treatments minus the additions of potassium
33	Full fertility treatment minus the additions of phosphorus
34	Manure applied at a rate of 6 tons per acre per year
35	No treatment
36	Full fertility treatments minus the red clover/lespedeza plow-down

Yields for this three-year rotation can be seen in Table 7.

**Table 7. Harvest data form the corn-soybean-wheat (rc) rotation on Sanborn Field in 2006.**

Plots	Treatment	2006 Crop	Yields			
			2006 Grain Bu/Acre	2006 Grain Kg/Ha	Average* Grain Bu/acre	Average* Grain Kg/Ha
31	Full	Corn	105.1	6591	110.8	6945
32	Full-K	Corn	84.6	5305	103.2	6470
33	Full-P	Corn	46.0	2885	99.4	6232
34	Manure	Corn	87.9	5512	111.3	6980
35	None	Corn	61.7	3869	88.6	5558
36	Full-(rc)	Corn	99.9	6265	88.9	5575
37	Full	Soybeans	20.3	1364	33.5	2249
38	Full	Wheat/(red clover)	56.8	3816	44.6	2995
*Average is based on the past 4 times that particular plot was in the same crop as the year 2006.						
Bu/acre = Bushels/Acre						
(red clover) is plowed down and no harvest yields are taken						

### Four-Year Rotation (Corn-Soybeans-Wheat/rc-Red Clover): Plots 11, 12, 13, 14, 15, 16, 29, and 30

The main objective in this four-year rotation is to measure the impact of using no additional fertilizer nitrogen versus nitrogen application. Plots 11, 13, 26, and 29 all receive fertilizer nitrogen and plots 12, 14, 15, and 30 do not receive any additional nitrogen. All the plots in this series receive full fertility application of fertilizer except the nitrogen which was stated earlier. Harvest data for this set of plots can be seen in Table 8.

**Table 8. Harvest data from the corn-soybeans-wheat/rc-red clover rotation on Sanborn Field in 2006.**

Plots	Treatment	2006 Crop	2006 Grain Bu/ acre	2006 Grain Kg/ Ha	2006 Forage tons/ acre	2006 Forage Kg/ Ha	Average*			
							Grain Bu/ acre	Grain Kg/ Ha	Forage tons/ acre	Forage Kg/ Ha
11	Full Fertility	Red Clover			6.02	13484.8			3.73	8355.2
12	Full Fertility- N	Red Clover			6.1	13664			4.41	9878.4
13	Full Fertility	Corn	103.6	6496.76			133.5	8372		
14	Full Fertility- N	Corn	104.9	6578.28			119.1	7469		
15	Full Fertility- N	Soybeans	24.5	1646.16			38.1	2557		
16	Full Fertility	Soybeans	22.1	1484.9			37.3	2505		
29	Full Fertility	Wheat/Red Clover	68.6	4609.23	2.25	5040	57.2	3841	2.79	6242.13
30	Full Fertility- N	Wheat/Red Clover	56.9	3823.11	2.1	4704	43.0	2891	2.12	4756.27
*Average is based on the past 3 times that particular plot was in the same crop as the year 2006.										
Bu/Acre = Bushels/Acre										
N/A=Not Applicable-no yields were taken										

# **Agricultural Lime**

# **Final Report**

## **The Influence of Liming Acid Soils on Plant Available Phosphorus, Magnesium, and Aluminum Levels in Tall Fescue**

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### **Progress for 2006/Final Report**

#### **INTRODUCTION**

The objectives of this study were to determine: 1.) the influence of calcitic and dolomitic aglime of the release and uptake of “fixed” phosphorus for use by tall fescue and, 2.) the influence of these liming materials on the availability and uptake of magnesium and aluminum for tall fescue. This project was initiated in the late summer and early fall of 2004 with the selection of field plots at the Southwest Research Center (SWC) at Mt. Vernon and the Bradford Research and Extension Center (BREC) in Columbia. The soil resource at the SWC is a Gerald (fine, mesic, active, Aeric Fraguaqualf) while the soil resource supporting the research plots at BREC is the Mexico (fine, smectitic, mesic Aeric Vertic Epiaqualf). Plots 10 ft by 25 ft with 10 ft borders were utilized at each location with each treatment being replicated 6 times. Limestone treatments which were applied in 2004 at each location were calcitic and dolomitic limestone applied at 0, 0.5X, 1.0X, and 2.0X relative to soil test recommendations. Collared leaves were initially sampled in January 2005 and then monthly through April for analysis of calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P), and aluminum (Al) content. Additionally, forage harvests were performed in May and August at each location. Leaf samples were harvested again beginning in October 2005 and continued through April 2006. Also soil tests were conducted on the limed plots 19 months after initiation of liming.

#### **ACCOMPLISHMENTS**

Forage yield data for the 2005 and 2006 seasons are provided in Figures 1 through 6. The two year total forage yield was increased by both limestone applications at the SWC, but no consistent trend was observed at BREC. The response to increased limestone appeared to be more apparent in the May harvest rather than the August harvest.

With liming, leaf K, nitrogen (N), boron (B), and manganese (Mn) concentrations decreased, whereas leaf Ca (Figure 7), molybdenum (Mo), and sodium (Na) concentrations increased. Leaf P (Figures 8-11), Al, iron (Fe), Zinc (Zn), and copper (Cu) concentrations remained relatively unaltered. As a result of the consistent leaf P concentrations with liming, the long-term benefit to the producer may be increased by fertilizer P applied after the liming treatment rather than by the increased availability of residual soil P. Leaf Mg concentrations (Figures 12-13) decreased with calcitic limestone applications, but increased with the application of dolomitic limestone. Limestone treatments had little influence on leaf Al concentrations. The resultant leaf K, Mg, and Ca concentrations (Figures 14-15) provided a reduction in the grass tetany ratio of tall fescue leaves by liming could provide a lesser incident of grass tetany in the beef cow.

In general, changes in leaf concentrations on mineral elements reflected those in soil test values 19 months after liming. Soil pH-salt values were increased while neutralizable acidity (Figures 16-19),

exchangeable K, and extractable Mn decreased with increasing limestone application. The addition of calcitic limestone increased soil test Ca with little influence on soil test Mg; whereas, dolomitic limestone applications increased soil test Mg with lesser increases in soil test Ca. Soil organic matter (Figures 20 and 21); Bray P-I; Bray P-II; Zn; Cu; and Fe values were not increased by increased limestone application.

This study resulted in an M.S. thesis by Elizabeth Hamilton titled “Elemental Concentration Changes in Soil and Stockpiles Tall Fescue Leaves After Liming” (December 2006). A copy of this thesis will be supplied by CD to the Director of the Fertilizer/Ag Lime Control Services. A presentation on this topic related to the influence on grass tetany was presented at the 2006 SWC Field Day by Elizabeth Hamilton. Additionally, an oral presentation by Elizabeth Hamilton (Hamilton, et. al. 2006) was presented at the 2006 American Society of Agronomy meeting in Indianapolis. Currently two research manuscripts are being written from two of the chapters from the M.S. thesis for submission to the refereed journal, Plant & Soil.

Work over the next three months on soil Al will continue to elucidate the types of extractable Al available by treatment. Extractions have been performed with analysis to be completed in the near future.

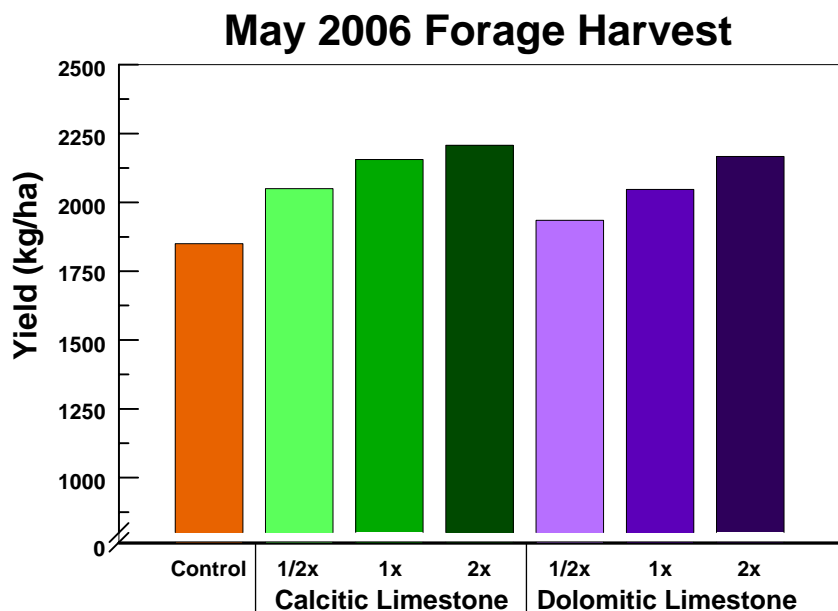


Figure 1. May 2006 forage harvest of tall fescue treated with 0x, 1/2x, 1x, and 2x the recommended rate of dolomitic and calcitic limestone at SWC. Means (n=6). LSD (P<0.05) = 290.30 for comparing treatments.

## August 2006 Forage Harvest

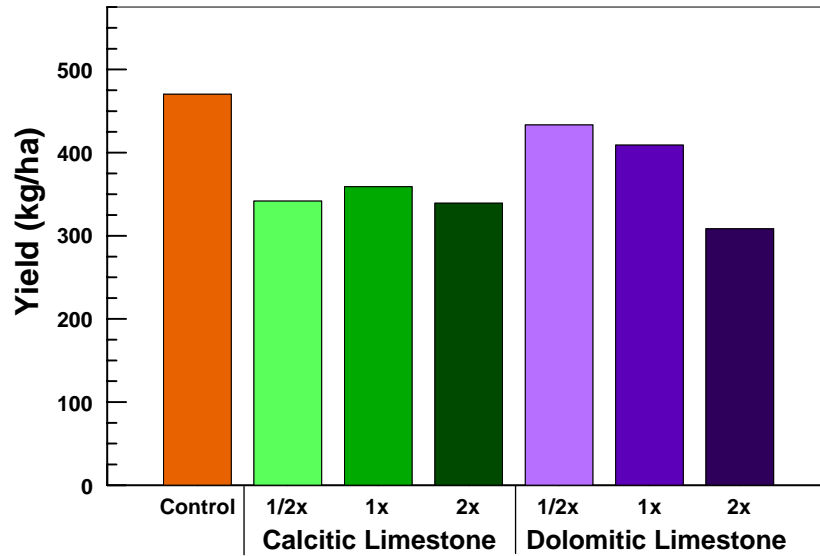


Figure 2. August 2006 harvest of tall fescue treated with 0x, 1/2x, 1x, and 2x the recommended rate of dolomitic and calcitic limestone at SWC. Means (n=6). LSD (P<0.05) = 91.18 for comparing treatments.

## Two Year Total Forage Harvest

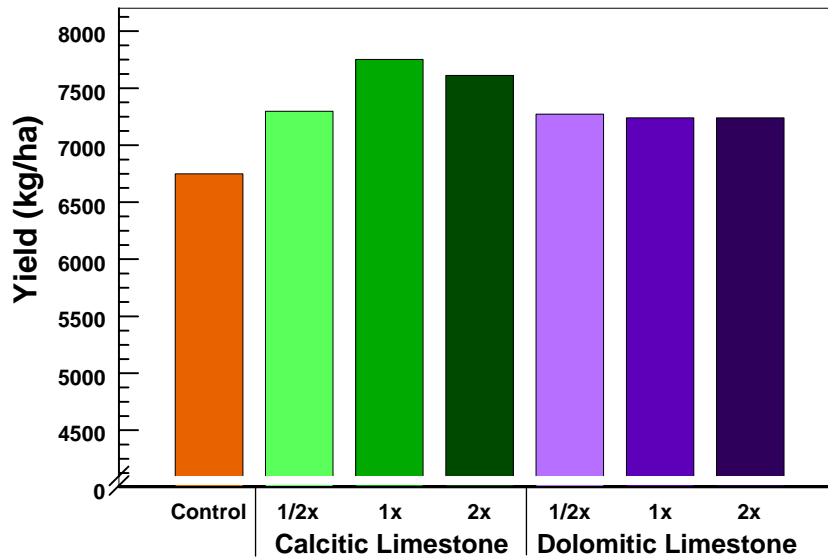


Figure 3. Two year total forage harvest of tall fescue treated with 0x, 1/2x, 1x, and 2x the recommended rate of dolomitic and calcitic limestone at SWC. Means (n=6). LSD (P<0.05) = 602.58 for comparing treatments.

### May 2006 Forage Harvest

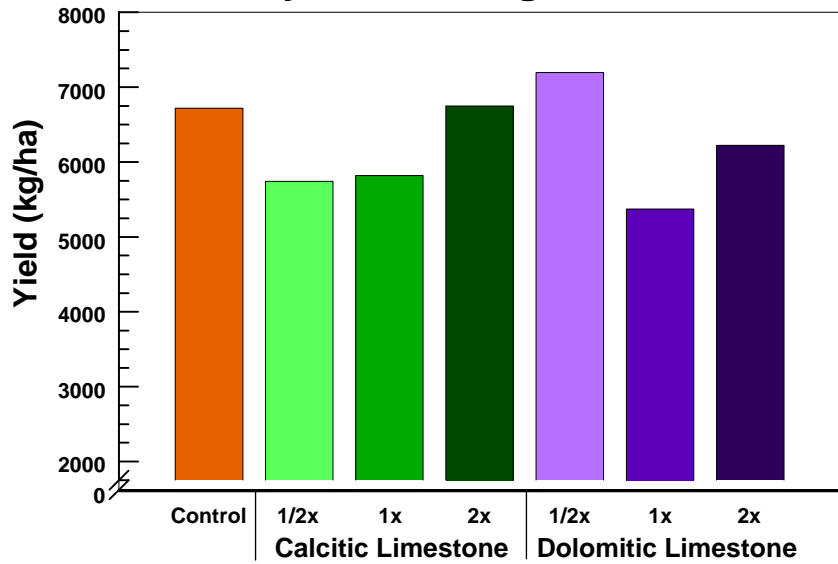


Figure 4. May 2006 forage harvest of tall fescue treated with 0x, 1/2x, 1x, and 2x the recommended rate of dolomitic and calcitic limestone at BREC. Means (n=6). LSD (P<0.05) = 1209.23 for comparing treatments.

### August 2006 Forage Harvest

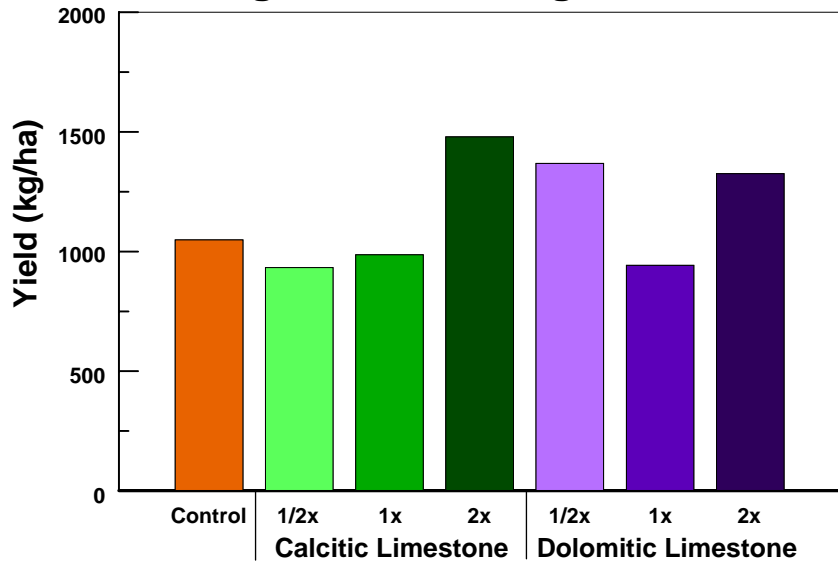
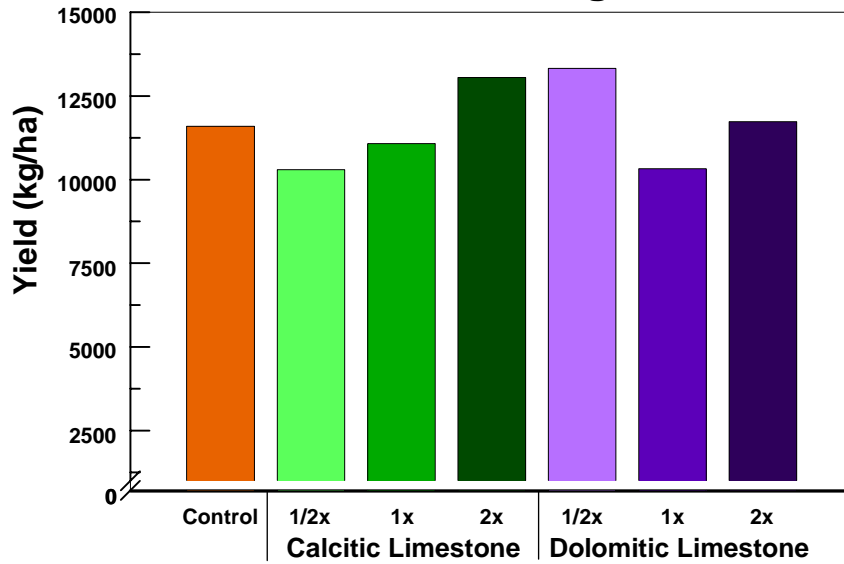


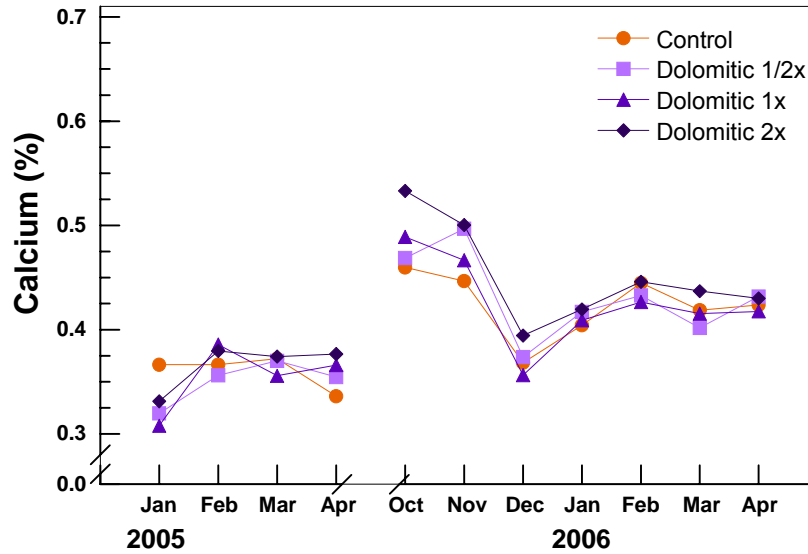
Figure 5. August 2006 forage harvest of tall fescue treated with 0x, 1/2x, 1x, and 2x the recommended rate of dolomitic and calcitic limestone at BREC. Means (n=6). LSD (P<0.05) = 419.87 for comparing treatments.

## Two Year Total Forage Harvest



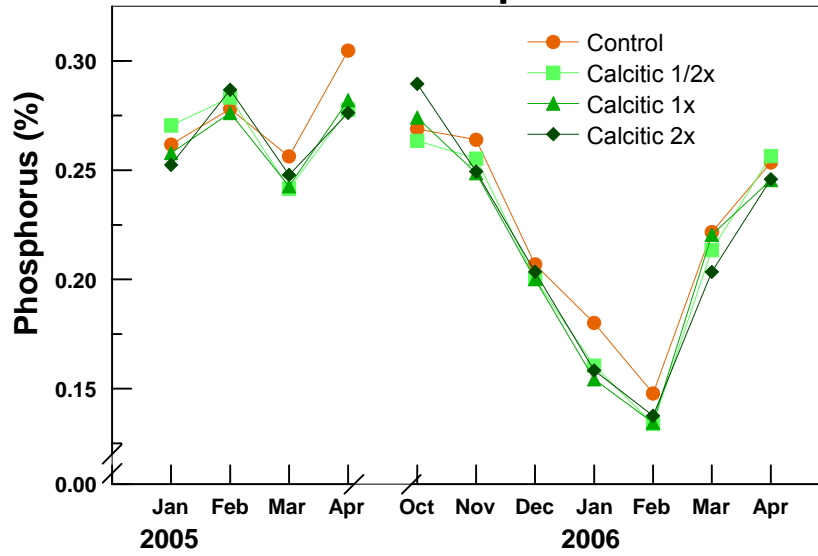
**Figure 6** Two year total forage harvest of tall fescue treated with 0x, 1/2x, 1x, and 2x the recommended rate of dolomitic and calcitic limestone at BREC. Means (n=6). LSD (P<0.05) = 1867.90 for comparing treatments.

## Leaf Calcium



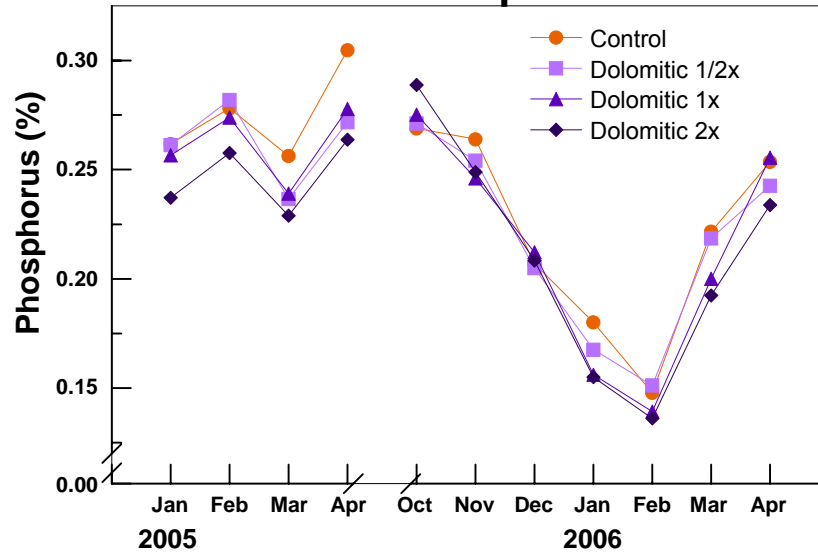
**Figure 7.** Calcium concentrations in stockpiled tall fescue leaves harvested monthly from plots treated with 0x, 1/2x, 1x, and 2x the recommended rate of dolomitic limestone at SWC. Means (n=6). LSD (P<0.05) = 0.043 for comparing treatments within a month and LSD (P<0.05) = 0.016 for comparing months within the same treatment.

## Leaf Phosphorus

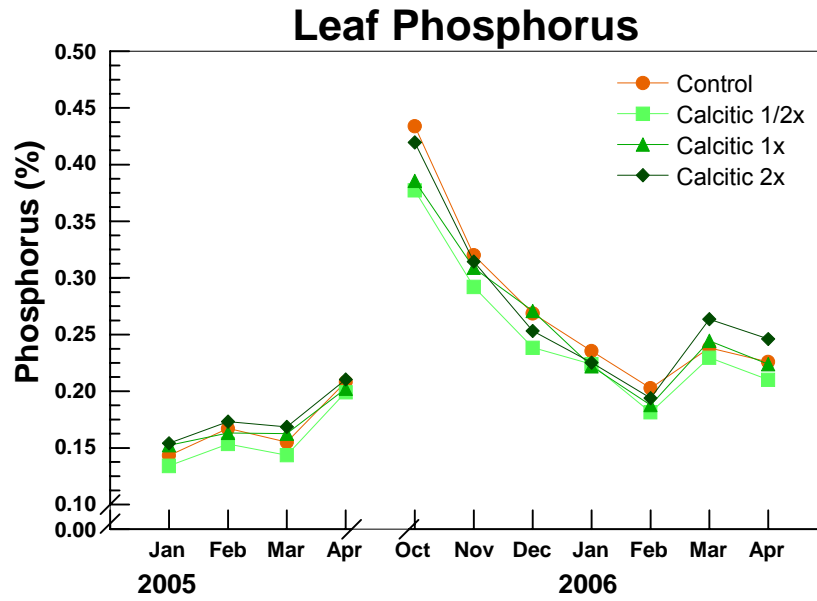


**Figure 8** Phosphorus concentrations in stockpiled tall fescue leaves harvested monthly from plots treated with 0x, 1/2x, 1x, and 2x the recommended rate of calcitic limestone at SWC. Means (n=6). LSD (P<0.05) = 0.022 for comparing treatments within a month and LSD (P<0.05) = 0.008 for comparing months within the same treatment.

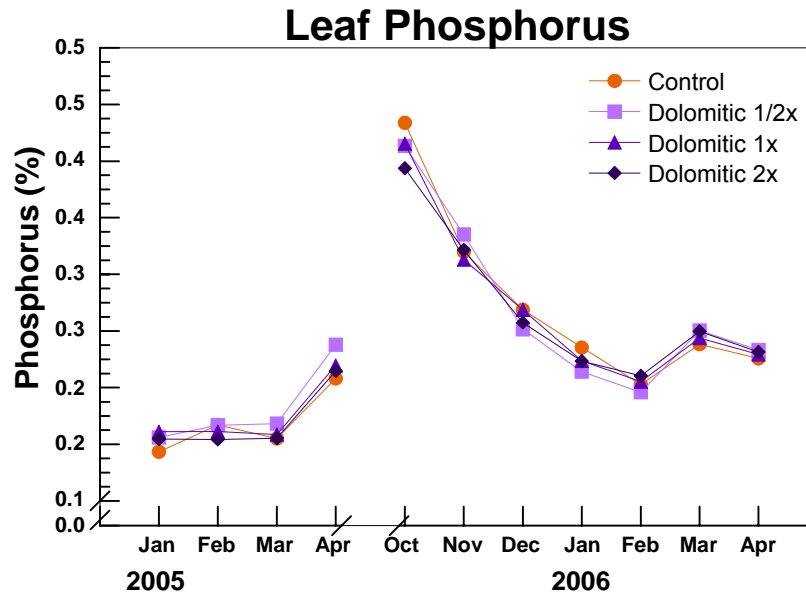
## Leaf Phosphorus



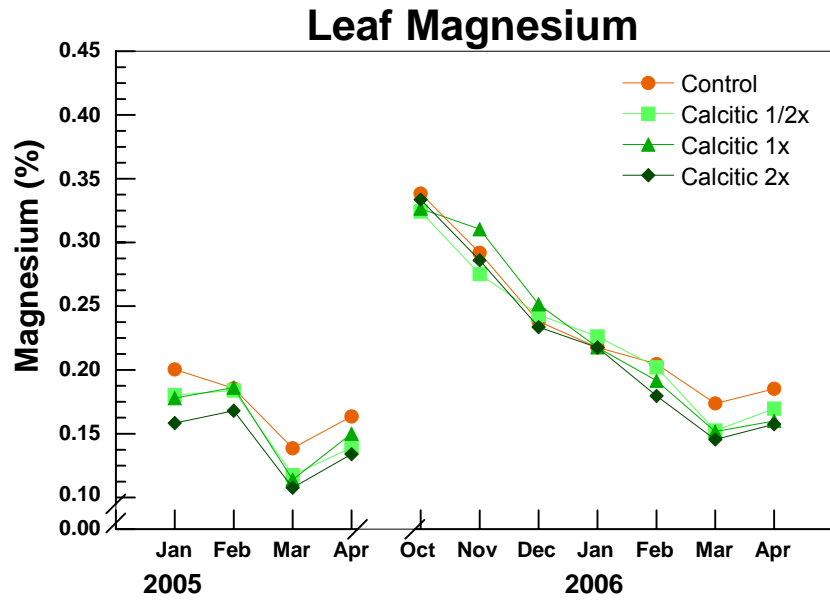
**Figure 9** Phosphorus concentrations in stockpiled tall fescue leaves harvested monthly from plots treated with 0x, 1/2x, 1x, and 2x the recommended rate of dolomitic limestone at SWC. Means (n=6). LSD (P<0.05) = 0.022 for comparing treatments within a month and LSD (P<0.05) = 0.008 for comparing months within the same treatment.



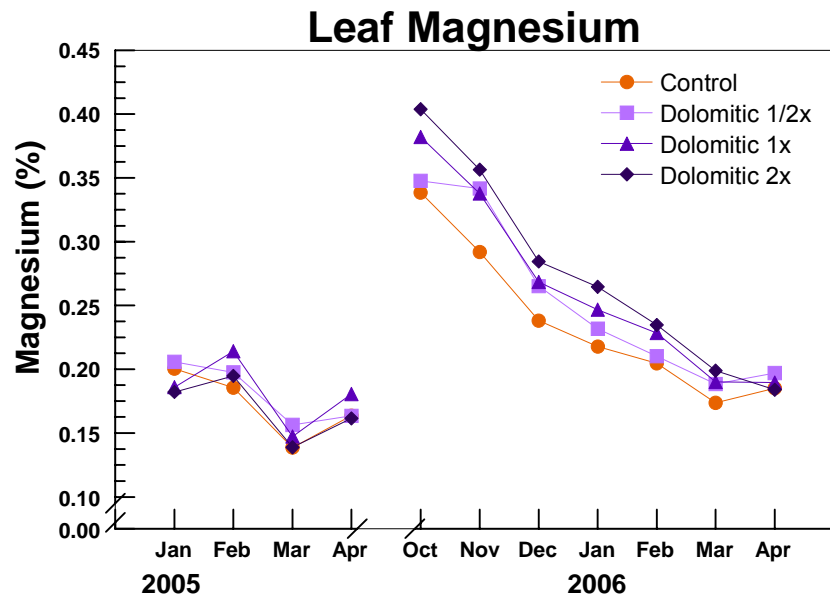
**Figure 10.** Phosphorus concentrations in stockpiled tall fescue leaves harvested monthly from plots treated with 0x, 1/2x, 1x, and 2x the recommended rate of calcitic limestone at BREC. Means (n=6). LSD (P<0.05) = 0.034 for comparing treatments within a month and LSD (P<0.05) = 0.010 for comparing months within the same treatment.



**Figure 11.** Phosphorus concentrations in stockpiled tall fescue leaves harvested monthly from plots treated with 0x, 1/2x, 1x, and 2x the recommended rate of dolomitic limestone at BREC. Means (n=6). LSD (P<0.05) = 0.034 for comparing treatments within a month and LSD (P<0.05) = 0.010 for comparing months within the same treatment.



**Figure 12.** Magnesium concentrations in stockpiled tall fescue leaves harvested monthly from plots treated with 0x, 1/2x, 1x, and 2x the recommended rate of calcitic limestone at SWC. Means (n=6). LSD (P<0.05) = 0.021 for comparing treatments within a month and LSD (P<0.05) = 0.007 for comparing months within the same treatment.



**Figure 13.** Magnesium concentrations in stockpiled tall fescue leaves harvested monthly from plots treated with 0x, 1/2x, 1x, and 2x the recommended rate of dolomitic limestone at SWC. Means (n=6). LSD (P<0.05) = 0.021 for comparing treatments within a month and LSD (P<0.05) = 0.007 for comparing months within the same treatment.

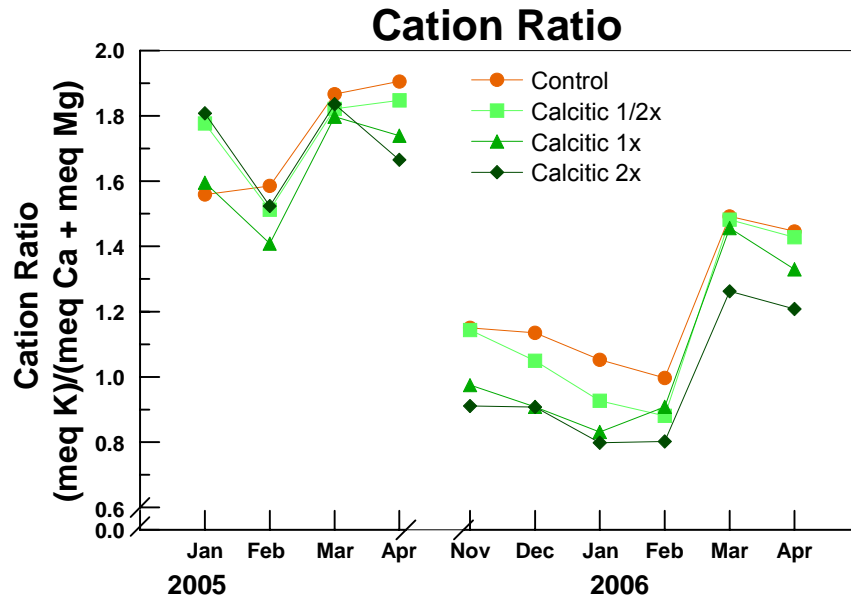


Figure 14. Cation ratio of stockpiled tall fescue leaves harvested monthly from plots treated with 0x, 1/2x, 1x, and 2x the recommended rate of calcitic limestone at SWC. Means.

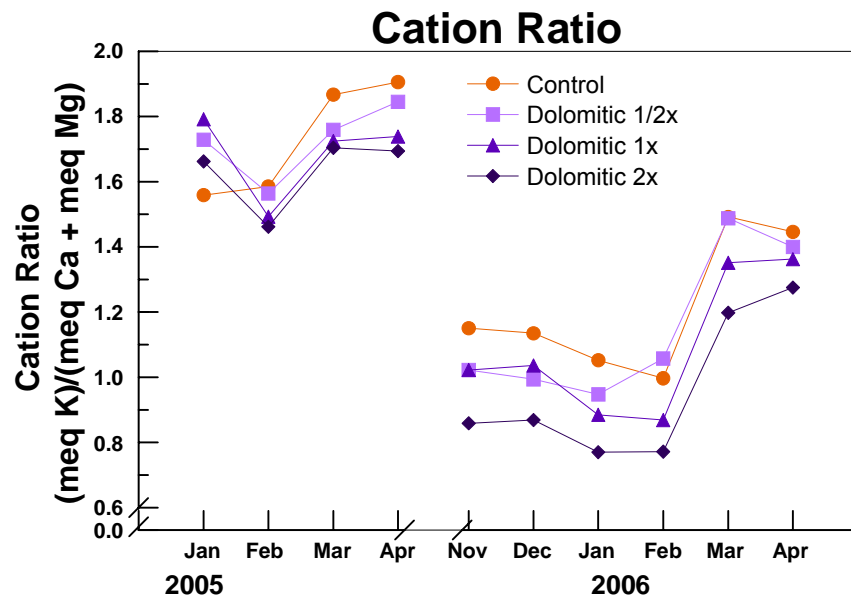


Figure 15. Cation ratio of stockpiled tall fescue leaves harvested monthly from plots treated with 0x, 1/2x, 1x, and 2x the recommended rate of dolomitic limestone at SWC. Means.

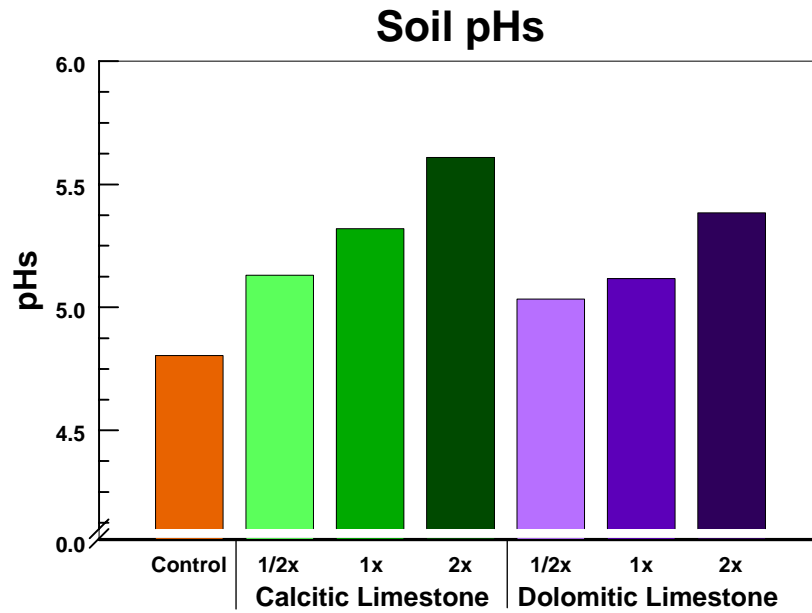


Figure 16. Soil pHs 19 months after application of 0x, 1/2x, 1x, and 2x the recommended rate of calcitic and dolomitic limestone at SWC. Means (n=6). LSD (P<0.05) = 0.202 for comparing treatments.

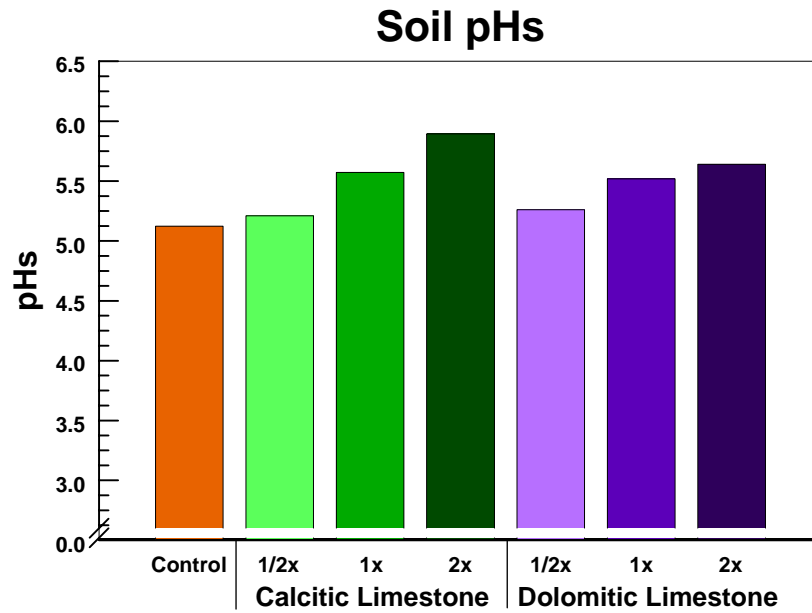


Figure 17. Soil pHs 19 months after application of 0x, 1/2x, 1x, and 2x the recommended rate of calcitic and dolomitic limestone at BREC. Means (n=6). LSD (P<0.05) = 0.131 for comparing treatments.

### Soil Neutralizable Acidity

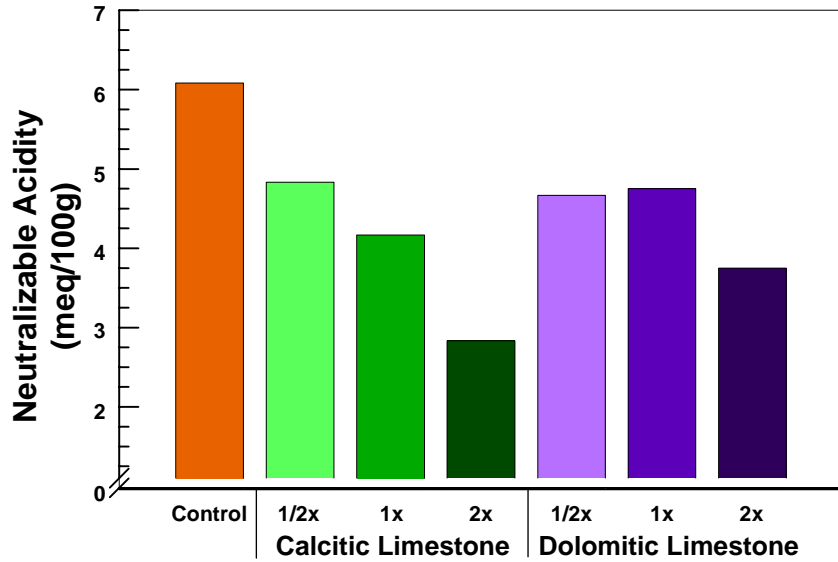


Figure 18. Soil neutralizable acidity 19 months after application of 0x, 1/2x, 1x, and 2x the recommended rate of calcitic and dolomitic limestone at SWC. Means (n=6). LSD (P<0.05) = 0.848 for comparing treatments.

### Soil Neutralizable Acidity

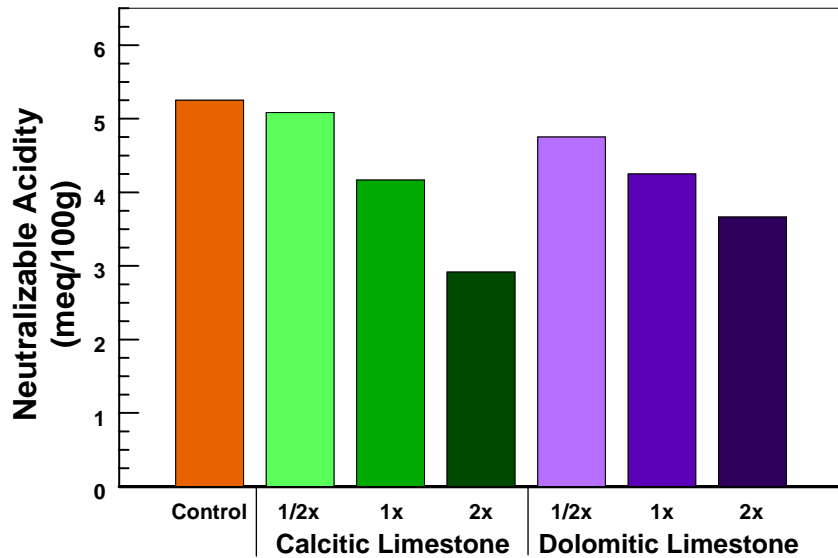
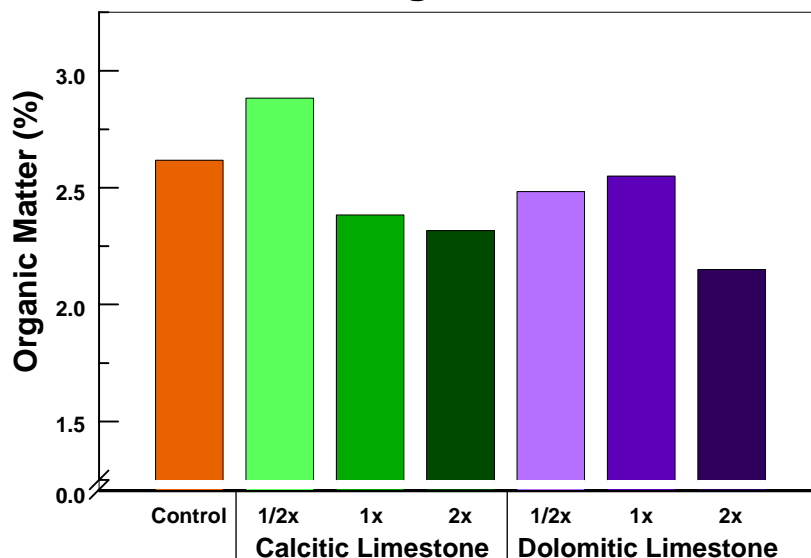


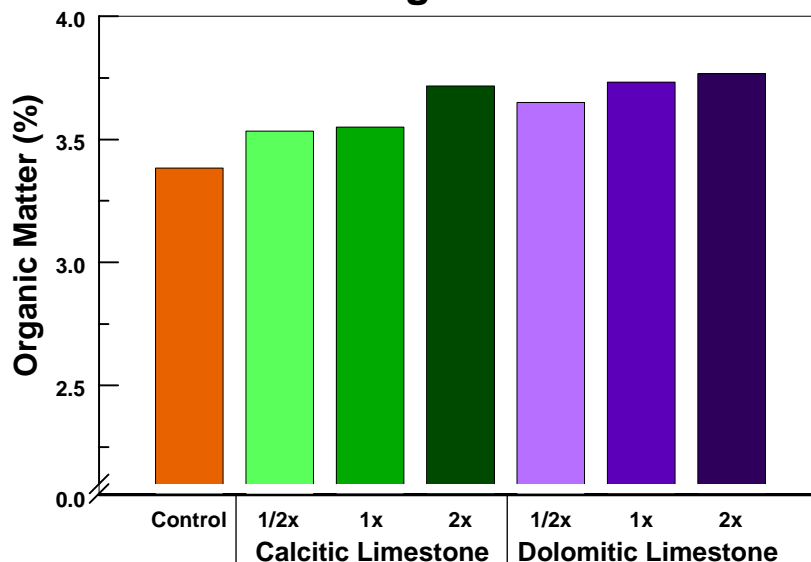
Figure 19. Soil neutralizable acidity 19 months after application of 0x, 1/2x, 1x, and 2x the recommended rate of calcitic and dolomitic limestone at BREC. Means (n=6). LSD (P<0.05) = 0.587 for comparing treatments.

## Soil Organic Matter



**Figure 20** Soil organic matter content 19 months after application of 0x, 1/2x, 1x, and 2x the recommended rate of calcitic and dolomitic limestone at SWC. Organic matter is 58% carbon. Means (n=6). LSD (P<0.05) = 0.410 for comparing treatments.

## Soil Organic Matter



**Figure 21.** Soil organic matter content 19 months after application of 0x, 1/2x, 1x, and 2x the recommended rate of calcitic and dolomitic limestone at BREC. Organic matter is 58% carbon. Means (n=6). LSD (P<0.05) = 0.347 for comparing treatments.

## LITERATURE CITED

1. Hamilton, Elizabeth, Dale Blevins, and Randall Miles. 2006. Liming Stockpiled Tall Fescue Changed Macro- and Micronutrient Concentrations. Agronomy Abstracts, p. 61.

## **Progress Reports**

### **The Influence of Calcitic and Dolomitic Lime and Phosphorus on Species Composition in Tall Fescue Pastures**

**R.J. Miles and D.G. Blevins, Co-PI's  
E.J. Hamilton and Will McClain, Graduate Student**

**Progress for 2006-Year 2**

#### **INTRODUCTION**

The objective of this study is to ascertain the effect that lime and phosphorus (P) has on the species composition in tall fescue pastures. This project was initiated during the summer of 2005 with the selection of field plots at the Southwest Research Center (SWC) at Mt. Vernon. An established tall fescue stand with a diverse plant community was selected for the study. The soil resource in the plot area is primarily the Gerald (fine, mesic, active, Aeric Fragiaqualf) with some inclusions of the Creldon silt loam (fine, mixed, mesic Oxyaquic Fragiudalf). Plots 10 ft by 25 ft with 10 ft borders were utilized with each treatment being replicated 6 times. Original selected soil test values were as follows: neutralizable acid=5.2 meq/100g; pHs of 4.6; and Bray P-I of 6 lbs/A. Limestone treatments were applied in Fall 2005 with calcitic and dolomitic limestone at 0, 0.5X, 1.0X, and 2.0X relative to soil test recommendations. Additionally, phosphorus (P) treatments of 0 and 50 lbs/A were applied for each aglime treatment. Maintenance potassium (K) was added as called for by soil test value and 100 lbs nitrogen (N)/A was also applied.

Initial species composition assessment of the plot site was reported last year. In summary, the north half of the study area was dominated by tall fescue at slightly greater than 55% cover, followed by sumac, litter, purple top, and eastern gamma grass with less than 5% coverage being broomsedge. The southern sector of the study plots was more diverse with a lesser dominance of tall fescue (slightly less than 30 percent) and much greater coverage of broomsedge followed by sumac, litter, purple top, and western panicgrass.

#### **ACCOMPLISHMENTS**

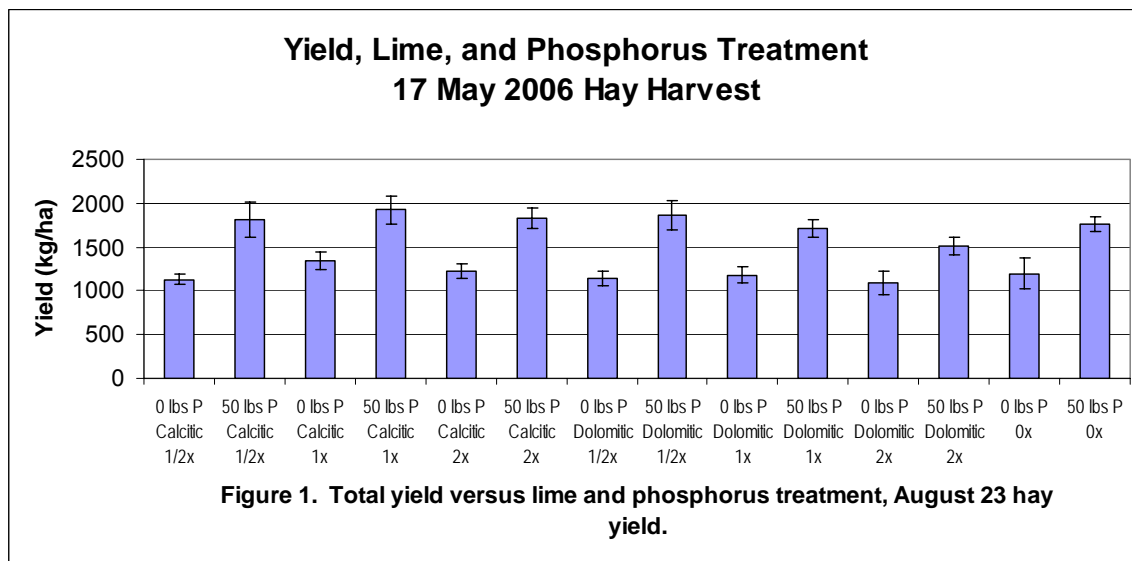
Forage yield data and assessment for 2006 is provided in Figures 1 through 3. The 50 lb P/A increased total dry yield for the May harvest for all liming treatments as well within the control (Figures 1 and 2). This increase can be explained by the plants large need for P in the early portion of the growing season. The response to increased limestone and phosphorus appeared to be more apparent in the May harvest rather than the August harvest as there was little discernable trends in the response to limestone and P additions in August. This lack of a response may partially be explained by the lesser need of plants for P in the later segment of growth cycle. Additionally, the species composition changes over the course of the growing season could contribute to this trend.

Species composition of plots (Figures 4 through 7) reflect an increase in coverage of tall fescue with increasing calcite (except with the 2.0X application) with the addition of fertilizer P; few trends could be

found with dolomite applications. The lack of coverage change for the control aglime treatment with P inputs could indicate the need to increase pH for a positive influence to fertilizer P. In most treatments, the coverage of broomsedge decreased with an increase in fertilizer P for each liming increment (Figure 5). Again, there was no response in coverage with P inputs with 0 lime treatment. Coverage of dewberry tended to decrease in most aglime treatments with fertilizer P. The major exception would be for the two larger dolomitic applications (Figure 6). A slight decrease in dewberry was observed with fertilizer P with no aglime input. Coverage of purple top increased with increased fertilizer P for almost each aglime treatment (Figure 7). Forage quality samples have been collected and prepared for Near-Infrared Analysis. Many of the analysis have been performed, but not summarized. Pictures of the plots have been taken over the growing season.

### OBJECTIVES FOR 2007

The objective of this study for 2007 will be to ascertain the effect of aglime and P additions on species composition in a diverse tall fescue pasture with little management. Species composition will be measured on each of the six replications of every treatment in May and August via a line transect method. In January, March, May, and November forage quality will be assessed by NIR for ADF and NDF. Samples will also be digested for analysis for percent P, K, Ca, and Mg. Additionally, forage harvests will take place in May and August to compare yields. Sequential pictures of the plots will be performed.



### Yield, Lime, and Phosphorus Treatment 17 May 2006 Hay Harvest

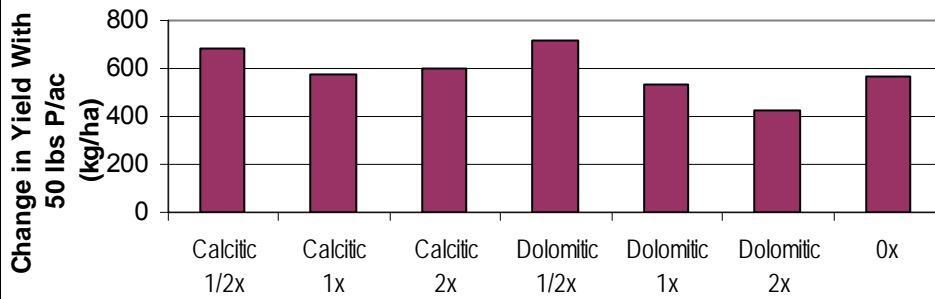


Figure 2. Total change in dry yield versus lime and phosphorus treatment, May 17 hay harvest.

### Yield, Lime, and Phosphorus Treatment 23 August 2006 Hay Harvest

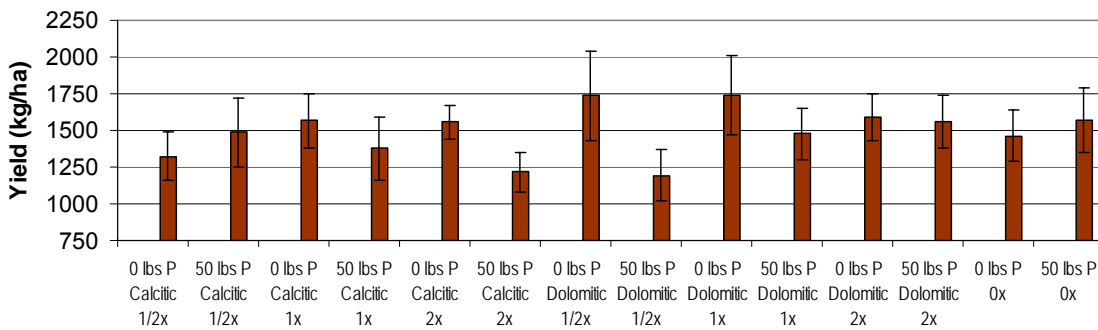


Figure 3. Total yield versus lime and phosphorus treatment, August 23 hay harvest

### % Cover of Tall Fescue

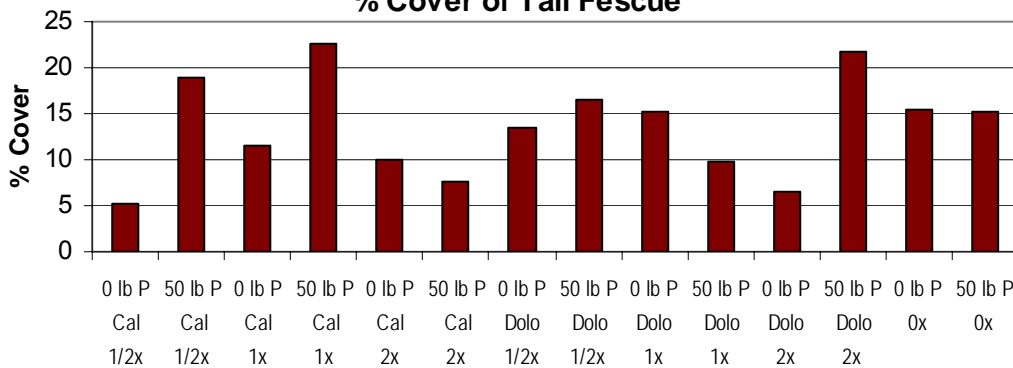
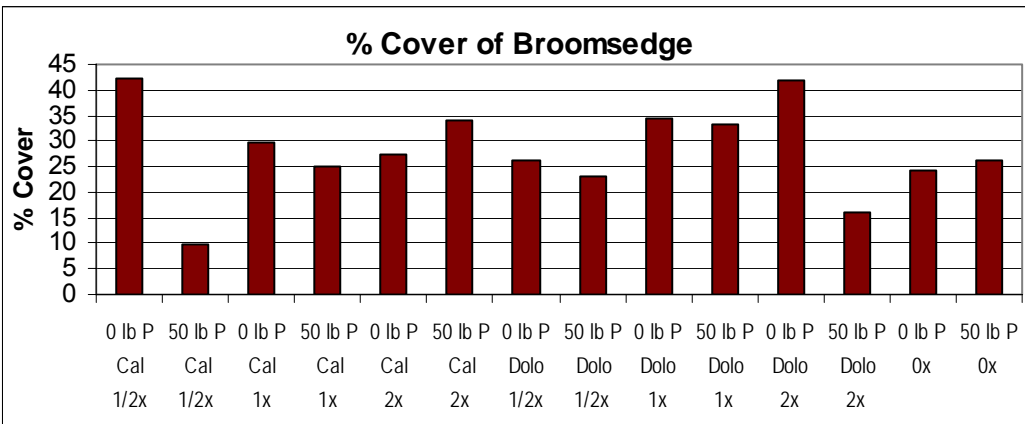
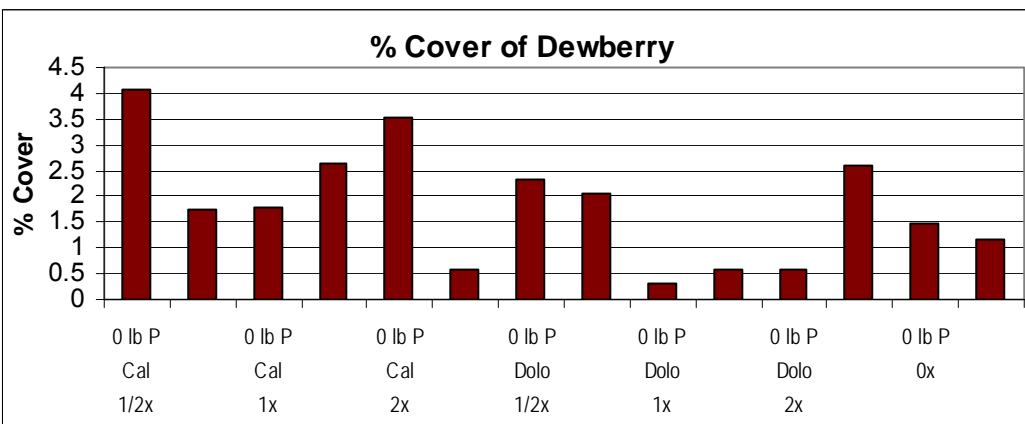


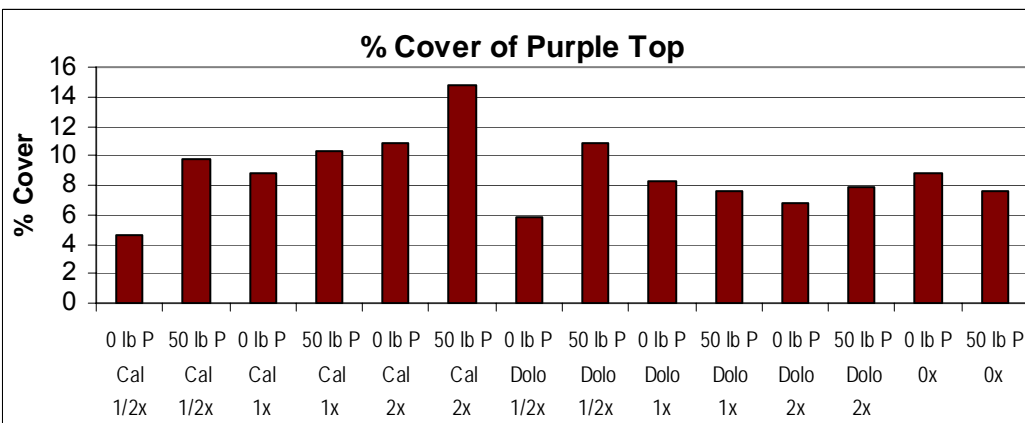
Figure 4. Percentage cover of tall fescue versus lime and phosphorus treatment August 23 hay harvest.



**Figure 5. Percentage cover of broomsedge versus lime and phosphorus treatment August 23 hay harvest.**



**Figure 6. Percentage of Dewberry coverage versus lime and phosphorus treatment August 23 hay harvest.**



**Figure 7. Percentage of purple top coverage versus lime and phosphorus treatment August 23 hay harvest.**

## **Pelletized Lime for Short-Term Treatment of Soil Acidity**

Gene Stevens and David Dunn

University of Missouri-Delta Research Center

Correct soil pH is the cornerstone of a successful crop nutrient management program. Annual applications of nitrogen fertilizers on crops slowly produce acid conditions in fields. If low pH is not corrected by agricultural lime applications, soil acidity will reduce nutrient availability to plants (especially P), produce toxic levels of aluminum and manganese, and diminish the weed control activity of some herbicides.

In recent years, agricultural fertilizer dealers have reported 2 to 3 fold increases in sales of pelletized lime. Pelletized lime is finely ground limestone, which is made into small pellets for broadcasting with conventional fertilizer equipment. Because pelletized lime is relatively expensive per ton, it is applied at lower rates (<300 lbs/acre) as compared to recommended rates of agricultural lime. A “1:10 ratio” rule of thumb has been promoted for comparing the short-term neutralizing effectiveness of pelletized lime to agricultural lime. (Example: if a soil test recommends the ENM equivalent of 2000 lbs of agricultural lime per acre apply 200 lbs of pelletized lime/acre). Most farmers realize that pelletized lime is not a long-term “fix”, but expect it to reduce soil acidity to tolerable levels for one year. Typically, farmers apply this material on fields that a landlord is unwilling to share part of the cost of applying agricultural lime or will not provide a lease agreement for more than one year.

A study was initiated to evaluate the general philosophy of using finely ground lime to provide a short-term, “quick fix” of soil acidity and compare corn and cotton yield response of pelletized lime to agricultural lime.

### **Accomplishments in Year 2**

#### **Soybeans**

Elemental sulfur (2000 lb/acre) was applied to acidify a non-irrigated Reelfoot sandy loam soil at the Delta Research Center at Portageville in February 2005. Soil samples collected in early May of 2005 showed 1209 ENM/acre was needed. Ag lime (514 ENM/ton) and pelletized lime (720 ENM/ton) were applied to 10' X 40' plots with four replications. Lime materials were incorporated with tillage before soybean planting. Each lime was evaluated at ¼ recommended ENM, ½ recommended ENM, ¾ recommended ENM, and 100% of the recommended ENM per acre. Pelletized lime treatments were included with low rates dribbled over the seed furrow behind the planter press wheel and applied directly in the seed furrow with soybean seeds. Soil samples collected in March 2006 showed that the sulfur apparently continued to acidify the field after lime treatments were applied in 2005 (Figure 1). After having a year to react in the soil, agricultural and pelletized lime achieved similar pH changes from the same ENM rates. Additional agricultural and pelletized lime was applied in April 2006 using the same pattern of rates with percentage of MU recommendations. Soybean harvested in October showed that both lime sources increased soybean yields compared to checks when at least 50% of recommended lime was applied but the very low rates often used with pelletized lime was not effective (Table 1).

## Corn

A second test site was located in 2006 with a soil pH of 4.9. This field was not artificially acidified with sulfur. Soil tests showed that approximately 2 tons of ag lime was needed to correct soil pH. Four rates of ag lime and four rates of pelletized lime were applied and incorporated before corn planting. Each pelletized lime rate was 1/10 of a corresponding agricultural lime treatment. Corn with agricultural lime increased in yield 20 to 45 bushels per acre. Yields from pelletized lime were averaged less than 5 bushels greater than untreated checks.

### Objectives for Year 3

We will continue to monitor the soybean site and add another corn experiment in another field. In 2006, we observed great plot to plot variability in the effectiveness of dribble and in-furrow pelletized lime. In 2007, we will evaluate this more closely and hopefully develop a way to minimize crop damage from soil acidity using a short-term, close-contact liming practice.

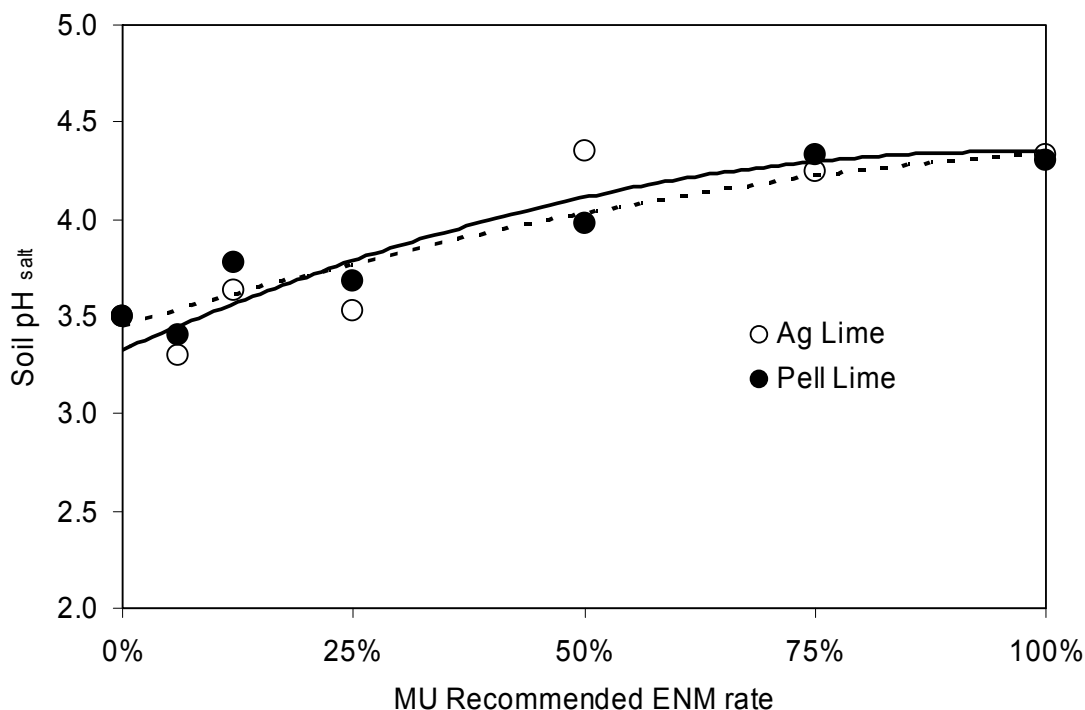


Figure 1. Soil pH<sub>salt</sub> collected in March 2006 from sulfur treated soybean field in as affected by agricultural and pelletized lime treatments applied in 2005.

Table 1. Soybean yields as affected by agricultural and pelletized lime.

Lime	MU Rec % applied	Material per acre	Yield bu/acre
Check	0	0	27
Ag lime	6	0.1 ton	30
	12	0.3 ton	34
	25	0.6 ton	30
	50	1.2 ton	41
	75	1.7 ton	39
	100	2.3 ton	44
Pell lime	6	0.1 ton	30
	12	0.2 ton	35
	25	0.4 ton	26
	50	0.8 ton	31
	75	1.3 ton	28
	100	1.7 ton	39
Infur Pell	< 1	4 lb	27
	< 1	8 lb.	19
	< 1	12 lb	28
	< 1	16 lb	31
Drib Pell	< 1	4 lb	26
	< 1	8 lb	26
	< 1	12 lb	31
	< 1	16 lb	31

Table 2. Corn yield response to agricultural and pelletized lime.

Lime	Material per acre	Yield bu/acre
Check	0	98
Ag lime	0.5 ton	126
	1.0 ton	123
	1.5 ton	145
	2.0 ton	121
Pell lime	100 lb	100
	200 lb	96
	300 lb	98
	400 lb	103

# **Nitrogen Management**

## Final Reports

### **Variable Source N Fertilizer Applications to Optimize Crop N Use Efficiency**

Peter Motavalli, Kelly Nelson, Newell Kitchen, Steve Anderson, and Peter Scharf

#### Summary:

Research was conducted in 2005 and 2006 to determine methods to delineate and map areas in fields which are more vulnerable to N loss due to wet conditions, to examine the use of a *variable-source* strategy to optimize crop N fertilizer use efficiency and, to calculate the cost-effectiveness of using this *variable-source* strategy compared to uniform applications of conventional or other N fertilizer sources.

Among the findings of this study were:

- The 2005 cropping year had relatively lower rainfall than that observed in 2006 and was characterized by a long period of drought after the middle of June. This lack of rainfall may have reduced possible crop N response in 2005 and accounted for the generally lower yields observed in 2005.
- Evaluation of the distribution of surface soil water content prior to planting in 2005 at the Greenley site in Northeast Missouri suggest that elevation alone may be a good predictor of spatial patterns of surface soil water content at this site.
- Visual symptoms of plant N deficiency were observed both in control plots and in low-lying areas, possibly due to water collecting in those areas from spring and early summer rainfall during both the 2005 and 2006 seasons.
- Significantly higher yields due to addition of N fertilizer were observed at the summit and low-lying landscape positions in Greenley in 2005 and at all landscape positions in 2006. The greater yield response to application of N in 2006 was probably due to higher rainfall during that year.
- Application of anhydrous ammonia or polymer-coated urea (PCU) resulted in significantly higher yields than application of urea at the low-lying landscape position in both 2005 and 2006 at the Greenley site. The PCU application had a consistent 24 to 29 bu/acre increase in corn yields in 2005 and 2006, respectively, compared to conventional urea applications in low-lying areas of the field. Similarly, anhydrous ammonia application resulted in a 24 and 26 bu/acre increase in yields in 2005 and 2006, respectively, compared to urea in the low-lying area. These differences in performance of the N fertilizer sources at different landscape positions was possibly due to the relatively wetter conditions in the low-lying area affecting the fate of the applied N. At the Centralia site in 2006, the PCU application had a 19 bu/acre increase over the urea application only in the footslope landscape position in a no-till cropping system with a corn-soybean-wheat rotation.
- Measurements of surface nitrous oxide (N<sub>2</sub>O) flux at the Greenley site in 2005 did not show consistent differences in N<sub>2</sub>O gas losses between urea and PCU fertilizer applications, although the N<sub>2</sub>O flux in the control treatment was generally higher in the low-lying area compared to the summit and sideslope landscape positions in the field.

- Based on calculations assuming a corn price of \$3/acre, a urea price of \$0.40/lb N, a PCU price of \$0.50/lb N, an average increase of 26.5 bu/acre with use of PCU over urea, and an application cost of \$5/acre for both urea and PCU, the extra profit obtained with applying PCU instead of urea in the low-lying areas of the experimental site in Northeast Missouri was approximately \$64/acre. In addition, assuming an anhydrous price of \$0.31/lb N and the same application cost as the other N sources and an average increase of 25 bu/acre with application of anhydrous compared to urea, the extra profit with applying anhydrous ammonia instead of urea in the low-lying areas was \$88/acre.

### **Materials and Methods:**

Two field trials were initiated in 2005 at the MU Greenley Experiment Station (Fig. 1) and in a farmer's field in Centralia. In 2006, the Centralia site was switched from the farmer's field to a long-term experimental site (i.e. Agricultural Systems for Environmental Quality or ASEQ) in Centralia supervised by the U.S. Agricultural Research Service. This site was considered preferable because it contained plots which contained different landscape positions which were similar to the Greenley site in addition to allowing for a comparison of different cropping and tillage systems. All the sites were mapped for elevation and apparent electrical conductivity ( $EC_a$ ) using a EM-38 sensor (Fig. 1). Measurement of soil  $EC_a$  gives an indication of relative depth to the claypan subsoil layer (Kitchen et al., 1999). Soil gravimetric water content was determined on 6 in depth soil samples collected in a 10 by 25 ft grid over the Greenley site on March 31<sup>st</sup> in order to compare the effects of spatial distribution of elevation and  $EC_a$  on the distribution of soil water content.

At the Greenley site, N fertilizer treatments included a control and 150 lb N/acre of either urea, polymer-coated urea (PCU) (ESN, Agrium, Inc.), a 50% urea/50% polymer-coated urea mixture, or anhydrous ammonia were injected or broadcast-applied and incorporated in 10 m by 1500 ft strips across three landscape positions representing shallow, deep and low-lying areas (Fig. 1A). At the Centralia ASEQ site, N fertilizer treatments of 150 lb N/acre of either urea or PCU were broadcast surface-applied in 10 by 25 ft strips within cropping/tillage systems (i.e., minimum tillage with a corn-soybean rotation, no-till with a corn-soybean rotation and no-till with a corn-soybean-wheat (legume) rotation) and at different landscape positions representing the summit, sideslope and footslope positions in the field.

Corn (*Zea mays*. L.) silage and grain yields were determined at each site. Site harvest locations for the Greenley site are shown in Fig. 1. Total aboveground biomass tissue samples at harvest and periodically during the growing season were taken and are currently being analyzed for total N content in order to determine fertilizer N use efficiency. The rate of soil  $N_2O$  gas loss or efflux was also measured periodically over the 2005 and 2006 growing season at the Greenley site for each N fertilizer treatment and landscape position. Soil  $N_2O$  gas was collected using small sealed chambers fitted with rubber septa inserted into PVC collars in the soil. The head space gas was collected from the chambers in the different treatments and analyzed by gas chromatography (GC).

### **Results**

Rainfall at the Greenley site during the 2005 cropping year was relatively low compared to the 2006 season (Fig. 2 A&B). However, early season rains shortly after application of N fertilizer and planting which caused temporary saturation of the low-lying area were observed in both years.

Measurement of the spatial distribution of soil water content in the top 6 in depth at the Greenley site was undertaken prior to planting in 2005 to evaluate whether measurements of elevation and  $EC_a$  would assist in predicting spatial differences in soil water content that might affect the fate of applied N fertilizer. Initial evaluation of the distribution of surface soil water content (Fig. 3), suggests that

elevation may be a better predictor of spatial patterns of surface soil water content. However, this analysis did not take into account the possible effect of differences in soil water availability deeper in the soil profile on the fate of applied N fertilizer. In claypan soils, the amount of available water in the soil profile is probably affected by the depth to the claypan layer which is a property related to soil EC<sub>a</sub>.

At the Greenley site, visual symptoms of plant N deficiency were observed both in control plots and in low-lying areas in 2005 and 2006, possibly due to water collecting in those areas from spring and early summer rainfall. However, lack of sufficient water for crop growth after the middle of June in 2005 also affected corn growth response to added N fertilizer in 2005. Grain yields at Greenley increased 20 to 46. bu/acre with added N fertilizer at the summit (shallow) and low-lying landscape positions (Table 1). In 2006, grain yield response to added N fertilizer was observed at all landscape positions and ranged from 47 to 105 bu/acre (Table 1). Application of anhydrous ammonia or polymer-coated urea (PCU) resulted in significantly higher yields than application of urea at the low-lying landscape position in both 2005 and 2006 at the Greenley site. The PCU application had a consistent 24 to 29 bu/acre increase in corn yields in 2005 and 2006, respectively, compared to conventional urea applications in low-lying areas of the field. Similarly, anhydrous ammonia application resulted in a 24 and 26 bu/acre increase in yields in 2005 and 2006, respectively, compared to urea in the low-lying area (Table 1).

At the ASEQ site in Centralia in 2006, poor corn stand establishment in the cropping system with minimum tillage resulted in no significant grain yield differences among the N fertilizer treatments at the different landscape positions (Table 2). The greatest grain yield response to N fertilizer application was observed at the footslope position of the no-till cropping system and at all landscape positions with the no-till cropping system with wheat in the rotation (Table 2). The PCU application had a 19 bu/acre grain yield increase over the urea application only at the footslope landscape position in the no-till cropping system with a corn-soybean-wheat rotation.

Measurements of surface nitrous oxide (N<sub>2</sub>O) flux at the Greenley site in 2005 are shown in Table 3 for the early part of the growing season since the highest losses of N<sub>2</sub>O gas are generally observed shortly after N fertilizer application. A total of 10 sampling times for N<sub>2</sub>O flux was taken over the 2005 growing season and a total of 9 sampling times were taken in 2006. Emissions of this greenhouse and ozone-depleting gas were measured to determine the relative magnitude of this N loss under the soil and climatic conditions experienced in Missouri and to assess possible environmental benefits of the different N fertilizer sources evaluated in this study. In general, the 2005 results do not show consistent differences in N<sub>2</sub>O gas losses between urea, anhydrous ammonia and PCU fertilizer applications, although the N<sub>2</sub>O flux in the control treatment is generally higher in the low-lying area compared to the summit and sideslope landscape positions in the field (Table 3). Data for the 2006 surface N<sub>2</sub>O flux measurements are still being processed. Further information will also be available from this study on the relative N fertilizer efficiency of the different N fertilizer sources at different landscape positions, but the N analysis of the harvested silage tissue has still not been completed.

Assessment of the economic costs and benefits of using the different N fertilizer sources suggests an economic advantage of using anhydrous ammonia and PCU over urea in low-lying areas of the field. Based on calculations assuming a corn price of \$3/acre, a urea price of \$0.40/lb N, a PCU price of \$0.50/lb N, an average increase of 26.5 bu/acre with use of PCU over urea, and an application cost of \$5/acre for both urea and PCU, the extra profit obtained with applying PCU instead of urea in the low-lying areas of the experimental site in Northeast Missouri was approximately \$64/acre. In addition, assuming an anhydrous price of \$0.31/lb N and the same application cost as the other N sources and an average increase of 25 bu/acre with application of anhydrous ammonia compared to urea, the extra profit with applying anhydrous ammonia instead of urea in the low-lying areas was \$88/acre.

The results of this study suggest that a variable source approach to applying N fertilizer sources based on identifying areas in a field which are periodically wet due to their lower landscape position, may improve crop production and increase economic returns. However, further research is required under different soil types and climatic conditions at a farm scale to determine if this approach has a wider application. An initial step would be to identify a procedure which would allow for delineation and mapping of these areas of higher risk for N loss in a field and then allow for export of that information to a fertilizer spreader which has a capacity to selectively spread different N fertilizer sources based on the mapped information.

### **Outreach and Training:**

A M.S. graduate student in soil science and two undergraduate students majoring in soil science and environmental science have been involved in working on this project as part of their training. The first year research results were presented at the 2005 American Society of Agronomy National Meetings and to growers and agricultural professionals at the 2005 and 2006 Greenley Center Field Day in Northeast Missouri. In addition, the graduate student presented a poster of the 2005 and 2006 results to the 2006 North Central Industry-Extension Soil Fertility Conference in Des Moines, Iowa. Some of the results of this study were also presented at a symposium on use of enhanced efficiency fertilizers at the 2006 American Society of Agronomy National Meetings and in an international conference on N management in South Korea.

Table 1. Effects of N fertilizer source and landscape position on corn grain yields at the Greenley site in 2005 and 2006.

N fertilizer treatment	Landscape Position			LSD <sub>(0.05)</sub> *
	Summit	Sideslope	Low-lying	
<b>2005</b>				
----- bu/acre -----				
Control	73.6	72.3	71.0	NS**
Urea	93.5	79.1	92.8	NS
PCU	94.0	73.9	117.2	29.5
PCU/Urea	95.1	77.2	104.2	NS
Anhydrous	100.6	88.7	116.3	24.1
LSD <sub>(0.05)</sub>	8.7	NS	19.6	
<b>2006</b>				
Control	97.1	92.1	129.4	30.9
Urea	190.6	176.2	176.0	NS
PCU	199.4	187.3	204.9	NS
PCU/Urea	201.3	190.4	189.1	NS
Anhydrous	201.9	186.2	202.5	NS
LSD <sub>(0.05)</sub>	15.8	12.7	16.8	

\* Fisher's (protected) least significant difference at  $p < 0.05$

\*\* NS = not significant

Table 2. Effects of cropping system, N fertilizer source and landscape position on corn grain yields at the ASEQ site at Centralia in 2006.

N fertilizer treatment	Minimum tillage*				No-till**				No-till with rotation***			
	Summit	Sideslope	Footslope	LSD <sub>(0.05)</sub> <sup>†</sup>	Summit	Sideslope	Footslope	LSD <sub>(0.05)</sub>	Summit	Sideslope	Footslope	LSD <sub>(0.05)</sub>
	----- bu/acre -----											
Control	65.1	46.0	65.0	NS	45.2	30.1	61.7	30.4	72.1	75.7	103.4	NS
Urea	69.4	49.1	95.8	NS	104.3	66.8	142.4	59.4	110.7	109.9	113.1	NS
PCU	78.4	63.4	96.2	NS	89.0	67.9	141.3	25.2	107.7	102.3	132.1	17.9
LSD <sub>(0.05)</sub>	NS <sup>††</sup>	NS	NS		37.2	NS	51.8		33.5	23.4	15.0	

\*Minimum tillage with a corn-soybean rotation

\*\*No-till with a corn-soybean rotation

\*\*\*No-till with a corn-soybean-wheat (legume) rotation.

<sup>†</sup> Fisher's (protected) least significant difference at  $p < 0.05$ .

<sup>††</sup> NS = not significant

Table 3. Effects of N fertilizer source and landscape position on nitrous oxide flux on four selected dates after application of N fertilizer treatments at the Greenley site in 2005.

N fertilizer treatment	Landscape Position			LSD <sub>(0.05)</sub> *
	Summit	Sideslope	Low-lying	
<b>8 DAA</b>				
----- mg N <sub>2</sub> O-N/m <sup>2</sup> /day -----				
Control	0.506	0.271	1.363	0.423
Urea	1.284	0.599	2.500	NS
PCU	0.312	1.203	0.683	NS
PCU/Urea	1.199	1.148	0.517	NS
Anhydrous	1.211	0.542	1.442	NS
LSD <sub>(0.05)</sub>	0.880	0.923	1.848	
<b>22 DAA</b>				
Control	0.413	0.935	1.622	0.911
Urea	2.285	0.805	3.263	NS
PCU	2.251	4.067	2.244	NS
PCU/Urea	2.005	2.232	2.027	NS
Anhydrous	1.624	1.190	0.700	NS
LSD <sub>(0.05)</sub>	NS	2.452	2.016	
<b>30 DAA</b>				
Control	1.423	0.823	5.946	NS
Urea	1.562	1.229	1.345	NS
PCU	2.665	2.389	5.316	NS
PCU/Urea	1.196	6.706	1.578	NS
Anhydrous	7.640	2.660	0.929	NS
LSD <sub>(0.05)</sub>	5.247	NS	NS	
<b>35 DAA</b>				
Control	0.513	1.941	2.177	NS
Urea	0.758	1.324	1.458	NS
PCU	0.719	5.471	1.371	NS
PCU/Urea	0.350	0.777	1.703	NS
Anhydrous	1.333	0.928	2.494	NS
LSD <sub>(0.05)</sub>	NS	NS	NS	

\* Fisher's (protected) least significant difference at  $p < 0.05$

\*\* NS = not significant

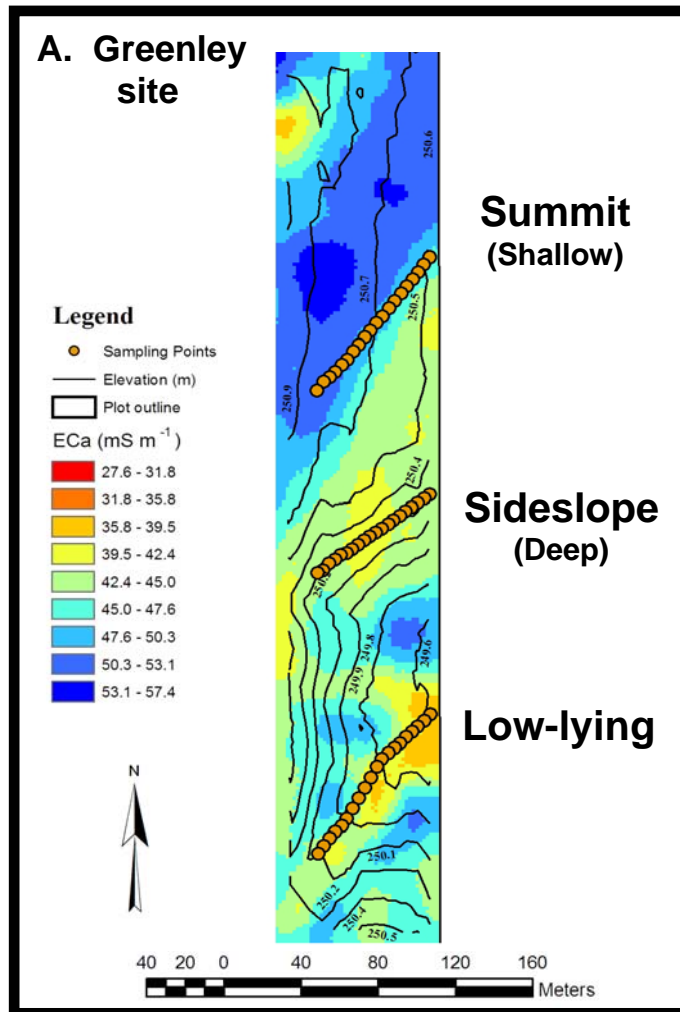


Fig. 1 . Map showing the spatial distribution of elevation and  $\text{EC}_a$  at the Greenley site. Circles in the Greenley site map show the location of the sampling collars for soil  $\text{N}_2\text{O}$  gas loss and the approximate location for the grain and silage harvests.

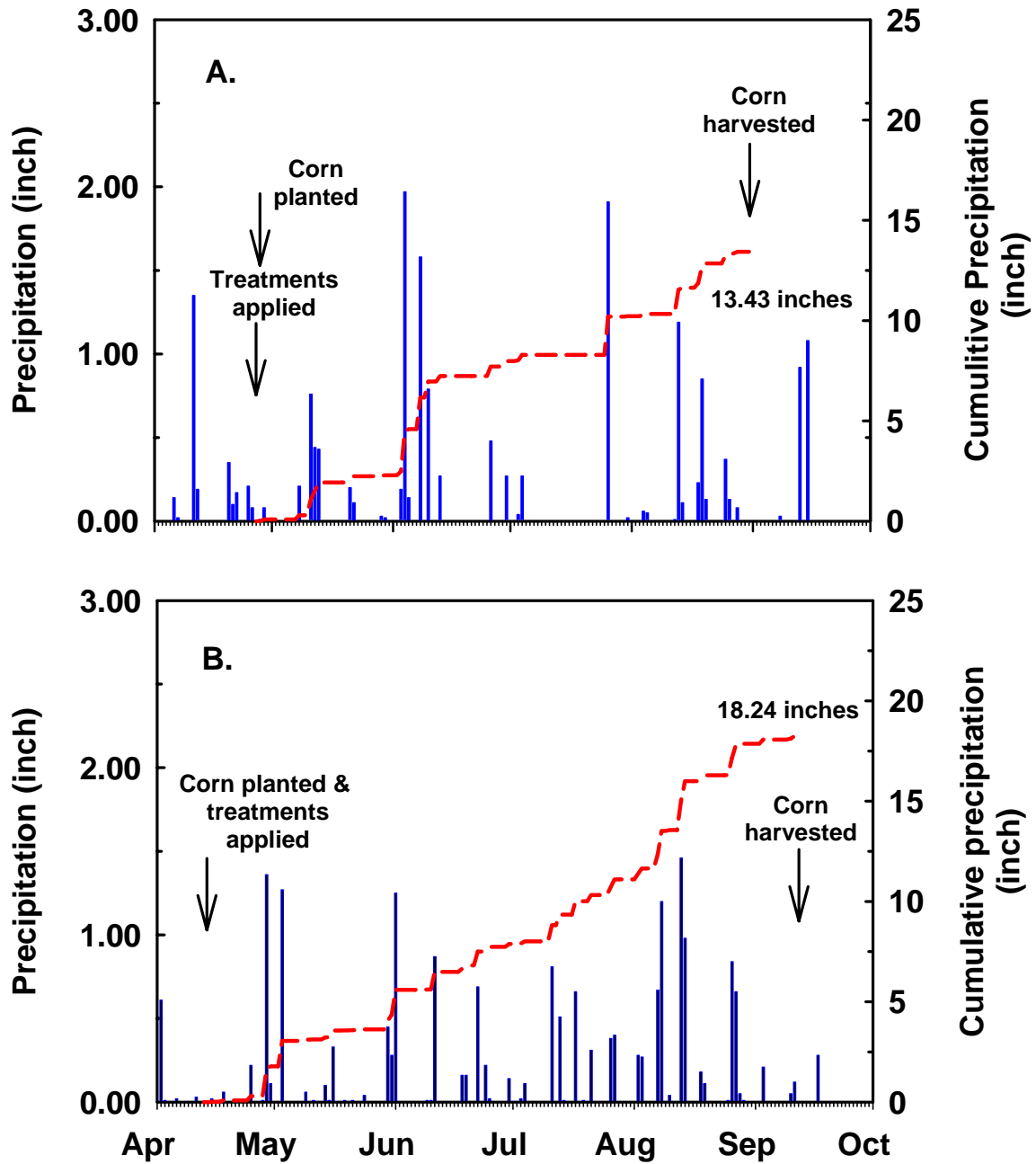


Fig. 2 A & B. Daily and cumulative precipitation at the Greenley site in A) 2005 and B) 2006. Figures also show the times of important cropping events in relation to rainfall.

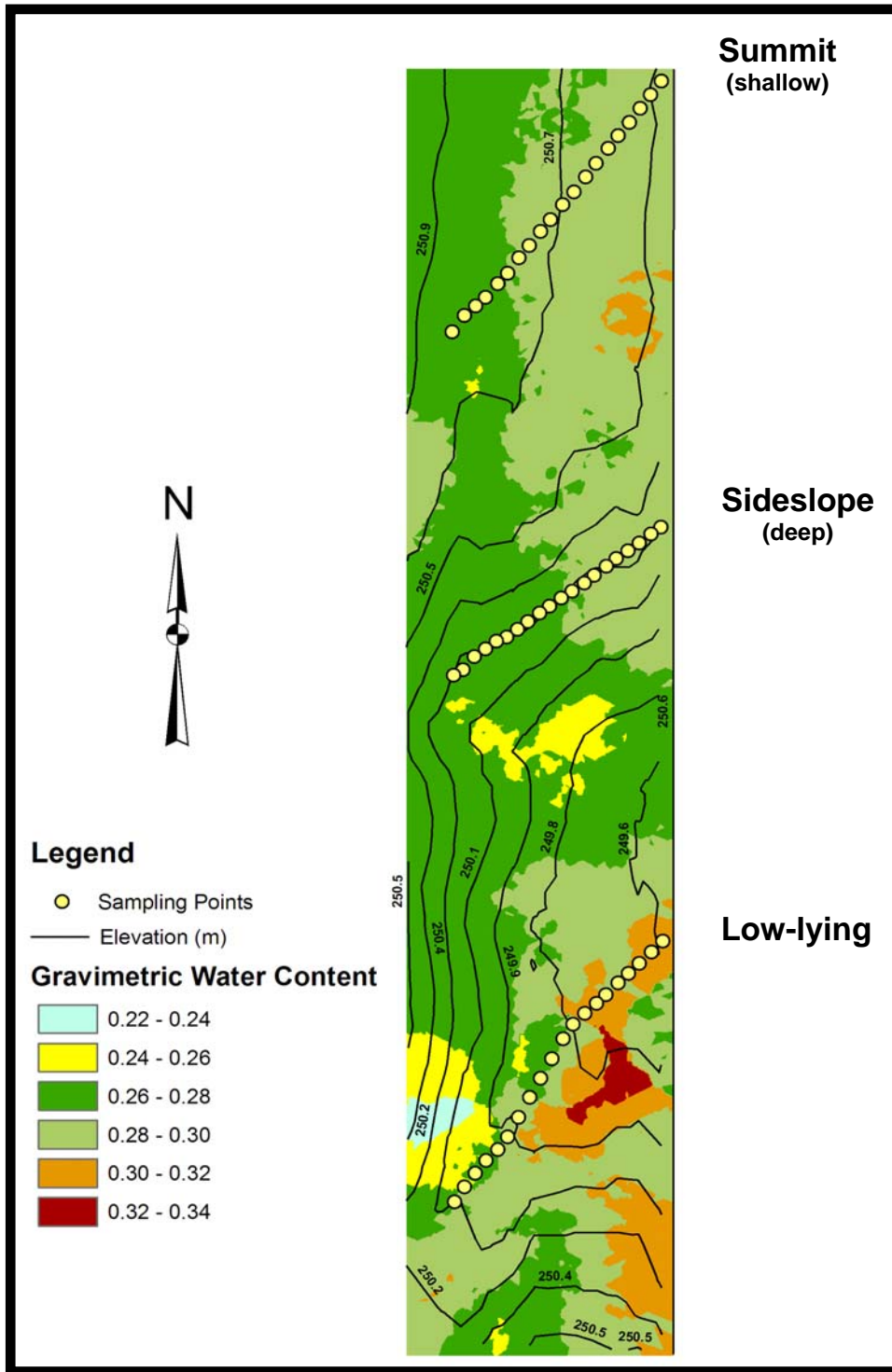


Fig. 3. Spatial distribution of soil gravimetric water content at the Greenley site on March 31<sup>st</sup>, 2005.

## **Cost-Effective N Management Using Reduced Rates of Polymer Coated Urea in Corn**

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### **Introduction:**

Poorly drained soils are common in Missouri. Farmers with poor drainage have additional options for N management using polymer coated urea (Merchán Paniagua et al., 2005; Schwab et al., 2005). Polymer coated urea has been shown to reduce N<sub>2</sub>O flux in plots with poor drainage (Merchán Paniagua et al., 2005). Performance of polymer coated urea has been equivalent to anhydrous ammonia in Northern Missouri (Motavalli et al., 2005) and less consistent in Central Missouri (Medeiros et al., 2005). Preliminary research in 2005 at Novelty has indicated that polymer coated urea rates may be reduced up to 30% while maintaining corn grain yields similar to a 150 lb/a rate regardless of application timing. This may be a cost-effective management option for farmers to offset the cost of the polymer coating.

Availability of ammonium nitrate and anhydrous may be limited in the future. The slow-release properties of polymer coated urea have appealing characteristics for corn producers in watersheds with the potential of surface water runoff or soils with high leaching potential (Rosen and McNearney, 2005). Placement of polymer coated urea has demonstrated improved utility and yield of potato in Wisconsin (Rosen and McNearney, 2005) and corn in Minnesota (Randall, unpublished) compared to other N sources. Finally, incentive payments through the Conservation Security Program were available to producers in Missouri utilizing coated urea technology. This could impact over 1.8 million acres in qualified watersheds (NRCS, 2005). Recently, N prices have increased dramatically while corn prices have been variable. A polymer coating may increase cost of N up to \$0.11/lb; therefore, reduced rates of polymer coated urea need to be evaluated to balance the additional cost of the coating while maintaining the yield potential of corn. In addition, no published research has evaluated the release of the polymer coated urea for corn in field experiments on poorly drained soils. No research has evaluated degradation as affected by residue, tillage, or placement in the soil. No published research has reported the effects of reduced rates of polymer coated urea and determined the interaction with application timing as a cost-effective method to reduce N application rates.

The objectives of this study were to: 1) evaluate yield response of no-till corn with reduced rates of polymer coated urea compared with non-coated urea at different application timings, 2) determine the interaction between application timing and N source on ammonium-N and nitrate N in the soil profile, and 3) assess the impact of application timing and placement on polymer coated urea degradation.

### **Materials and Methods:**

A field trial with four replications was established at the Greenley Research Center in plots 10 by 40 ft to evaluate crop response to polymer coated urea (ESN) compared to non-coated urea at 0, 50, 100, and 150 lbs N/acre. 'Asgrow RX752' was no-till planted on April 28, 2006 at 30,000 seeds/acre. A fall application of 23-60-100 was applied as recommended by the University of Missouri soil test lab. Nitrogen application timings included: 1) fall (November 4), 2) early preplant (April 5), 3) preemergence (broadcast applied on April 28), and 4) broadcast sidedress (1-2 ft corn on June 5) treatments. An untreated and standard anhydrous treatment at 150 lbs N/acre was included as a control. The field trial was monitored for ammonium-N and nitrate-N at three timings throughout the season (first rainfall after the sidedress timing, prior to silking, and black layer) and throughout the profile at three incremental depths (0-6, 7-12, 13-18 inches). The untreated control and 150 lb N/a rates of polymer coated urea, urea alone, and anhydrous treatments were monitored for N concentrations and are currently undergoing analysis.

An additional field study utilized buried bags to evaluate degradation of the polymer-coated urea to determine N release throughout the growing season. This method has been utilized in wheat research

on poorly drained soils (Schwab et al., 2005) and potato research on sandy soils (Rosen and McNearney, 2005), but N release has not been evaluated on poorly-drained soils for corn planted in different residues common in Missouri. This study included a factorial arrangement of 3 residues (no-till wheat stubble with red clover, no-till soybean residue, and reduced till soybean residue), 3 application depths (surface applied, 2 inch depth, and 4 inch depth), 3 application timings (March, April, and May), and 5 removal timings (April, May, June, July, and black layer). An additional air exposed control was included in the design. Each treatment was replicated three times. A nylon window screen packet was constructed for each treatment. Each screen packet held approximately 10 grams of polymer coated urea. Packets were weighed prior to placement in the field. The packets were then recovered from each treatment, washed with ice water, dried and weighed. Release of urea was calculated as  $(1 - (\text{removal date weight} / \text{weight at application})) * 100$ . All data were subjected to an analysis of variance and means separated using Fisher's Protected LSD ( $p=0.05$ ).

### **Results in 2006:**

Grain yields were above average at Novelty in 2006. No-till corn yield with polymer coated urea at 150 lb/a was similar to anhydrous at 150 lb/a at all four application timings while yields with anhydrous were 24 to 59 bu/acre greater than urea at the fall, early preplant, and side-dress timings (Figure 1). Rainfall following application of the pre-emergence N treatment probably contributed to grain yields that were similar among the N sources at this timing in this research. Reduced rates of polymer coated urea appear justified at later application timings when compared with urea alone. Polymer coated urea rates that were reduced by 30% had yields similar to the 150 lb/a rate at the pre-emergence and side-dress timings in 2006, and were similar to anhydrous at 150 lb/acre.

Release of nitrogen from polymer coated urea granules was greatest for deep placement followed by the 1-2 inch depth placement in no-till wheat/clover residue (Figure 2). Moisture content may be greater in this cropping system. Surface applied polymer coated urea release was ranked no-till soybean stubble > no-till wheat/clover residue = conventional tillage.

November applied polymer coated urea released 20-30% of the fertilizer by mid-April, 2006 (Figure 3). Fertilizer release was similar for nearly all of the 1-2 and 4 inch deep placements for all of the recovery dates except November applied polymer coated urea. Surface applied polymer coated urea was slower for March applied fertilizer from mid-May to mid-July, April applied fertilizer from mid-June to mid-July, and May applied fertilizer at the mid-July recovery dates. Air exposed packets were included as control treatments to determine the effect of sunlight, rainfall, and other conditions on the integrity of the polymer coating. Sunlight was probably a major factor affecting the coating and may help in the degradation of the polymer coating. In the absence of direct soil contact, release of fertilizer from the polymer coating was generally less than surface applied treatments.

### **Summary and Conclusions:**

Reduced rates of polymer coated urea may be justified at pre-emergence and side-dress application timings. Tillage system and fertilizer placement affects the release of polymer coated urea. This may be related to the moisture content in the soil of these systems. Variable crop response from polymer coated urea during dry years may be related to slower fertilizer release especially when polymer coated urea was applied in no-till conditions. Polymer coated urea fertilizer release reached 70-90% by black layer while in the absence of direct contact with moist soil, fertilizer release was 50-60%. In general, yields with polymer coated urea were greater than or equal to non-coated urea in 2006.

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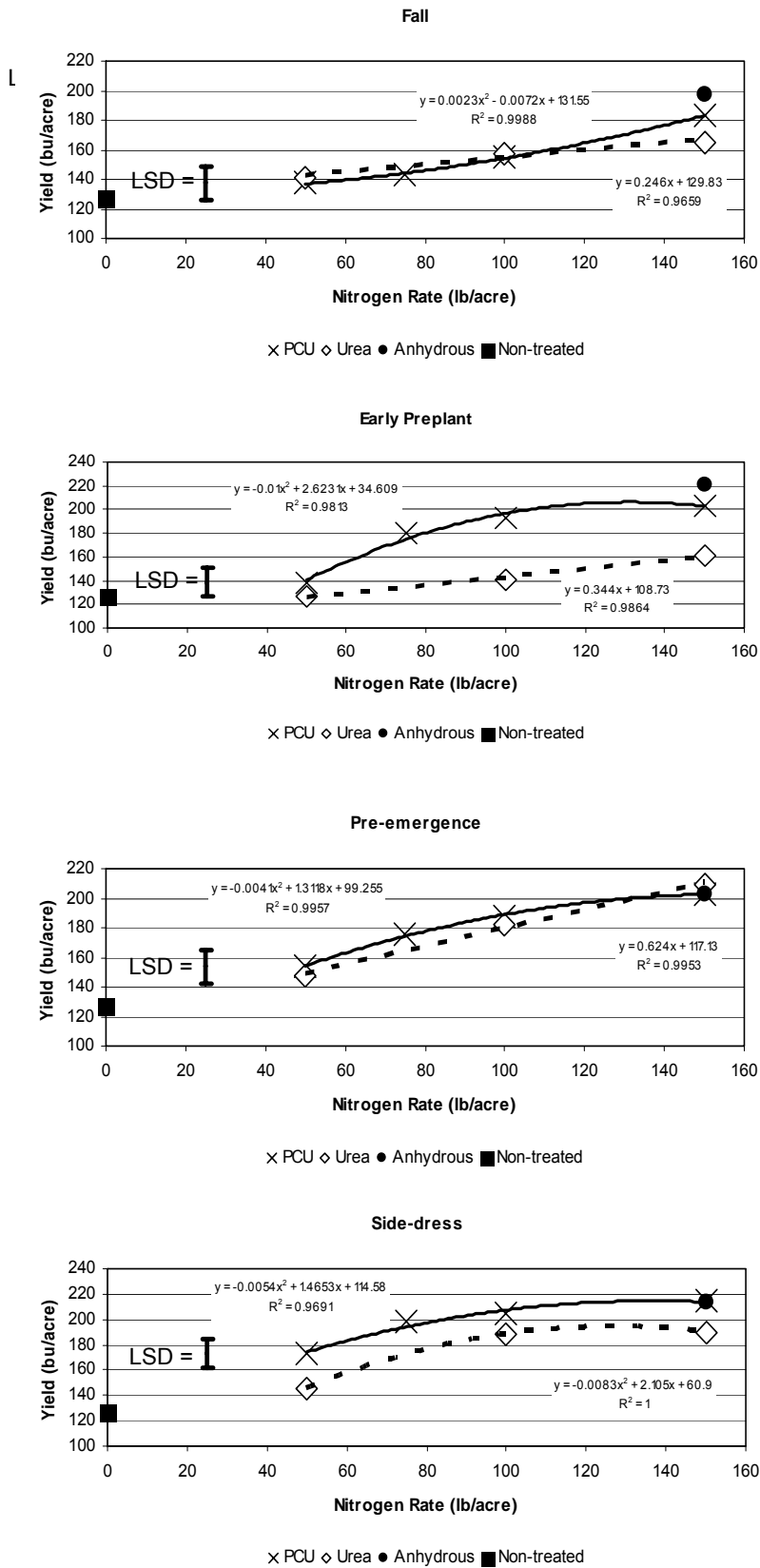


Figure 1. Yield response of no-till corn to reduced rates of polymer coated urea compared with non-coated urea at fall, early preplant, pre-emergence, and side-dress application timings.

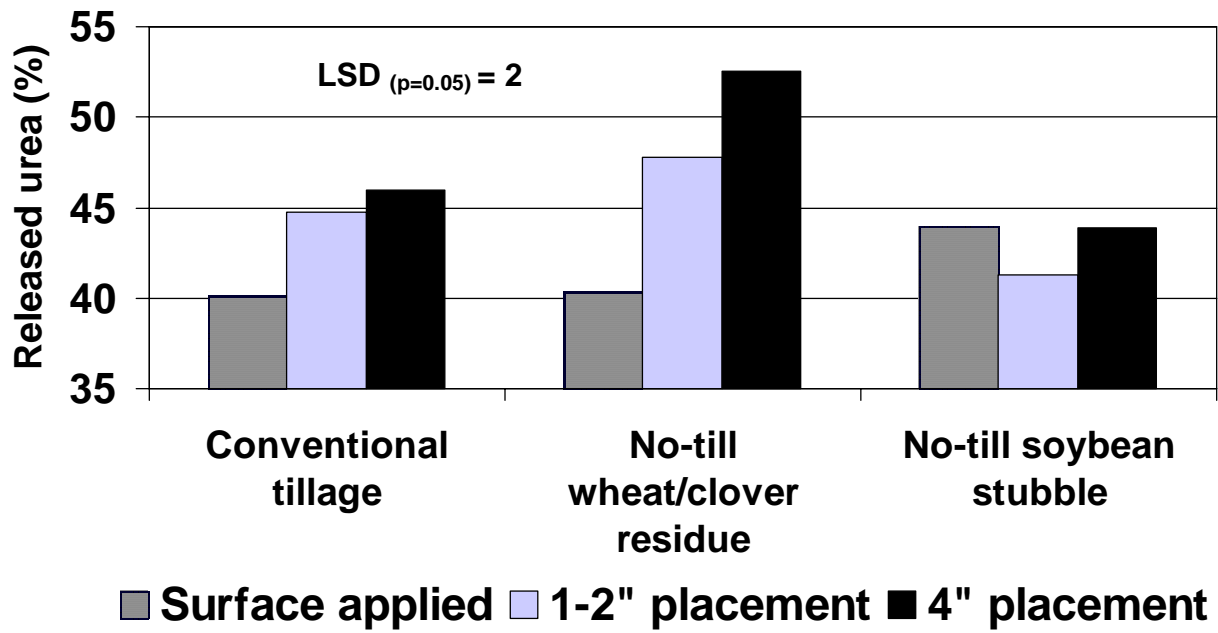


Figure 2. Effect of tillage and placement on release of fertilizer from polymer coated urea. Data were averaged over application and removal timings.

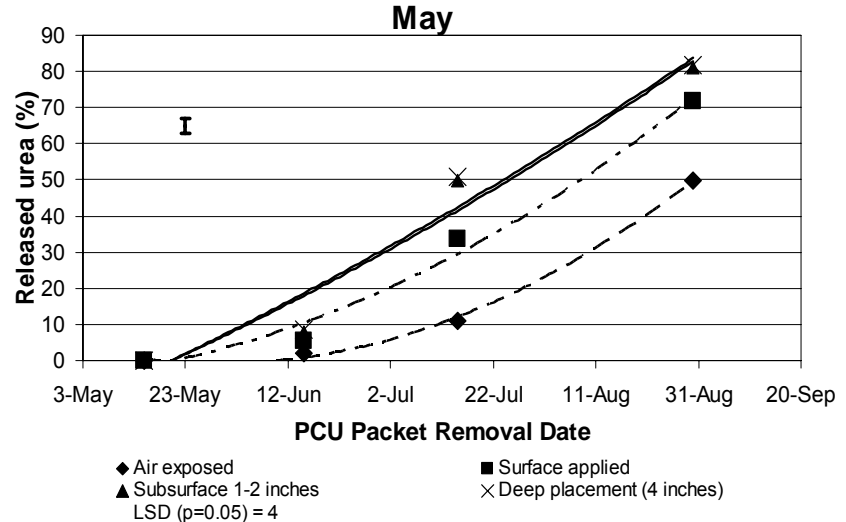
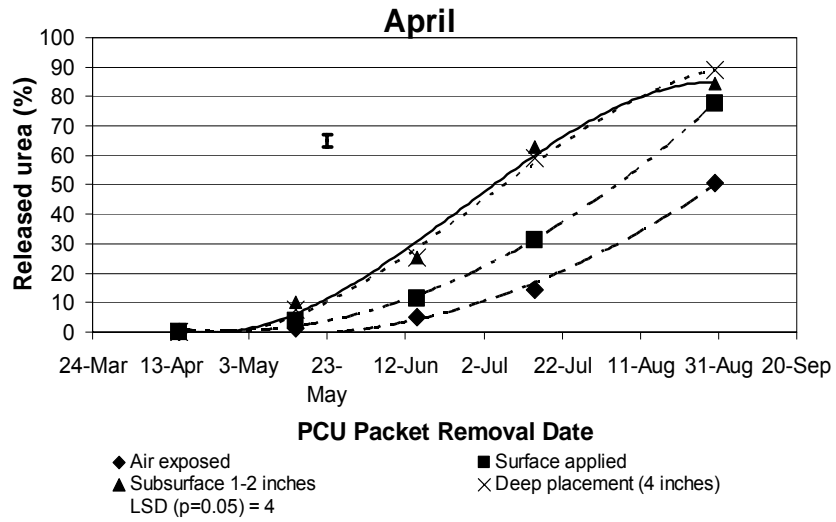
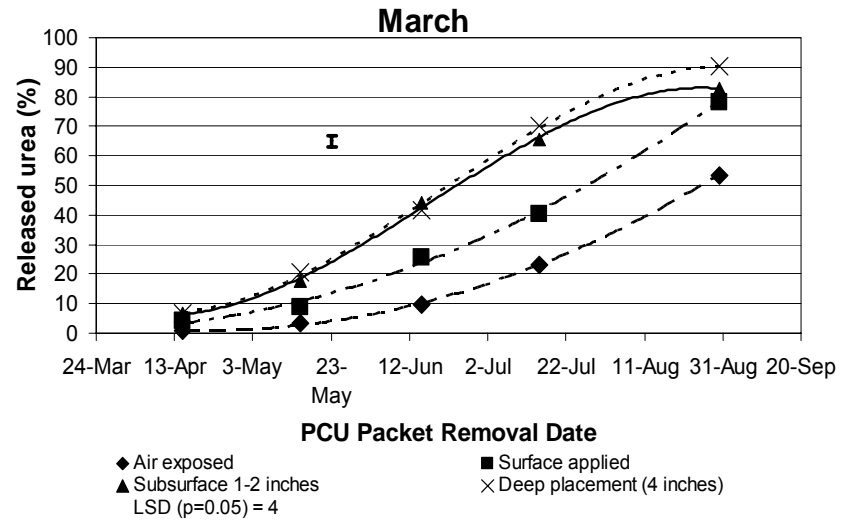
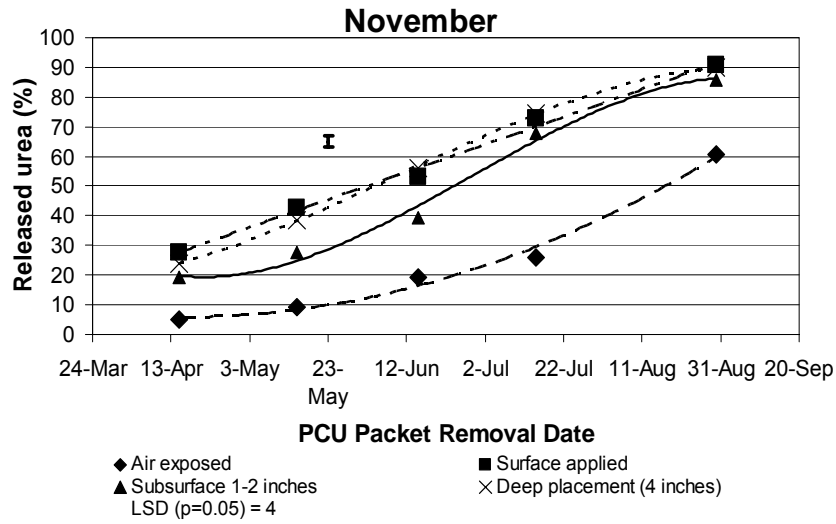


Figure 3. Polymer coated urea released from November 15, March 15, April 15, and May 15 application timings. PCU packets were removed on April 1, May 1, June 1, July 1, and August 31. Released urea values were calculated as  $(1 - (\text{removal date weight} / \text{weight at application})) * 100$ .

## **Making Urea Work in No-till: Final Report**

Peter Scharf, Joao Medeiros, and Larry Mueller  
University of Missouri Plant Sciences Division

### **Executive Summary**

The main findings from this three-year (2004-2006) project include:

- Agrotain treatment of urea was the most promising and consistent way to improve performance of broadcast, unincorporated urea in no-till wheat and corn.
- Topdress nitrogen timing had a strong influence on wheat yield.
  - March topdress gave the highest yields, averaging 20 bu/acre higher than January topdress and 13 bu/acre higher than February topdress (averaged over the N sources urea, urea + Agrotain, ammonium nitrate, and SuperU).
- Polymer coating of urea (trade name ESN) produced a substantial yield benefit when wheat was topdressed in January or February.
  - Yield benefit over urea was 16 bu in January, 10 bu in February.
  - Polymer coating protected N from early-season loss (leaching?).
  - But yield with polymer-coated urea in January/February was still 5 bu less than urea in March, and 9 bu less than ammonium nitrate in March.
  - Polymer coating of urea reduced yield by 4 bu for March topdressing.
    - Availability was too slow and plants were visually N-deficient.
- Agrotain treatment of urea gave a yield benefit and an economic benefit for wheat, and gave a yield benefit for corn that was economically borderline.
  - Average wheat yield benefit from Agrotain use was 4 bu/acre.
    - This benefit did not depend on whether N was topdressed in January, February, or March.
    - Treatment cost is about \$4/acre and economic benefit was clear.
  - Average corn yield benefit from Agrotain use was also 4 bu/acre.
    - There was not much problem with broadcast urea in 2 of 3 years as indicated by little or no yield difference between broadcast urea and broadcast ammonium nitrate. This was related to either rainfall within a few days of broadcast application, or drought that limited yield and need for N.
    - Treatment cost is about \$8/acre and about equal to value of added yield based on historical corn prices. With current high corn prices, there is an economic benefit.
    - Over 15 experiments (including these three) with Agrotain treatment of urea for corn production in Missouri, average yield benefit has been 6 bu/acre and economic benefit is clear.
- Agrotain added to UAN solution was beneficial for corn (average 6 bu/acre) but not for wheat (average 1 bu/acre).
- Polymer coating of urea (ESN) produced no yield benefit in corn.
- Starch gel coating of urea (Nurea) produced no yield benefit in corn or wheat.
- Knife injection of urea produced no yield benefit in corn.
  - Availability of all knifed N treatments was slower than for broadcast treatments according to in-season crop color measurements.
- Tillage to incorporate urea produced a 5 bu/acre yield advantage over broadcast urea for corn. This is the classical way to manage urea.

## **Objective:**

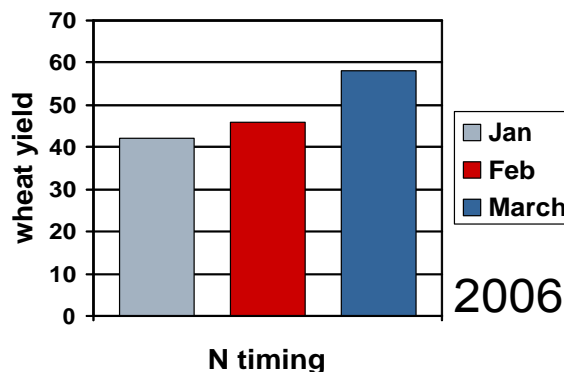
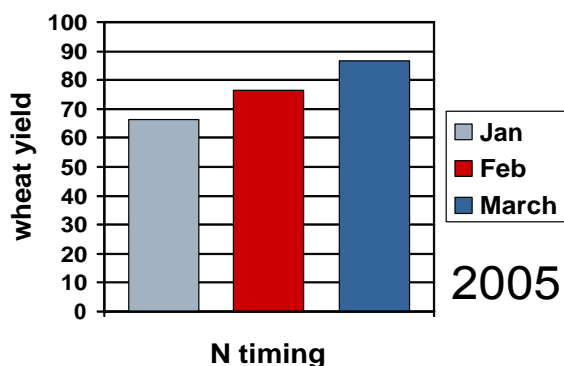
- The objective of this project is to evaluate several strategies to reduce the risk of ammonia volatilization loss from urea applied to no-till corn and wheat.
  - Strategies to be evaluated include:
    - Urea treated with Agrotain volatilization inhibitor
    - Urea coatings: polymer (ESN) or starch (Nurea)
    - Knife-injected urea
  - Yield and economic outcomes from these strategies will be compared with broadcast urea and with other N sources.

## **Procedures:**

- Two experiments were conducted each year from 2004-2006 on Bradford Research Farm near Columbia
  - Each year one wheat and one corn experiment were conducted.
  - Total of three wheat and three corn experiments over the duration of the project.
- Treatments were nitrogen fertilizer sources and placement.
  - All treatments were applied at rates of 140 lb N/ac for corn, 70 lb N/ac for wheat.
  - Broadcast treatments
    - Urea
    - Urea + tillage (corn only)
    - Urea with Agrotain volatilization inhibitor
    - SuperU (urea with Agrotain + DCD)
    - Polymer-coated urea (ESN)
    - Starch gel coated urea (Nurea)
    - Ammonium nitrate
    - 30% urea-ammonium nitrate solution
    - 30% urea-ammonium nitrate solution + Agrotain
    - 30% urea-ammonium nitrate solution + Agrotain + DCD
  - Knife-injected treatments (corn only)
    - Urea
    - Anhydrous ammonia
    - Ammonium nitrate
    - 30% urea-ammonium nitrate solution
  - An unfertilized check treatment was also included so that the size of the yield response to N fertilizer could be determined.
- In 2005 and 2006, the wheat experiments included a timing factor, with all dry treatments applied in either January, February, or March. (All liquid treatments were applied only in March, along with all treatments in 2004.)
- Each treatment was replicated eight times.

## Results for wheat:

- Wheat yields averaged 62 bu/acre for dry N sources applied in March over the three years of the study, which is fairly good. However, yields were highly variable between years:
  - 39 bu/acre in 2004
  - 88 bu/acre in 2005
  - 58 bu/acre in 2006
- Average yield response to nitrogen fertilizer (for dry N sources applied in March) was 29 bu/acre and the years followed a similar pattern:
  - 17 bu/acre in 2004
  - 41 bu/acre in 2005
  - 28 bu/acre in 2006
- The most surprising and important result of the wheat experiments was that N timing was the factor that had the biggest effect on wheat yield. This result was consistent between the two years when a timing factor was included (2005 & 2006). On average, February topdress produced 7 bu/acre higher yield than January topdress, and March topdress produced 20 bu/acre higher yield than January topdress.
  - Topdress timing was added to the experiment in 2005 after receiving industry comments that volatilization from urea shouldn't be a problem in cold weather.



- All N sources except polymer-coated urea (ESN) followed this pattern. Wheat yield with ESN was not affected by topdress timing (Table 1).
  - Apparently the polymer coating was able to protect the N from whatever processes were causing N loss in the other N sources.
  - As a result, ESN gave the highest wheat yield among dry fertilizers for January or February topdressing (Table 1).
  - It also gave the lowest yield among dry fertilizers for March topdressing. Low yields with March-applied ESN were associated with persistent slight N deficiency that was visible through most of the season compared to other plots. It appears that N release was too slow to meet wheat N uptake timing when ESN was applied in March.
  - Although January applications of N were clearly undesirable in this experiment, producers sometimes want to apply N at this time. ESN may provide a lower-risk alternative for January N applications to wheat.
- Agrotain increased no-till wheat yield by a 3-year average of 4 bu/acre when applied to urea.

- This effect did not depend on topdress timing. Average yield response to Agrotain was 5 bu/acre in January, 3 bu/acre in February, and 3 bu/acre in March, but these differences were not statistically significant.
- This brought yields with urea up to being equivalent to yields with ammonium nitrate.
- It appears that Agrotain was effective in preventing ammonia volatilization loss of N from broadcast urea.
- There was no difference in yield between (urea + Agrotain) and (urea + Agrotain + DCD) (trade name SuperU), suggesting that DCD made no contribution to reducing loss of N. Even though we found no evidence that SuperU gave higher yields than urea + Agrotain, it clearly gave the same benefits and may be preferable for some dealers since mixing is not required (as it is to coat Agrotain on urea).
- UAN solution (with or without additives) produced lower yields than dry N sources in all three years
  - Average yield penalty for broadcast UAN was 11 bu/acre (5 bu in 2004, 23 bu in 2005, 6 bu in 2006).
  - This agrees with previous Missouri research showing that UAN solution broadcast on residue in no-till systems performs poorly.
  - Average yield penalty in previous Missouri research was 8 bu/acre for broadcasting UAN in no-till wheat.
  - Tie-up of UAN droplets on residue is thought to be the reason for this poor performance.

**Table 1. Average wheat yields from 2005 and 2006 experiments for different broadcast spring N fertilizer sources and application timings.**

Fertilizer treatment	Yield with treatment applied in:		
	January	February	March
Urea	50	59	72
Urea + Agrotain	56	62	76
Urea + Agrotain + DCD (SuperU)	56	64	74
Polymer coated urea (ESN)	66	68	68
Starch gel coated urea (Nurea)	51	58	72
Ammonium nitrate	57	64	76
UAN solution*			59
UAN solution + Agrotain*			61
UAN solution + Agrotain + DCD*			60
Unfertilized check	39	39	39

**Least Significant Difference (95% confidence) between yields = 4 bu/acre**

\*Treatments based on UAN solution were only applied in March

- Agrotain added to UAN solution produced an average yield 1.4 bu/acre higher than UAN alone, but this difference was not statistically significant.

- Starch gel coating of urea (Nurea) did not increase wheat yield for any year or timing.

**Results for corn:**

- Average yield with ammonium nitrate as the N source was 110 bu/acre. Corn yields, like wheat yields, varied widely over the three study years:
  - 161 bu/acre in 2004
  - 58 bu/acre in 2005
  - 112 bu/acre in 2006
- Average yield response to N was 69 bu/acre. Yield response to N followed the same pattern as yield over the three years:
  - 101 bu/acre response in 2004
  - 37 bu/acre response in 2005
  - 69 bu/acre response in 2006
  - The 140 lb N/acre rate that we used is barely enough to support the 101 bu/acre response seen in 2004 and treatments with N loss would be expected to also have yield loss. In the same vein, yield differences between treatments would be expected to be small in 2006 and nonexistent in 2005, and this is what we observed.

**Table 2. Two-year average corn yields for different N fertilizer sources & placements (2005 excluded due to drought).**

Fertilizer treatment	Yield
Urea (broadcast)	123
Urea + Agrotain (broadcast)	130
Urea + Agrotain + DCD (SuperU) (broadcast)	127
Polymer-coated urea (ESN) (broadcast)	123
Starch gel coated urea (Nurea) (broadcast)	123
Urea (broadcast + till)	131
Urea (knife)	122
Ammonium nitrate (broadcast)	137
Ammonium nitrate (knife)	136
Anhydrous ammonia (knife)	136
UAN solution (broadcast)	112
UAN solution + Agrotain (broadcast)	117
UAN solution + Agrotain + DCD (broadcast)	113
UAN solution (knife)	121
Unfertilized check	56

Least Significant Difference (95% confidence) between yields = 7.5 bu/acre

- Agrotain treatment of urea was the best strategy for improving urea performance in no-till corn.

- Agrotain increased corn yield by 7 bu/acre (88% confidence) when applied with urea (Table 2).
  - This response was obtained by coating the Agrotain on the urea shortly before broadcasting.
  - Using SuperU (in which the Agrotain is cogranulated with urea and the nitrification inhibitor DCD) gave a similar but smaller yield response (Table 2).
  - Coating the urea on the Agrotain is generally cheaper, but SuperU provides an option for dealers without mixing equipment to provide a safer urea product for no-till.
  - Agrotain treatment typically costs about \$8/acre and appears to be economical when urea is used for no-till corn in Missouri.
- The DCD (dicyandiamide) nitrification inhibitor component of SuperU did not appear to provide any yield advantage in these experiments.
- Agrotain treatment only made up about half of the yield difference between broadcast urea and broadcast ammonium nitrate.
  - This is in contrast to the wheat study, where urea with Agrotain gave yields equivalent to yields with ammonium nitrate.
  - Averaged over 11 corn studies in Missouri, Agrotain made up 60% of the yield difference between urea and ammonium nitrate.
  - Averaged over 39 corn studies in Missouri, ammonium nitrate outyielded urea by an average of 14 bu/acre. If Agrotain made up 60% of the difference on average, 60% of 14 bu/acre is 8 bu/acre. This agrees well with the yield benefit due to Agrotain seen in this study.
  - Cost of urea with Agrotain and ammonium nitrate is generally comparable.
  - Ammonium nitrate may still be preferable to urea with Agrotain where it is available and where the quality is good enough to allow even spreading.
- Neither polymer (ESN) nor starch gel (Nurea) coating of urea produced yield benefits to corn in this study.
  - Polymer coating of urea did slow down urea release and availability to the corn, as indicated by color measurements of the corn taken in early and mid-June (Figure 2).
  - This slower release of urea N apparently did not prevent N loss associated with urea.
  - Starch gel coating did not appear to affect N release rate based on corn color measurements.
- Knife injection of urea was not effective in increasing yield, but tillage was.
  - Either practice should prevent volatile loss of ammonia from the urea.
  - Average yield response to light tillage to incorporate urea was 8 bu/acre.
  - Knife application of all N forms (urea, ammonium nitrate, UAN solution, anhydrous ammonia) resulted in slower N availability to the crop than broadcast N applications, as indicated by corn color measurements taken in early and mid June (Figure 2).
  - Slower availability could possibly explain why injection of urea did not increase yield even though it would prevent volatile N loss. However, this explanation does not fit well with the higher yields seen with injected anhydrous ammonia and ammonium nitrate, which were also more slowly available to the crop.
- Consistent with previous Missouri research, broadcast UAN solution was a poor N source for no-till corn.
  - Average yield was 25 bu/acre less than with ammonium nitrate.
  - This exactly matches the average 25 bu/acre difference seen in 20 previous experiments

in Missouri.

- Tie-up of N on residue is thought to be the main reason for poor performance of broadcast solution in no-till.
- Broadcast solution results in much more contact between residue and N than other sources & methods.
- Agrotain addition to UAN produced a 5 bu/acre yield increase (75% confidence).
  - This yield increase is clearly large enough to be profitable.
  - The fact that the yield increase was only 1 bu/acre when both Agrotain and DCD were added to UAN solution suggests that maybe the true yield response to Agrotain was smaller.
  - The average yield increase for both treatments with Agrotain added to UAN, 3 bu/acre, is probably a safer estimate of the benefit from Agrotain.
- Knife application of UAN solution produced a 9 bu/acre yield advantage over broadcast UAN (94% confidence). Knife application avoids contact between residue and fertilizer, and reduces tie-up problems.
  - Knife application appears to be more effective than Agrotain as a tool for improving performance of UAN in no-till corn.
  - Regardless of what management strategies we used for UAN, all other N sources were economically superior in these experiments.

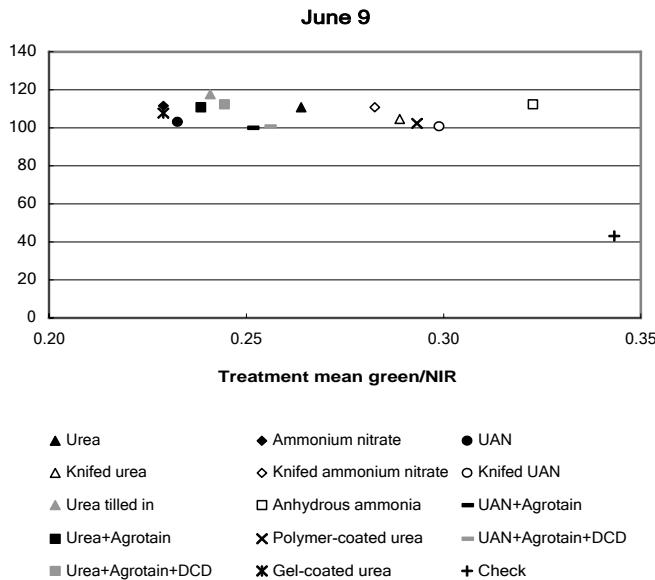


Figure 2. Color (reflectance) measurements indicated that polymer-coated urea (ESN) (shown as an 'x') and all knife-injected treatments (shown as open or hollow symbols) were more slowly available to corn than broadcast-applied treatments (solid symbols). Data points to the right were lighter green and those to the left were darker green on June 9, 2006.

## Progress Reports

### **Rice Nitrogen Management- Rates and Timing of Urea Fertilizer**

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Managing nitrogen fertilization in rice fields can be challenging for producers. In drill-seeded rice, urea fertilizer is usually broadcast immediately before flooding. Depending on irrigation well pump capacity, field size, and weather conditions, urea can be lost by volatilization while a field is being flooded. Optimum N rates vary by rice variety, soil texture, and previous crop rotations. Nitrogen can also be lost by denitrification if the urea is converted to nitrate in the soil.

For many years, rice agronomists have tried to develop an accurate method of determining whether supplemental nitrogen is needed at internode elongation growth stage. The Plant Area Board has shown good correlation to rice yield response to mid-season N in experiments. However, few growers use it because it is time consuming and requires tedious calculations. Likewise, Minolta SPAD chlorophyll meters have been used successfully in N rice research projects but are too expensive for most growers and consultants.

#### **Accomplishments in Year 2**

##### **Yardstick N test**

In 2004, we developed and tested a new inexpensive method using an ordinary, wooden yardstick for monitoring rice plant N. The objective of the experiments was to develop critical threshold values using simple yardstick measurements that farmers can use to determine whether midseason N is needed on a rice field. Field tests were conducted at Glennonville, Missouri on a Crowley silt loam soil and Portageville, Missouri on a Sharkey clay soil. At each location, plots were drill seeded (7.5-in row spacing) with Francis and Cheniere varieties. A split-plot design was used with varieties in main plots and N treatments in subplots. Five pre-flood urea nitrogen rates were applied at 0, 35, 70, 105 and 140 lb N/acre. One half of the subplot treatments received mid-season N and one half did not receive additional N. Subplots with mid-season N received 30 lb urea N/acre at internode elongation plus 30 lb urea N/acre one week later. Plots were mechanically harvested with a combine. Rice yields for each pre-flood N rate subplot without midseason N were subtracted from yields in pre-flood N rate subplots with midseason N.

Visual observations with a yardstick were made at green ring growth stage. Two center rows from each plot were selected. A wooden yardstick was placed halfway between the rice rows on the surface of floodwater. (The yardstick was positioned parallel to the rows.) Standing between adjacent rows and leaning over the sampling rows, we counted the inch numbers showing on the yardstick (not hidden by rice leaves) out of the 36 places possible. Two digit inch numbers were counted as one place. When a rice leaf obstructed the view of either of two digit numbers, we did not count that place.

Averaged across varieties, soils, and years; rice yields were highest when 140 lb N/acre was applied before flooding with no midseason N applications (Table 1 and 2). In eight out of twelve (2 varieties X 2 soils X 3 years) field observations, midseason N reduced rice yields in main plots with 140 lb N/acre applied pre-flood. In Cheniere rice in 2006, plots with only 70 lb N/acre applied pre-flood produced the highest yields.

Yield response to mid-season N was correlated with yardstick observations made at green ring (data not shown). We found that the most consistent critical yardstick value for making midseason N decision was twelve. In other words, when fewer than 12 digits were

showing little or no positive yield response to midseason occurred. Zero or negative rice yield responses were found from midseason when fewer numbers were showing. However, if rice is grown on a freshly graded field or a field with a history of lodging, midseason N may not be beneficial to rice yields unless fewer than 18 to 23 digits are showing at green ring.

### **Low population N test**

A field test was conducted at the Missouri Rice Research Farm in Glennonville, Missouri on a Crowley silt loam soil and the University of Missouri-Delta Center in Portageville, Missouri on a Sharkey clay soil and. The objective was to evaluate the yardstick method in sub-optimum rice plant densities in fields. The field was graded in the spring of 2004 and planted in soybeans. In 2005 and 2006, rice plots were drill seeded (7.5-in row spacing) with Wells cultivar at seeding rates of 5, 15, 25, and 35 seeds ft<sup>2</sup>. Three pre-flood nitrogen treatments were applied at 45, 90, and 135 lb urea N/acre. One half of the treatments received mid-season N while the other half received no mid-season applications. Plots with mid-season applications received 30 lb urea N/acre at internode elongation plus an additional 30 lb N/acre one week later. Plots were mechanically harvested with a combine.

Two methods of measuring leaf canopy were tested. For the first method, we used a macro developed at University of Arkansas for Sigma Scan<sup>TM</sup> image software to evaluate digital pictures based on the percentage of green leaf material in a given area. Digital photos were taken from each plot during the GR growth stage. A digital camera was positioned on 5-ft rod held at a 45-degree angle above the plot. Photos were taken at a downward angle over the rice rows. Photos were analyzed using Sigma Scan to determine the percentage of pixels in each picture that appeared green in color (near 510 nm in wavelength). For the second method, visual observations with a yardstick were also made at GR growth stage. The same procedure was used as in the “yardstick test” above.

At the Delta Center in 2006, yields were high even in low population treatments (Table 3). At the lowest seeding rate (5 seeds per foot), response to 135 lb N pre-flood plus midseason N was 17 bushels per acre compared to 45 lb N pre-flood. The reverse occurred at the highest seeding rate (35 seeds per foot). In this plant population, yield was 296 bushels per acre with only 45 lb N pre-flood. At the Missouri Rice Farm in 2006, rice plots were stunted from Command herbicide and water weevil injury (Table 4). At seeding rates less than 25 seeds per foot, adequate pre-flood N was needed to promote tillering.

### **Objectives for Year 3**

We will continue the rice nitrogen experiments in 2007 at the University of Missouri-Lee Farm and Missouri Rice Research Farm.

Table 1. Rice yields as affected by urea pre-flood and midseason nitrogen rates at the University of Missouri-Lee Farm at Portageville, Missouri on a Sharkey clay soil.

Nitrogen applications		Francis				Cheniere			
Preflood	Mid-season	2004	2005	2006	Avg change	2004	2005	2006	Avg change
-----lb N acre <sup>-1</sup> -----		-----bu acre <sup>-1</sup> -----							
0	0	113	169	160	+8	110	175	142	+23
0	30+30	125	180	162		130	182	183	
35	0	110	191	198	+2	129	194	184	+6
35	30+30	119	199	189		148	187	191	
70	0	118	212	210	0	134	200	205	-5
70	30+30	128	200	213		145	181	196	
105	0	125	208	219	-8	138	205	196	-9
105	30+30	137	184	208		143	168	200	
140	0	138	202	209	-5	145	185	195	-26
140	30+30	143	184	208		130	124	193	

Table 2. Rice yields as affected by urea pre-flood and midseason nitrogen rates at the Missouri Rice Research Farm at Glennonville, Missouri on a Crowley silt loam soil.

Nitrogen applications		Francis				Cheniere			
Preflood	Mid-season	2004	2005	2006	Avg change	2004	2005	2006	Avg change
-----lb N acre <sup>-1</sup> -----		-----bu acre <sup>-1</sup> -----							
0	0	142	125	95	+26	141	134	111	+18
0	30+30	164	150	126		164	163	113	
35	0	172	148	124	+21	151	146	133	+20
35	30+30	191	172	142		173	181	135	
70	0	185	172	105	+33	175	165	149	+3
70	30+30	201	197	164		179	190	129	
105	0	202	186	137	-4	182	169	133	+8
105	30+30	204	174	137		175	198	135	
140	0	211	207	152	-13	175	194	129	-14
140	30+30	194	203	135		162	177	117	

Table 3. Effect of rice seeding rate, preflood N and mid-season on lodging, leaf canopy at green ring growth stage and rice yields at the MU Delta Research Center in 2005 and 2006.

Preflood lb N/acre	Mid- season applied	Plant seed #/ft <sup>2</sup>	Height		Yardstick showing		Yield	
			2005	2006	2005	2006	2005	2006
			----inches---				-----bu/a----	
45	no	5	24	59	27	26	119	176
45	yes	5	24	22	29	27	130	178
90	no	5	24	22	21	24	155	175
90	yes	5	26	37	20	26	157	173
135	no	5	24	36	26	41	151	181
135	yes	5	24	22	25	26	134	195
45	no	15	25	23	23	38	172	199
45	yes	15	26	37	19	23	180	192
90	no	15	26	24	17	22	171	218
90	yes	15	26	24	14	21	175	216
135	no	15	28	23	14	23	153	218
135	yes	15	27	26	11	22	130	202
45	no	25	24	38	24	22	143	200
45	yes	25	26	27	18	21	187	223
90	no	25	26	25	18	20	168	225
90	yes	25	27	27	14	16	190	234
135	no	25	29	41	8	18	149	227
135	yes	25	28	71	9	61	152	216
45	no	35	26	37	19	39	166	212
45	yes	35	26	23	16	26	196	296
90	no	35	26	28	11	20	169	217
90	yes	35	28	28	8	14	175	230
135	no	35	29	28	12	31	169	225
135	yes	35	27	28	10	14	166	224

Table 4. Effect of rice seeding rate, preflood N and mid-season on lodging, leaf canopy at green ring growth stage and rice yields at the Missouri Rice Research Farm in 2005 and 2006.

Preflood lb N/acre	Mid- season applied	Plant seed #/ft <sup>2</sup>	Height		Yardstick showing		Yield	
			2005	2006	2005	2006	2005	2006
			----inches---		-----bu/a----			
45	no	5	23	21	36	36	15	25
45	yes	5	23	23	35	34	21	97
90	no	5	24	24	35	32	28	159
90	yes	5	18	24	36	22	29	129
135	no	5	24	23	36	30	25	133
135	yes	5	24	23	36	34	35	133
45	no	15	26	22	25	34	148	78
45	yes	15	28	21	21	34	200	58
90	no	15	30	21	21	36	163	52
90	yes	15	27	23	20	34	229	74
135	no	15	31	35	19	34	207	115
135	yes	15	28	25	21	31	216	104
45	no	25	28	36	24	33	192	116
45	yes	25	28	38	22	35	208	89
90	no	25	32	21	9	39	215	99
90	yes	25	32	20	10	34	245	38
135	no	25	32	23	13	32	248	38
135	yes	25	33	22	12	35	239	37
45	no	35	28	22	15	29	201	119
45	yes	35	29	25	18	30	222	122
90	no	35	31	24	15	25	221	128
90	yes	35	31	21	18	35	237	79
135	no	35	34	36	13	33	227	101
135	yes	35	32	35	11	34	245	90

## Finding Alternatives to Ammonium Nitrate as a Nitrogen Source for Tall Fescue Pastures

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Tall fescue grows on more than 12 million acres and provides forage for more than 4 million beef cattle in Missouri. About one-half of all tall fescue acres receive some nitrogen fertilizer in spring. Most of these applications are made in March or early April. Another time in which tall fescue acres are fertilized with nitrogen is in late-summer for stockpiling. Stockpiling tall fescue allows producers to extend the grazing season into winter and thereby cut winter feeding costs up to 70%.

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 “safest” source of N for forage production, particularly for late-summer applications, as the N in ammonium nitrate is much less likely to be lost to volatilization than is urea. However, ammonium nitrate has become a homeland security issue for the fertilizer industry because it can be used as an explosive. Additionally, few new ammonium nitrate plants have been constructed in the United States over the last 20 years, and given the current economic and security climate, domestic production is likely to decline over the next 10 to 20 years. These factors make ammonium nitrate more expensive than other N sources.

Given the pricing structure and potential problems with ammonium nitrate, urea is becoming more widely 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 parts of Missouri, 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.

Some old and new technologies might help alleviate these problems. The most promising solutions are to use a non-volatilizing N source such as ammonium sulfate or to treat urea fertilizer with a volatilization inhibitor. Ammonium sulfate is a sulfur rich (24% S), cost competitive, non-volatilizing source of nitrogen. In addition, several companies have developed products reported to reduce or eliminate volatilization of urea under field conditions. While the technology behind these “urea stabilization products” varies, there has been little “head-to-head” testing under typical field conditions. Technologies that allow safe application of urea would alleviate concerns from farmers and the fertilizer industry, but research is needed to determine which of these products would be most useful for fertilizing pastures in Missouri.

The **overall objective** is to develop research-based recommendations that help industry personnel and farmers determine the best alternative to ammonium nitrate fertilizer for spring and late-summer N applications to tall fescue pastures. Specifically, we are comparing ammonium nitrate to ammonium sulfate, urea, coated urea products, and mixtures of ammonium sulfate with urea and mixtures of ammonium sulfate with ESN polymer coated urea as a source of nitrogen for tall fescue.

### **Procedures:**

#### **Experiment 1 (Spring applied N treatments).**

*Treatments:* Established tall fescue was fertilized with 75 lb/acre N on 17 and 18 March 2005 at the Forage Systems Research Center near Linneus, MO and the Southwest Research and Education Center near Mount Vernon, MO. In 2006, fertilizer was applied at the same rate and time of year but the Bradford Research and

Extension Center in Columbia replaced the site at the Forage Systems Research Center. The sources of N are listed in Table 1 and include several urea based products already on the market, mixtures of some of these products, as well as untreated urea, ammonium sulfate, and ammonium nitrate as checks. The 75 lb/acre N rate was selected because it is a common fertilization rate for producers. Soil P and K levels are maintained at levels recommended by the University of Missouri Soil Testing Laboratory.

### **Experiment 2 (Late-summer applied N treatments).**

*Treatments.* Established tall fescue was fertilized with 75 lb/acre N in mid-August 2005 and 2006 at the same locations (but different plot areas) as described above for Experiment 1. The same sources of N were used as in Experiment 1. Our focus for this experiment was on autumn growth for stockpiling or deferred grazing regimes.

*Design.* Each treatment in both experiments is replicated five times in a randomized complete block design. Individual plots are 10 ft. x 35 ft.

*Measurements.* For the spring N application (Experiment 1) forage yield was measured in late May, late July and early October in 2005 and 2006. For the late-summer application (Experiment 2) yield was measured in late November or early December both years. Forage yield was determined by clipping a 4-ft. x 25-ft. strip in each plot using a Hege sickle bar harvester.

**At each date, sub-samples of forage harvested from each plot were retained for forage quality analyses {crude protein and *in vitro* true digestibility (IVTD)}. Samples were dried at 122° F in a forced-air oven before being ground to pass a 1-mm screen. Crude protein and IVTD were measured using near infrared reflectance spectroscopy.**

### **Preliminary Results:**

#### **Experiment 1**

Forage Yield. Our preliminary data for the first two years indicate that only the initial harvest responded to N applied in March. Nearly 80% of the annual dry matter was harvested at the first sampling date in May and few treatment differences were measured in the two subsequent harvests; thus yields are reported as annual totals for both years (Tables 2). We hypothesized that the “coated urea” products might have yielded greater the summer or autumn after application because of their slow N release activity. But this was not the case. Additionally, no one product was overwhelmingly consistent in producing high yields.

We noted that ammonium sulfate ranked in the top producing group at nearly all harvests and locations and its performance is perhaps the most surprising data from this experiment. Another somewhat surprising result was that ammonium nitrate, urea, and ammonium sulfate proved to be nearly equal N fertilizer sources for tall fescue in spring. We should note that in each year both locations received ample moisture within 5 days of the fertilizer application to get urea into the soil solution. An extended dry period after application of these products may have resulted in more volatilization of urea and thus a comparative advantage for the “coated urea” products.

Thus far, our preliminary data show that a spring application of 75 lb/acre N increased yields by approximately 2250 lb/acre over the unfertilized control or about 30 lb of additional forage for each pound of N fertilizer applied. Ground moisture affected this relationship drastically as the range was 987 to over 4800 lb/acre.

Soil Analysis. One of the questions posed while designing this research was whether the array of products and mixtures of products would alter the soil sulfate and/or nitrate such that forage quality might be enhanced. Another question regarded the fate of nitrate in the soil from different sources of N. At this point, we have

one year of data for two locations (Table 3). When ammonium sulfate was the only source of N applied, the concentration of sulfate in the soil solution was approximately two and three times greater, respectively, than those treatments that had mixtures with ammonium sulfate and those that contained no ammonium sulfate. Nearly all plots treated with ammonium sulfate showed a decline in soil sulfate concentration during the growing season. Soil sulfate concentrations from plots treated with only ammonium sulfate declined nearly 35%, those with ammonium sulfate mixed with another product declined nearly 25%, while there was virtually no decline in soil sulfate where no sulfate was applied. It is yet to be seen if sulfate levels in forage increased as a result of the greater plant available sulfur in the soil solution. We are monitoring soil pH and in the final report will describe how it is affected by yearly applications of ammonium sulfate.

Soil nitrate concentrations were rarely influenced by the source of N applied to the plots. However on 19 May 2006, treatments that included polymer coated urea showed 4.8 ppm nitrate, which was nearly 40% greater than treatments without polymer coated urea. It is interesting that this slow release activity of the polymer did not occur at the other location. The soil nitrate concentration averaged across locations and treatments was 2.9 ppm (data not shown).

Forage Quality. Only samples collected in Mt. Vernon from 2005 have been analyzed for nutrient content. Averaged over the three harvests, *in vitro* true digestibility of tall fescue was equal for nearly all treatments and averaged 69.8% when weighted based on yield. For crude protein, plots fertilized with ESN, ammonium sulfate, and mixtures of ESN and ammonium sulfate had about 1.0 percentage unit more crude protein at the first harvest (data not shown) than plots fertilized with other N sources. Averaged over the three harvests and all treatments, crude protein was 9.5%.

## **Experiment 2**

Forage Yield. For N applied in late-summer, many of the products yielded similarly and in most cases 10 or more of the products showed equal yields (Table 4). Consistently, urea, ammonium nitrate, and ammonium sulfate had comparable yields in three of four site-years. Tall fescue fertilized with urea yielded 35% less than that fertilized with ammonium nitrate during the dry autumn of 2005 in Mt. Vernon. Five days elapsed before any precipitation fell at the site and for 14 days only 0.20 inches of rain fell. This is a classic example of the risk associated with using urea as the N source for late-summer applications to pasture. Despite the promise in utilization of polymer coated urea to lessen this risk, it yielded less than most other treatments. The polymer coated urea has not shown much promise as a substitute for urea or ammonium nitrate for spring or late-summer N applications. We have yet to analyze the forage quality or soil fertility of samples collected in the autumn.

Table 1. Nitrogen fertilization treatments tested at the Southwest Research and Education Center near Mount Vernon, MO, the Forage Systems Research Center near Linneus, MO, and the Bradford Research and Extension Center near Columbia, MO. Each source is applied to deliver 75 lb/acre N. In addition, rate mixtures of ammonium sulfate/ESN, ammonium sulfate/urea and urea/ammonium sulfate/ESN are included.

Fertilizer Source	For mixture treatments	
	Rate applied (lb/acre S)	% N derived from ESN and/or Urea
Ammonium Nitrate		
Urea	-	-
Ammonium Sulfate	-	-
Urea treated with Agrotain	-	-
ESN polymer coated Urea	-	-
Nurea	-	-
Nurea with 10% polymer N	-	-
Ammonium Sulfate (10S)/Urea	10	88
Ammonium Sulfate (20S)/Urea	20	75
Ammonium Sulfate (40S)/Urea	40	53
Ammonium Sulfate (10S)/ESN	10	88
Ammonium Sulfate (20S)/ESN	20	75
Ammonium Sulfate (40S)/ESN	40	53
Equal N from Urea, Ammonium sulfate and ESN	28.6	67
Unfertilized Control	-	-

Table 2. Total annual forage yield of tall fescue fertilized with different nitrogen sources at the Southwest Research and Education Center near Mount Vernon, MO and the Bradford Research and Extension Center near Columbia, MO. Nitrogen was applied 16 March  $\pm$  2 days in both years at 75 lb/acre for each fertilizer source. Values are the total of three harvests taken during the growing season.

Fertilizer Source	Total Annual Forage Yield		
	Mt. Vernon 2005	Mt. Vernon 2006	Columbia 2006
	----- lb/acre -----		
Ammonium nitrate	<b>10232</b>	6178*	5679*
Urea	<b>9784</b>	<b>5736</b>	<b>5078</b>
Ammonium sulfate	10793*	<b>5697</b>	<b>5431</b>
Urea treated with Agrotain	<b>10518</b>	<b>6010</b>	<b>5069</b>
ESN polymer coated Urea	8983	4223	3947
Nurea	<b>10105</b>	<b>5359</b>	<b>5267</b>
Nurea with 10% polymer N	9376	<b>5590</b>	4772
Ammonium Sulfate (10S)/Urea	<b>9987</b>	<b>5755</b>	<b>4887</b>
Ammonium Sulfate (20S)/Urea	<b>9649</b>	<b>5871</b>	<b>5296</b>
Ammonium Sulfate (40S)/Urea	<b>9931</b>	<b>5748</b>	4370
Ammonium Sulfate (10S)/ESN	8856	4431	4246
Ammonium Sulfate (20S)/ESN	8513	4740	4213
Ammonium Sulfate (40S)/ESN	9492	<b>5767</b>	<b>4870</b>
Equal N from Urea, Ammonium sulfate and ESN	<b>9613</b>	<b>5250</b>	<b>5034</b>
Unfertilized Control	5943	3444	2658
LSD (0.05)	1228	828	845

\* Highest numerical yield within a column.

Bolded values within a column do not differ from the highest numerical yield.

Table 3. Soil sulfate concentrations at the Southwest Research and Education Center near Mount Vernon, MO and the Bradford Research and Extension Center near Columbia, MO. Nitrogen was applied 16 March  $\pm$  2 days at 75 lb/acre for each fertilizer source. Soil samples were collected to a six-inch depth on the dates reported below.

Fertilizer Source	Columbia			Mt. Vernon		
	6/1/06	8/23/06	10/19/06	5/19/06	7/27/06	10/11/06
	----- sulfate ppm -----					
Ammonium nitrate	6.1	6.5	6.2	4.5	4.8	4.0
Urea	5.9	6.2	5.4	4.8	5.1	5.3
Ammonium sulfate	19.1	10.8	12.4	12.0	8.2	9.2
Urea treated with Agrotain	6.1	6.7	4.6	5.1	4.9	4.8
ESN polymer coated Urea	6.2	6.4	5.0	5.2	5.1	4.3
Nurea	5.8	6.2	5.4	4.9	4.8	4.2
Nurea with 10% polymer N	5.7	6.1	6.3	4.7	4.8	4.8
Ammonium Sulfate (10S)/Urea	7.2	7.8	7.6	5.9	5.8	3.9
Ammonium Sulfate (20S)/Urea	8.8	7.2	6.1	7.0	5.5	5.6
Ammonium Sulfate (40S)/Urea	11.7	8.3	7.6	7.7	6.4	5.5
Ammonium Sulfate (10S)/ESN	7.4	6.5	6.2	5.8	5.7	4.6
Ammonium Sulfate (20S)/ESN	8.6	6.5	5.4	6.9	5.3	5.3
Ammonium Sulfate (40S)/ESN	11.8	8.0	6.9	7.7	6.1	6.1
Equal N from Urea, Ammonium sulfate and ESN	9.6	7.7	6.9	6.3	5.8	5.5
Unfertilized Control	6.6	6.6	5.8	5.4	5.3	5.2
LSD (0.05)	1.8	1.4	2.3	1.4	0.9	2.1

Table 4. Yield of autumn accumulated tall fescue fertilized with different nitrogen sources at the Southwest Research and Education Center near Mount Vernon, MO, the Forage Systems Research Center near Linneus, MO, and the Bradford Research and Extension Center near Columbia, MO. Nitrogen was applied August 17 ± 1 day in both years at 75 lb/acre for each fertilizer source. Forage was allowed to grow until harvested on the date reported below.

Fertilizer Source	Autumn accumulated yield			
	Mt. Vernon 12/2/2005	Linneus 12/13/2005	Mt. Vernon 11/29/2006	Columbia 11/28/2006
	-----lb/acre-----			
Ammonium nitrate	1932*	<b>1853</b>	<b>1918</b>	<b>2700</b>
Urea	1245	<b>1879</b>	<b>2201</b>	<b>2865</b>
Ammonium sulfate	<b>1579</b>	2174*	<b>2245</b>	<b>2787</b>
Urea treated with Agrotain	<b>1523</b>	<b>1820</b>	<b>1880</b>	<b>2696</b>
ESN polymer coated Urea	1249	<b>1795</b>	1549	2117
Nurea	<b>1437</b>	1655	<b>2188</b>	<b>2738</b>
Nurea with 10% polymer N	988	1681	<b>2176</b>	<b>2725</b>
Ammonium Sulfate (10S)/Urea	<b>1696</b>	<b>1929</b>	<b>2282</b>	<b>2539</b>
Ammonium Sulfate (20S)/Urea	1259	<b>1904</b>	<b>2137</b>	2877*
Ammonium Sulfate (40S)/Urea	<b>1903</b>	<b>1872</b>	2327*	<b>2763</b>
Ammonium Sulfate (10S)/ESN	<b>1856</b>	1717	1664	<b>2378</b>
Ammonium Sulfate (20S)/ESN	<b>1741</b>	1638	<b>2079</b>	2243
Ammonium Sulfate (40S)/ESN	<b>1761</b>	<b>2008</b>	<b>1882</b>	<b>2547</b>
Equal N from Urea, Ammonium sulfate and ESN	<b>1822</b>	<b>1953</b>	<b>2312</b>	<b>2819</b>
Unfertilized Control	492	881	834	1721
LSD (0.05)	522	430	616	586

\* Highest numerical yield within a column.

Bolded values within a column do not differ from the highest numerical yield.

Timetable for proposed research: **These studies began in March 2005 and are scheduled to end in December 2007 (three years of study). The table below gives a brief summary of the project's activities. (\* indicates a task to be done on an annual basis throughout the three-year study)**

Take soil core samples for initial soil nitrogen determinations for spring application.	3/15/2005*
Apply N fertilizer sources at the rate of 75 lb/acre to appropriate plots for spring application experiment.	3/15/2005*
Harvest plots for forage yield and retain subsamples for forage quality analysis from spring fertilized plots. Take soil cores from each plot to determine residual soil N and sulfate after each harvest.	5/20/2005 and 7/15/2005, and 10/5/2005*
Take soil core samples for initial soil nitrogen determinations for late-summer N application.	8/15/2005*
Apply N fertilizer sources at the rate of 75 lb/acre to appropriate plots for late-summer application experiment.	8/15/2005*
Harvest plots for forage yield and retain subsamples for forage quality analysis from late-summer fertilized plots. Take soil cores from each plot to determine residual soil N and sulfate.	12/15/2005*
Analyze latest results & report findings to Fertilizer/Ag Lime Advisory Council	12/15/05*
Incorporate latest findings into soil testing reports, grazing school curriculum and educational workshops. Work with popular press on articles.	8/2008
Prepare updated MU guide on fertilization of pastures with different N sources.	9/2008
Prepare and submit an article on this research to a peer-reviewed journal.	10/2008

Application/transfer of knowledge: **As we develop a more complete data set, we intend to transfer our results in four ways. First, we will incorporate the results and recommendations from this study into the curriculum of the Missouri Grazing Schools. Second, we will work with the Soil Fertility Working Group and the MU Soil Testing Laboratory to refine the recommendations printed on soil testing results. Third, we will publish a guidesheet on N fertilization of pastures in Missouri that incorporates the findings from this research. Finally, we will prepare articles to be published in statewide and national magazines such as Missouri Ruralist, Graze, Stockman Grass Farmer and scientific (peer-reviewed) journals.**

# Impact of N Fertilizer Source and Drainage on Spatial Variation in Nitrogen Use Efficiency and Environmental N Loss

Peter Motavalli, Kelly Nelson, and Steve Anderson

## Accomplishments for First Year:

Research was initiated in 2006 to compare the relative corn growth response and environmental N losses after application of different N fertilizer sources under a range of soil moisture conditions imposed by drainage and irrigation, to examine spatial differences in soil N transformations and N losses during the growing season between drainage tile and subirrigation lines, and to evaluate the relative cost-effectiveness of use of several N fertilizer sources and drainage and irrigation systems to control soil moisture conditions that may reduce N use efficiency.

A field trial was established in 2006 at the University of Missouri Drainage and Subirrigation (MUDS) trial. The MUDS trial was initiated in 2001 at the MU Ross Jones Farm in Northeast Missouri to evaluate the use of subsurface tile drainage at different drain tile spacings with or without subsurface irrigation to improve soybean and corn production. For this study, 150 ft long plots planted to corn (Roundup Ready and Bt resistant variety DKC61-68) containing treatments of: i) no drainage or subirrigation (NIN), ii) drainage with tile drains spaced 20 ft apart and no subirrigation (NID), iii) drainage with tile drains spaced 20 ft apart and subirrigation (SUB), and iv) no drainage and overhead sprinkler irrigation (OND) was split into a control and N fertilizer treatments of either spring-applied pre-plant injected anhydrous ammonia, or broadcast-applied urea-ammonium nitrate (UAN) solution, urea, or polymer-coated urea (PCU) (ESN<sup>®</sup>, Agrium) applied at a rate of 150 lbs N/acre. Each treatment combination had 3 replications. All plots were chisel plowed in the fall (11/10/05) and N treatments incorporated in the spring with a field cultivator (4/11/06). Based on preliminary soil test results, no additional P and K fertilizer or lime were applied prior to planting.

Changes in soil inorganic N ( $\text{NH}_4^+$ -N and  $\text{NO}_3^-$ -N) content and soil gravimetric water content due to the irrigation/ drainage treatments were monitored by periodic soil sampling using a Gator-mounted Giddings hydraulic soil core sampler at depths of 0-6, 6-12, 12-18, and 18-24 inches. In the NID and SUB treatments, samples were collected by compositing 3 subsamples taken at a distance of 0, 5, and 10 ft from the drainage or subirrigation lines. For the anhydrous ammonia treatment, the subsamples were taken in the injection band and two distances towards the next band. All samples were collected in coolers and stored in a cold room before processing. These samples are still being analyzed and, therefore, no data is presented in this report regarding changes in soil inorganic N and soil water content.

Silage yields were determined by harvesting 15 to 25 ft of corn plants at physiological maturity in one row either above the tile line or 10 ft from the tile line. All harvested plants were weighed and a subsample taken to determine moisture content and analyze for tissue N (data not shown). Both the silage yield and N content will be used to calculate crop N recovery of applied fertilizer N. Grain yields and grain moisture were determined on approximately 25 ft of row with a two row plot combine.

Table 1 shows the grain yields resulting from the different irrigation/drainage and N treatments and the effects of distance from the tile lines in the non-irrigated, drained and sub-irrigated and drained plots. Sufficient rainfall was present in 2006 for all the irrigation/drainage treatments to show crop N response to the different N fertilizer sources. However, highest yields were obtained with the overhead irrigation treatment and directly over the subirrigation lines. Except for the anhydrous treatment, a small yield increase of approximately 15 to 20 bu/acre was also observed with drainage (NID) compared to the

non-irrigated, non-drained treatment (NIN). No significant yield differences were observed over the tile drain and between the tile drain with the NID treatment, but yield differences of between 5 to 101 bu/acre were observed within the subirrigation (SUB) treatment (Table 1). This result may indicate that the diffusion of water from the subirrigation line is not adequate to provide sufficient water for the interrows between the tile lines. The results of the soil sampling will indicate the impact of this spatial difference in soil water content on the fate of applied N from the different N sources.

An additional observation was that over the subirrigation line which was relatively wet, both PCU and urea N sources caused significantly higher grain yields than anhydrous ammonia and UAN solution (Table 1). This result contrasts with our previous findings from comparisons of PCU, urea and anhydrous ammonia in which we have observed improved crop performance with applications of PCU and anhydrous ammonia compared to urea under wet conditions.

### **Outreach and Training:**

A M.S. graduate student in soil science and undergraduate students majoring in environmental science has been involved in working on this project as part of their training. The first year research results will be presented to growers and agricultural professionals at the 2007 Greenley Center Field Day 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:

1. To compare the relative corn growth response and environmental N losses after application of different N fertilizer sources under a range of soil moisture conditions imposed by drainage and irrigation.
2. To examine spatial differences in soil N transformations and N losses during the growing season between drainage tile and subirrigation lines.
3. To evaluate the relative cost-effectiveness of use of several N fertilizer sources and drainage and irrigation systems.

The field studies will be repeated for a second year to assess variation in climate on crop performance and N use efficiency. In addition, we will examine the fate of the different N fertilizer sources under the variable soil water content conditions created by the irrigation and drain systems. An economic analysis will be conducted to determine which of the combination of irrigation and drainage systems and N fertilizer sources would be cost-effective for Missouri farmers.

Table 1. Grain yields in 2006 at the Ross Jones Farm due to differences in N fertilizer sources, drainage and irrigation systems and the distance between tile lines. “Over” refers to harvest rows over the tile line and “Between” refers to harvest rows between the tile lines

N treatment	NIN <sup>†</sup>	OND <sup>§</sup>	NID <sup>‡</sup>			SUB <sup>¶</sup>		
			Over	Between	LSD <sub>(0.05)</sub> <sup>*</sup>	Over	Between	LSD <sub>(0.05)</sub>
			----- bu/acre -----					
Control	81.3	113.8	96.1	97.5	NS	104.9	99.9	NS
Anhydrous	135.3	240.0	135.3	137.5	NS	202.8	157.9	NS
Urea	130.7	237.9	145.1	141.9	NS	239.0	160.8	12.6
PCU	126.9	240.5	149.1	138.3	NS	253.5	152.6	16.6
UAN	121.8	231.5	141.3	145.9	NS	208.8	148.6	30.0
LSD <sub>(0.05)</sub>	27.0	17.6	28.2	18.8		22.9	10.0	

\* LSD<sub>(0.05)</sub> = Least Significant Difference at p < 0.05; NS = Not statistically significant

<sup>†</sup> NIN = No irrigation, no drainage

<sup>§</sup> OND = Overhead irrigation, no drainage

<sup>‡</sup> NID = No irrigation, drainage

<sup>¶</sup> SUB = Subirrigation, drainage

# **Phosphorus Management**

## **Final Reports**

### **Characterizing the effects of excessive phosphorus rates on soil test phosphorus**

John A. Lory and Peter C. Scharf, University of Missouri

Applications of poultry litter, swine slurry, lagoon sludge and other manures can result in phosphorus applications that exceed agronomic need. Some lagoon sludge material can have an nitrogen:phosphorus (N:P) ratio substantially less than 1 whereas N:P ratio of harvested crops typically run 4:1 to 8:1.

Applying these rich phosphorus materials based on crop N needs can result in P application rates that exceed crop removal by a factor of 10 or more.

Rapid increase in soil test P from high rates of applied P may be beneficial to crop yields on P deficient soils. Previous research has shown P application rate and soil test P are typically are linearly related in the agronomic range.

The objective of this research was to see if high rates of P application create conditions likely to result in higher P losses from agricultural fields.

#### **Methods and Materials**

Phosphorus was applied to established fescue stands at three locations.

- Mexico soil (Fine, smectitic, mesic Aeric Vertic Epiaqualfs), University of Missouri South Farm, Columbia MO.
- Lagonda soil (Fine, smectitic, mesic Aquertic Argiudolls), University of Missouri Forage Systems Research Farm, Linneas MO.
- Creldon soil (Fine, mixed, active, mesic Oxyaquic Fragiudalfs), University of Missouri Southwest Research Center, Mt. Vernon MO.

Phosphorus was surface-applied as ammonium polyphosphate (AP) solution at the rate of 0, 67, 111, 177, 892, and 2,231 kg P ha<sup>-1</sup>. Treatments were replicated three times in a randomized block design. Plots were 3.3 m<sup>2</sup> and any plot down-slope from another plot was separated by 14 m of fescue sod. Plots were mowed every 2 to 4 weeks during the growing season with a mulching mower returning all forage growth to the surface of the plot.

Soil samples were taken 31, 198, 408 and 607 days after P application on the Mexico and Lagonda soils and 31, 195 and 580 days after application on the Creldon soil. Only the 0 P control and the highest 3 P rates were sampled on the last sampling date.

Two sets of 20 cores were removed from each plot at each sampling. Sampling depth was 15 cm. The first set of cores were placed in a bucket, mixed well and subsampled. The second set of cores was divided into three, 5-cm sections (0 to 5 cm, 5 to 10 cm and 10 to 15 cm). The 4 samples from each plot were dried to a constant weight at 35°C, pulverized with a chain flail mill and analyzed for Bray-1 P concentration.

## Results and Discussion

### Agronomic P rates

In this experiment, two consecutive sampling times with the same slope in the relationship of added ammonium polyphosphate versus Bray-1 soil test was interpreted as evidence that Bray-1 soil test levels had equilibrated. Added P equilibrated with the soil (0- to 5-cm increment) in less than 30d for the Lagonda and Creldon soils and in less than 199 days for the Mexico soil according to this standard (Fig. 1). The slope value of the surface soil at equilibration was significantly affected by soil type ( $P=0.02$ ). Orthogonal contrasts indicated the Lagonda soil was significantly more responsive to added P than the Mexico ( $P=0.10$ ) and the Creldon ( $P=0.01$ ) soils.

Surface applied P increased B1-STP in layers of soil below the surface (data not shown). Mean effect of 1 kg ha<sup>-1</sup> added P was to raise Bray-1 soil test P 0.2 ug g<sup>-1</sup> in the 0- to 5-cm layer, 0.012 ug g<sup>-1</sup> in the 5- to 10-cm layer and 0.005 ug g<sup>-1</sup> in the 10- to 15-cm layer. There was evidence that added P moved into the soil layers below the surface after the first sampling date. The highest values for B1-STP in the 2 sub-surface layers were observed on the last sampling date (198 d for the Creldon; 408 d for the Lagonda and Mexico).

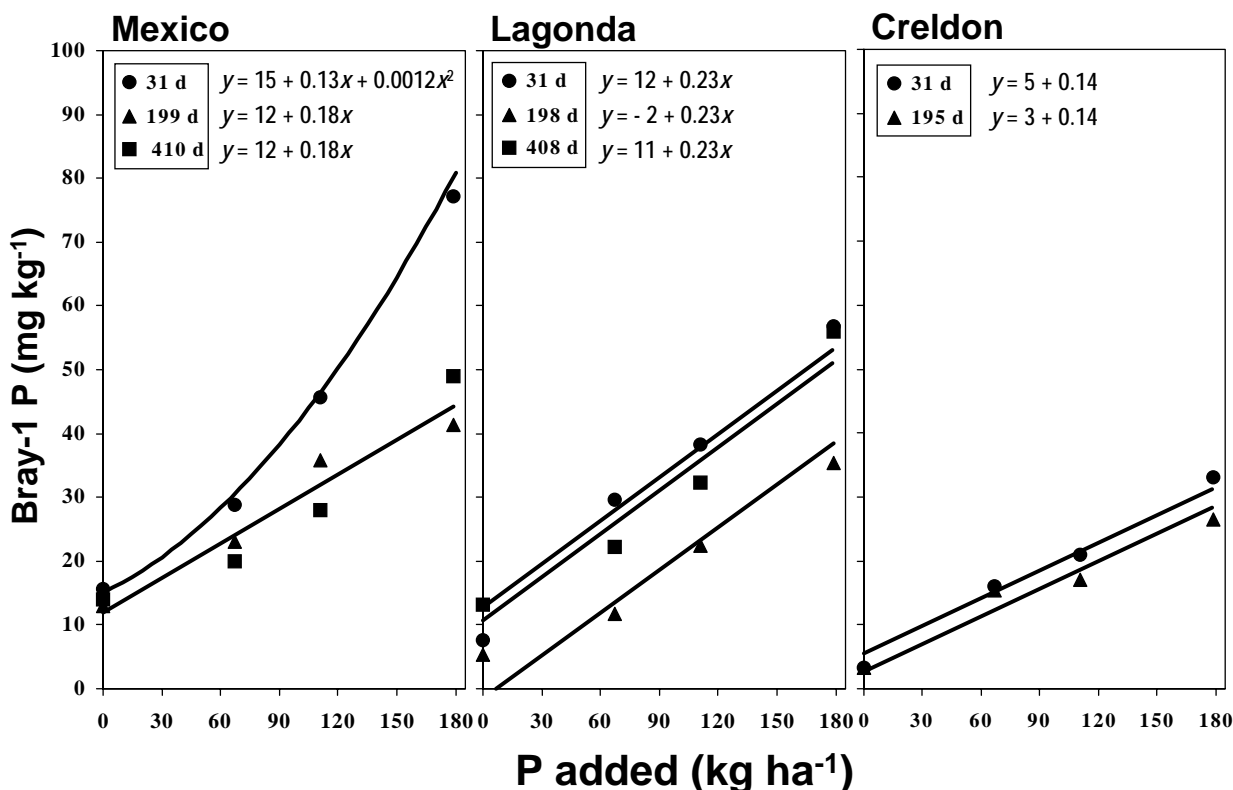


Figure 1. The effect of agronomic rates of ammonium polyphosphate, soil type and sampling date on Bray-1 soil test phosphorus in the surface 0- to 5-cm soil depth.

*Excessive P rates*

Response to high rates of P addition resulted in a linear response in Bray-1 soil test P in the 0- to 5-cm soil depth (Fig. 2). Initially, high rates of P resulted in higher soil test values than predicted by agronomic rates. Agronomic rates (see Fig. 1) were projected to the high rates applied (see dotted line in Fig. 2). By the last sampling date all soil test levels matched the levels predicted by agronomic rates (Fig. 2). Phosphorus movement below 5 cm was greater than predicted by agronomic rates and increased with time (data not shown).

There was evidence that soils differ in the speed of equilibration with these high rates. There was little change in slope coefficient between 408 and 604 d in the Lagonda soil implying these soils were approaching equilibrium and the equilibrium was similar to what was predicted by agronomic response. Regression analysis indicated the slope coefficient continued to decrease from day 410 to day 607 in the Mexico soil implying it was taking longer to equilibrate.

The rate of equilibration for the excessive rates of P was substantially slower than what had been observed with agronomic rates of P. Agronomic rates equilibrated within 31 days and did not exceed 200 days. Equilibration exceeded 200 days on all soils with excessive rates. These results imply that excessive rates increase the potential for phosphorus loss from such fields because they maintain a higher than predicted soil test P level for an extended period of time.

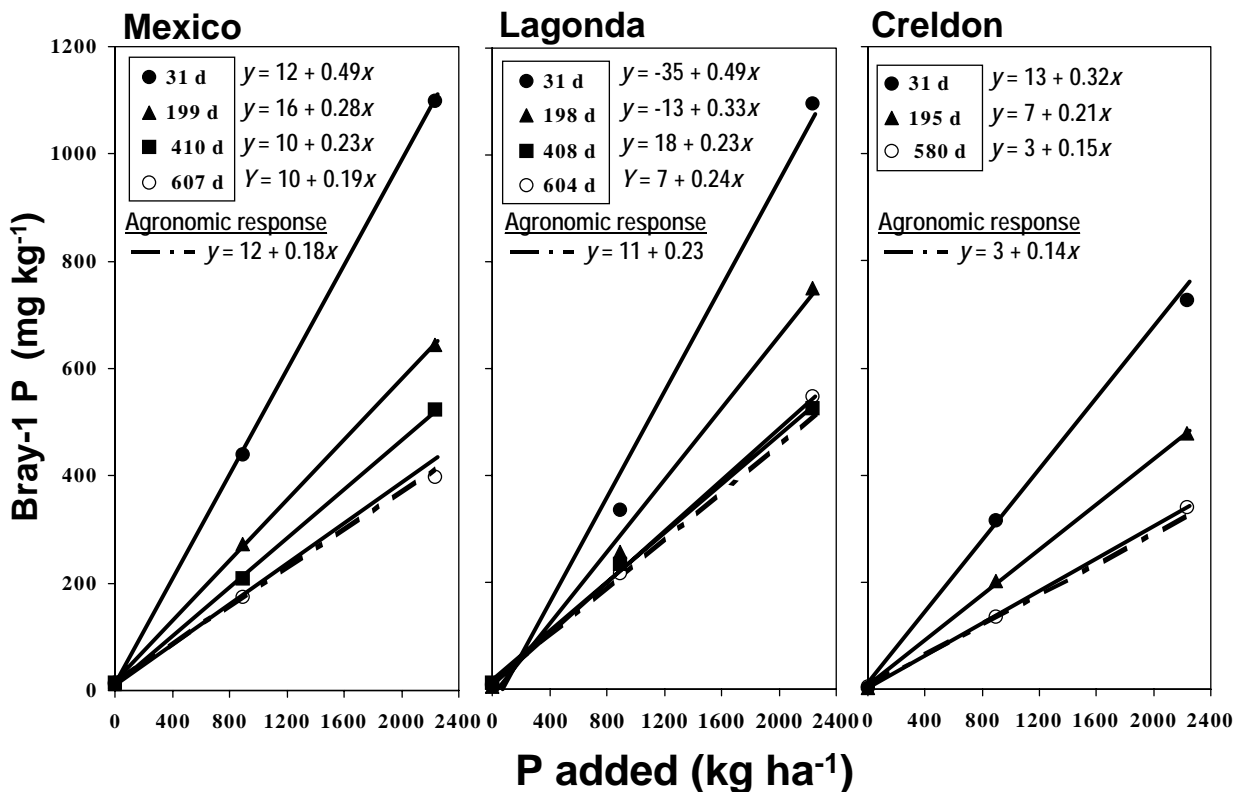


Figure 2. The effect of high rates of ammonium polyphosphate rate, soil type and sampling date on Bray-1 soil test phosphorus in the surface 0- to 5-cm soil depth. Agronomic response was based on the last sampling date in Fig. 1.

### Soil sampling depth effect

A 15-cm (6-inch) taken too soon after a surface P application of both agronomic (Fig. 3A) and excessive (Fig. 3B) rates will lead to erroneous estimates of soil test P levels. Initially, 15-cm cores under estimated Bray-1 soil test P. Eventually the phosphorus in the soil equilibrates eliminating the effect (Fig. 3). It takes substantially longer for the effect to disappear with excessive rates of P.

The effect is likely due to soluble P in the surface soil being fixed during sample processing with lower layers. On soils where the three layers are sampled separately, the surface soil rich in recently applied P is kept separate from the low-P subsoil. In the 15-cm core the three regions of soil are mixed allowing the soluble P in the surface soil to react with the lower-P sub-surface soil while the sample is being transported and air dried.

The implication of these results is that shallow cores are needed to accurately characterize surface soil test phosphorus levels for a significant period after excessive P applications.

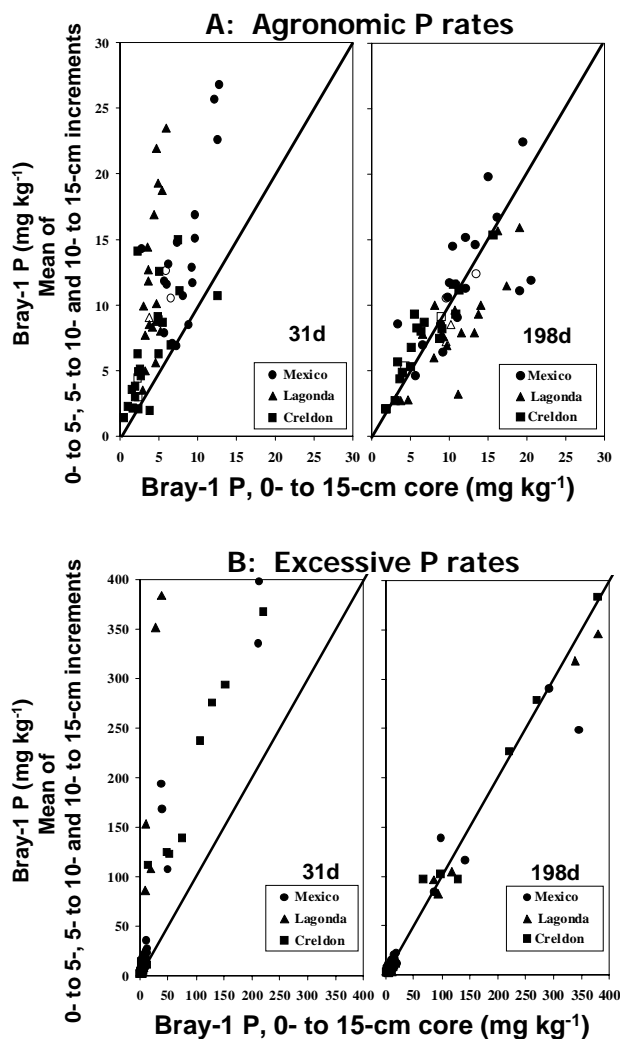


Figure 3. Bray-1 soil test phosphorus of 0- to 15-cm cores versus the mean value of the 0- to 5-cm, 5- to 10-cm, and 10- to 15-cm cores.

## **Conclusions**

Agronomic rates of P caused a linear increase in soil test P although soils differed in time needed to reach their equilibration point.

High P rates required substantially longer periods to equilibrate and resulted in higher levels of soil test P below 5 cm than was predicted by agronomic rates. The equilibration period was less than 31 days for agronomic rates on 2 of 3 soils but greater than 195 days for all soils at high P rates. During the equilibration period there was a greater risk to water quality from a large application on a smaller field than smaller applications spread over a larger area.

We recommend phosphorus application rates not exceed in a single application the amount needed to raise Bray-1 soil test P 30 mg P kg<sup>-1</sup> in the surface 5 cm of the soil or 20 mg P kg<sup>-1</sup> in the surface 15 cm of soil. These guidelines would allow building soil test phosphorus from almost any soil test level up to or exceeding the agronomic optimum with one P application.

## Soil-specific Phosphorus Rates: A Laboratory Analysis

John A. Lory and Peter Scharf, University of Missouri

The relationship between the amount applied phosphorus (P) and the resulting impact on soil test levels is an important component of soil test recommendations. Many states, including Missouri, have a buildup component in their soil test recommendations that estimates the quantity of fertilizer needed to raise soil test P to a target level considered optimum for crop production. The equation currently in use in Missouri applies the same equation to all soils in Missouri and is curvilinear recommending more fertilizer per unit of soil test change on low testing soil than soil close to the optimum soil test P level (Brown et al., 2004).

Phosphorus applied to soil caused a linear increase in soil test P in 28 of 36 reviewed field trials (Table 1). Three of the trials demonstrating a curvilinear response were Missouri studies (Kroth and Mattas, 1982; Kroth and Meinke, 1981) and all non-linear responses were associated with studies that included soils with very low available soil test P (Bray-I P  $\leq$  5 ppm). In some soils there apparently was a mechanism that required significantly more added P to raise soil test P on very low testing soils.

Differences among soils in their response to added phosphorus has been found to be significant (e.g. Cox, 1994). However, only one state varies buildup P applications among soils; Vermont measures extractable aluminum (Morgan's extract) in soil samples and uses that information to adjust the quantity of P recommended for soil test buildup of P.

The three objectives of this lab study were to:

1. Test if Missouri soils responded linearly to additions of phosphorus;
2. Determine if soils differ in the response of soil test P to P additions; and
3. Determine if there are indicators easily available to a soil test lab that can be used to these predict differences among soils if they exist.

### Methods and Materials

We worked with MU Extension regional faculty to identify a diverse set of 20 soils from around Missouri. From each location we collected 5 kg of soil from the surface 15 cm of the soil profile. Collected soils were air-dried and ground before treatments were applied.

Table 2 summarizes selected characteristics of the 20 collected soils. Soil type was determined from the soil survey description of the location where the sample was obtained. Subsamples of untreated soils were extracted with Bray-I (Bray and Kurtz, 1945) and Mehlich-III (Mehlich, 1984) solution and analyzed by ICP for aluminum (Al), iron (Fe) and P. Standard Missouri soil sampling procedures were used to analyze the samples for Bray-I P, cation exchange capacity (CEC) and organic matter. Samples were fractionated to determine the percent composition of sand, silt and clay. Field capacity moisture content was also determined.

Phosphorus sorption ratio of each soil was estimated using the Al, Fe and P concentrations in either the Bray-1 or Mehlich-3 soil extract (Maguire and Sims, 2002). The sorption ratio was calculated as the ratio of P to the sum of Al plus Fe concentrations measured in mmol/kg soil.

Five P treatments (3 replicates) were added to 150 g of soil (based on oven-dry weight) as diammonium phosphate. The treatments were 0, 0.01, 0.03, 0.05, and 0.08 mg P/g soil. These rates were equivalent to 0, 42, 125, 209, and 334 lbs phosphate/acre assuming incorporation into a 15-cm deep plow layer with a bulk density of 1.35 g/cm<sup>3</sup>. The phosphorus treatment was sprayed onto the air-dried soil in a volume of

water needed to bring soil to near field capacity water content while mixing the soil with a plastic spatula in a plastic cup. Water was then added to the soil to bring the soil to the target weight at field capacity. Cups were covered with a cap with an air exchange hole, placed in the dark and incubated at 20°C. Initially, cups were shaken and water was added to return the cups to field capacity water content every ten days for the first month. Moisture loss was such that the time between water additions was expanded to 20 days.

Cups were sampled 33, 91 and 235 days after treatments were applied. At sampling time cups were adjusted to the target weight, approximately 10g soil (dry weight) was removed, and the cups were reweighed and the new target weight was recorded. Samples were dried to constant weight at 30°C. Dried samples were extracted using Bray-I procedure and phosphorus was determined using colorimetric analysis.

This analysis focuses on the day 235 sampling date. Data was normalized by subtracting the control value and the regression analysis was performed on the non-zero treatments. Regression methods were used to assess the impact of added P on soil test P and to correlate the responsiveness of soil to added P with characteristics of the collected soils.

## Results

The mean response of all locations was linear and the mean response was equivalent to 4.5 lbs P<sub>2</sub>O<sub>5</sub> needed to raise soil test P 1 lb/acre. The soil-by-rate interaction was significant ( $P<0.01$ ) implying that soils differed in their response to add P.

Regression analysis by soil entry indicated added P caused a linear response in soil test P in 19 of 20 of soils 235d after P addition; only in the Putnam soil collected from a pasture was the quadratic term in the regression model significant ( $P\leq 0.01$ ). Response to added P ranged from 3.0 to 7.8 lbs phosphate added to raise soil test P 1 lb/acre (Fig. 1).

Response to added P was highly variable in the Bootheel region (Fig.1). When the Bootheel data was removed, region is a significant descriptor of variability in soil test response ( $P=0.03$ ). The Claypan region required significantly more phosphate to raise soil test P than all the remaining regions except the Osage region.

Phosphorus sorption ratio estimated from Mehlich-3 extraction was the most significant descriptor of phosphate fertilizer needed to raise soil test P (Fig. 2). Soils with a higher fraction of phosphorus sorption required less phosphate fertilizer to raise soil test phosphorus. Stepwise regression methods indicated that adding soil pH to the model increased  $r^2$  to 0.41 ( $P=0.06$ , positive correlation). Bray-I P sorption ratio provided a much lower correlation ( $r^2=0.09$ ).

## Discussion

This lab study indicated there are opportunities to improve the buildup equation used in Missouri soil test recommendations. Added phosphorus resulted in a linear increase in soil test P. This project also determined that soils differed in the quantity of phosphate needed to raise soil test P one unit. Soil test regions had some value in differentiating soil phosphate build up rates.

Any system that successfully incorporates soil-specific phosphorus buildup rates must use parameters that are easily obtained as part of the soil testing process. Soil region could be selected by the client as part of submitting a sample or based on the county of origin for the sample. The correlation of P sorption ratio (Mehlich-3 method; Fig. 2) with differences in soil phosphate buildup rates provides hope that a chemical

test could be used. This test would require using a Mehlich-3 extraction procedure and analyzing Al, Fe and P on the ICP, all procedures not currently used by the University of Missouri soil test laboratory. Unfortunately, the sorption ratio calculated from the Bray-1 solution did not show promise. Previous research has shown P sorption ratio calculated using Mehlich-3 is highly correlated with and can be used as a replacement for the more traditional approach to calculating P sorption ratio based on oxalate extractable P (Maguire and Sims, 2002).

There is an apparent conflict in our finding that less phosphate was needed to raise soil test P on soils with higher P sorption ratios yet phosphate added to 19 of 20 soils resulted in a linear response to added P. Intuitively, soils that need less phosphate to raise soil test P at higher P sorption capacities should be more responsive to higher rates of P. Yet we did not observe this in our results. Observed P sorption ratios were low on all soils tested (mean=0.05). Adding agronomic rates of P may have a small impact on P sorption ratio making this more a soil characteristic than an active process affecting soil test buildup rates.

This research supports the need to further investigate opportunities to improve the Missouri soil buildup equation. Direct application of these results laboratory to field conditions should be done with caution. However we recommend additional lab and field work to confirm the conclusions from this study that soil test buildup rates vary among soils and are best modeled as a linear response to added P.

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Table 1. Field studies evaluating the effect of added P on soil test P.

Data source	Soil Type	Location	P source	Duration	Extractant	Soil depth	STP range (units)	Basis <sup>1</sup>	Response	Regression Coefficients <sup>2</sup>		
										a <sub>1</sub>	b <sub>1</sub>	c <sub>1</sub>
						cm						
Barber, 1979	Aquic Argiudoll	Indiana	Fertilizer	25 yrs. – A	Bray-I	15	10 - 70 (ppm)	Net	Linear	21	0.06	-
Brown et al., 1990	Mollic Fragiudalf	Missouri	Fertilizer	4 yrs.	Bray-I	7.5	7 – 67 (ppm)	Total	Linear	8	0.14	-
Cox et al., 1981	Typic Hapludult	N. Carolina	Fertilizer	1 yr.	Bray-I	NR <sup>3</sup>	5 – 35 (ppm)	Total	Quadratic	4	0.01	0.00005
	Typic Umbraquult	N. Carolina			Bray-I		25 – 200		Quadratic	25	0.16	0.0002
	Waskada cl	Canada			Olsen		5 – 200		Linear	5	0.50	-
	Carroll c	Canada			Olsen		5 – 200		Linear	5	0.50	-
	Haverhill Wood Mountain cl	Canada			Olsen		10 – 150		Linear	12	0.35	-
	Sceptre c	Canada			Olsen		5 – 200		Linear	5	0.50	-
Batcombe cl	England	Olsen	10 – 25	Linear	8	0.10	-					
Evans et al., 1977	Udic Haploborolls	Minnesota	Manure	4 yrs	Bray-I	30	10-170 ppm	Net	Linear	34	0.02	-
Fageria, et al., 1997	Typic Haplaquept	Brazil	Fertilizer	1 yr.	Mehlich-III	20	5 – 25 (ppm)	Total	Quadratic	5	0.002	0.00010
			Fertilizer	1 yr.	Mehlich-III	20	1 - 25	Total	Quadratic	0.7	0.020	0.00007
Kroth and Mattas, 1982	Umbric Fragiudalf	Missouri	Fertilizer	6 yrs	Bray-I	7.5	3 – 30 (ppm)	Net	Quadratic	7	0.14	0.0006
	Umbric Fragiudalf	Missouri	Fertilizer	5 yrs.	Bray-I	7.5	4 – 32 (ppm)	Net	Quadratic	9	0.2	0.0008
Kroth and Meinke, 1981	Shelby silt loam	Missouri	Fertilizer	7 yrs.	Bray-I	7.5	3 – 30 (ppm)	Net	Linear	6	0.12	-
	Shelby silt loam	Missouri	Fertilizer	5 yrs.	Bray-I	7.5	3 – 25 (ppm)	Net	Quadratic	8	0.11	0.0008
Lins and Cox, 1989	Typic Acrustox	Brazil	Fertilizer	1 yr.	Bray-I	NR	2 – 80 (kg ha <sup>-1</sup> )	Total	Linear	3	0.11	-
	Typic Haplustox	Brazil							Linear	5	0.13	-
	Typic Haplustox	Brazil							Linear	3	0.13	-
	Typic Haplustox	Brazil							Linear	9	0.31	-
	Typic Haplustox	Brazil							Linear	12	0.46	-
Lucero et al., 1995	Fluventic Dystrochrept	Virginia	Poultry Litter	2 yrs. – A	Mehlich-III	5	11 - 190 (ppm)	Total	Linear	4	0.3	-
Mallarino et al., 1983	Typic and Aquic Argiudolls	Iowa	Fertilizer	1 yr	Bray-I	7.5	10 – 35 ppm	Total	Linear	12	0.17	-
										21	0.31	-
										15	0.20	-
McCollum, 1991	Portsmouth Fine Sandy Loam	N. Carolina	Fertilizer	1 yr	Mehlich-I	15	20 - 100 (g m <sup>-3</sup> )	Total	Linear	20	0.5 <sup>4</sup>	-
	Portsmouth Fine Sandy Loam	N. Carolina	Fertilizer	9 yrs. – A	Mehlich-I	15	20 - 130 (g m <sup>-3</sup> )	Total	Linear	21	0.2 <sup>4</sup>	-
Moore et al., 1997	Typic Fragiudult	Arkansas	Poultry Litter		Mehlich-III		105 - 270 (ppm)	Total	Linear	110	0.9	-
Nguyen et al., 1989	Udic Ustrochrept	N. Z.	Fertilizer	6 yrs. - A	Olsen	7.5	10 - 23 (ppm)	Net	Linear	10	0.006	-
Peterson and Krueger, 1980	Typic Arguidoll	Wisconsin	Fertilizer	5 yrs.	Bray-I	15	30 – 220 (ppm)	Total	Linear	29	0.28	-
Rehm et al., 1984	Orthentic Haplustoll	Nebraska	Fertilizer	5 yrs. - A	Bray-I	15	5 - 35 (ppm)	Total	Quadratic	5	0.002	0.0006
Richards et al., 1995	Brunisolic Gray Brown Luvisol	Canada	Fertilizer	10 yrs. –A	Olsen	15	25 - 80 (ppm)	Total	Linear	24	0.06	-
	Gleyed Melanic Brunisol						5 - 60		Linear	6	0.06	-
	Gleyed Grey Brown Luvisol						20 - 70		Linear	27	0.06	-
Sanderson and Jones, 1997	Udic Paleustalf	Texas	Dairy	4 yrs.	Un stated	15	5 – 81 ppm	Net	Linear	6	0.13	-
Sharpley , 1996	Torrertic Paleustoll	Oklahoma	Beef manure	8 yrs.- A	Bray-I	15	20 - 420 (ppm)	Total	Linear	7	0.01	-
Suton et al., 1982	Aeric Ochraqulf	Indiana	Swine manure	3 yrs	Bray-I	15	160 - 380 (ppm)	Total	Linear	162	0.26	-
Vivenkanandan and Fixen, 1990	Udic Haplustolls	S. Dakota	Beef manure	1 yr.	Bray-I	20	45 - 390 (ppm)	Total	Linear	-	-	-

1/ Total basis is when P applied is calculated from the total amount of P applied; Net basis is when P applied is calculated as the total P applied minus P uptake in harvested portions of the crop. This can be important when P uptake is heavily influenced by P application rate.

2/ Regression coefficients for the equation  $STP = a + b X (\text{applied P, kg ha}^{-1}) + c X (\text{applied P, kg ha}^{-1})^2$ . When original paper did not report relationship, regression done on treatment means using a  $P=0.05$  to evaluate the linear and quadratic coefficients.

3/ Not reported

4/ Applied P has the units of  $\text{g m}^{-3}$ .

Table 2. Selected characteristics of 21 Missouri soils used in the project.

Region Of state	County	Soil type	pH	CEC g/100g	Sand %	Clay %	Organic matter %	Moisture Content: Field capacity %
Bootheel	Mississippi	Commerce silty clay loam	6.7	17.6	38.1	19.5	2.5	29.0
Bootheel	New Madrid	Sharkey clay	6.1	34.1	40.4	38.0	3.1	33.1
Bootheel	Stoddard	Lilbourn fine sandy loam	6.7	6.3	50.9	12.2	2.0	15.5
Bootheel	Stoddard	Loring silt loam	6.4	11.4	9.4	10.3	2.6	28.8
Clay pan	Knox	Putnam silt loam	6.4	22	7.8	16.6	2.8	33.1
Clay pan	Monroe	Putnam silt loam	5.9	16	13.2	15.1	2.2	27.7
Clay pan	Monroe <sup>2</sup>	Mexico silt loam	6.6	19.5	31.8	17.9	4.7	35.2
Loess/Drift	Gentry	Grundy Silt Loam	6.4	25.5	3.1	18.6	2.3	33.4
Loess/Drift	Lafayette	Higginsville silt loam, eroded	5.5	19.7	38.0	18.2	3.3	25.4
Loess/Drift	Linn	Loganda silt loam	6.0	21.3	11.7	24.7	4.9	32.9
Loess/Drift	Ray	Sharpsburg silt loam	6.1	20.3	33.7	28.6	2.5	24.5
Osage plain	Vernon	Barco loam	5.6	16.1	48.4	23.9	3.2	18.9
Osage plain	Vernon	Osage silty clay	5.1	7.9	33.7	16.0	1.8	22.1
Osage plain	Vernon	Barden silt Loam	7.0	12.7	40.5	16.1	2.1	23.4
Osage plain	Vernon	Barden silt Loam	7.4	10	37.5	24.9	2.2	23.6
Ozarks	Christian	Clarksville very cherty silt loam	6.2	12.3	10.7	17.5	4.0	32.0
Ozarks	Laclede	Viraton silt loam	4.6	10.9	16.3	17.5	2.3	25.6
Ozarks	Lawrence	Creldon silt loam	5.1	13.9	10.4	20.8	3.6	27.1
Ozarks	Polk	Goss gravelly silt loam	6.0	17.5	22.7	12.9	4.9	32.3
River bottom	Saline	Haynie silt loam	5.9	12.7	22.4	29.4	2.3	33.9

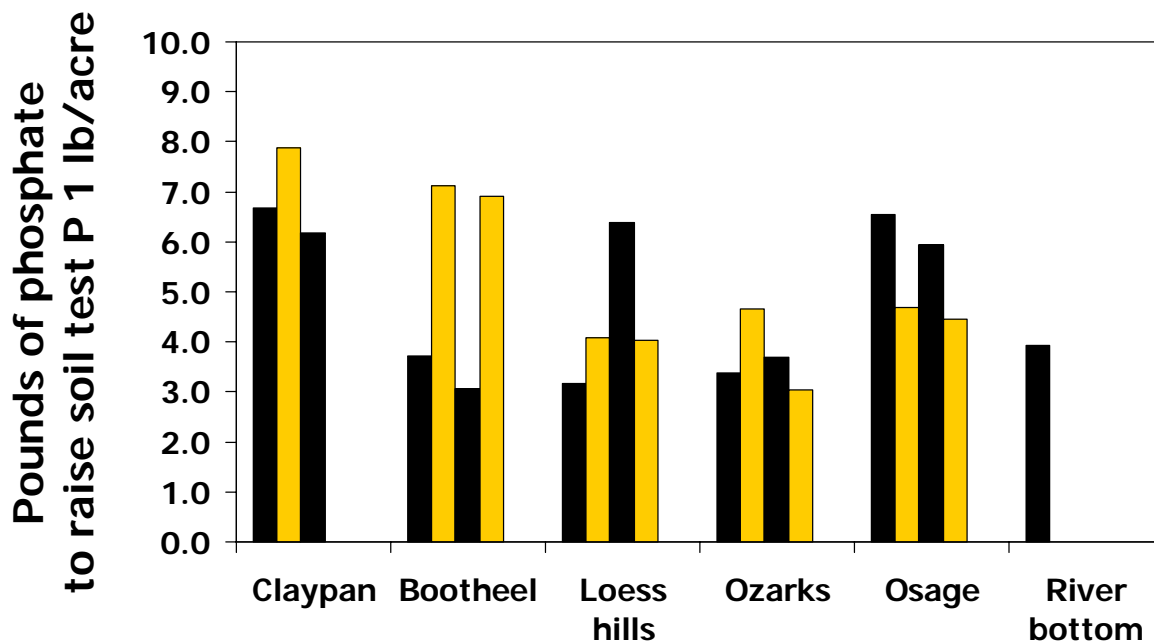


Figure 1. Pounds of phosphate fertilizer needed to raise soil test phosphorus one pound per acre on 20 Missouri soils. Soils are divided into major soil regions within the state..

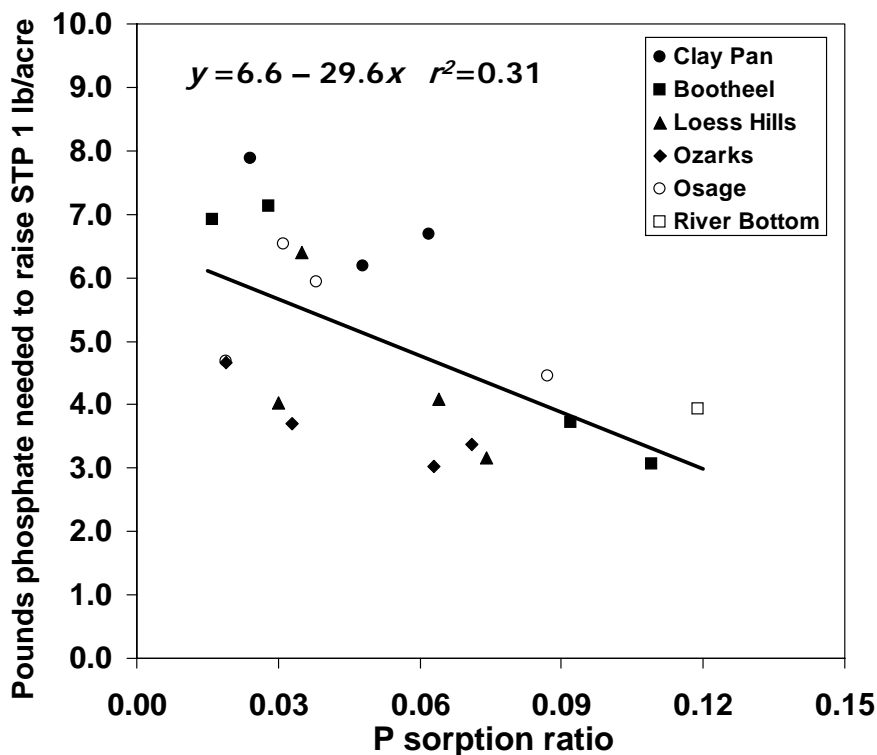


Figure 2. Effect of phosphorus sorption ratio on quantity of phosphate needed to raise soil test phosphorus 1 lb/acre. The phosphorus sorption ratio is the molar ratio of the phosphorus concentration to the sum of aluminum plus iron concentrations measured in the Mehlich-3 soil extract.

## **Phosphorus Fertilization of Tall Fescue Pastures Improves Rate of Gain and Weaning Weight of Beef Calves in Missouri**

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**Objectives:** To increase the rate of gain and weaning weight of nursing beef calves in Missouri with phosphorus fertilization of tall fescue pastures.

**Procedure:** Several tall fescue (K31, endophyte infested) pastures were selected at the Forage Systems Research Center near Linneus, MO in March, 2005. Pasture selection was based on low to moderately low soil Bray I phosphorus analysis (Table 1). Pastures were organized into treatment groups, according to proximity for convenient pasture rotation. Annual fertilization treatments were 0 or 50 lbs P/acre (0-46-0), and 100 lbs N/acre (urea-N), and K (0-0-62), as recommended by soil test results. All pastures were supplied with salt blocks containing only NaCl. At least four replicated pastures were used for each treatment and pastures size averaged about 15 acres. We used 150 cow/calf pairs total in the experiment, therefore each replicate set of pastures had 25 cow/calf pairs. Calving of this herd began around February 15 and ended around March 15 each year. About 90% of the calves were siblings from the same red Angus bull (AI). Cows were preconditioned on the same large stockpiled tall fescue pasture for at least four weeks before being put on the treated pastures. On April 14, 2005 and on April 15, 2006, cows and calves were weighed and placed on appropriate pastures. Stocking rates were adjusted to produce similar grazing pressures on the various pastures. The amount of forage available was determined by using 50 different measurements with an Elinbank Rising Plate meter. The forage meter readings were calibrated with monthly forage harvests taken with a flail-type forage harvester. Using the forage harvester, we harvested, weighed and sub-sampled forage from ten 32" x 15' cuts from one pre-grazed pasture and one post-grazed pasture in each replicate set of pastures monthly. Sub-samples grabbed from each of the 10 harvested samples were pooled, dried, and stored for determination of quality components. The cows and calves were weighed monthly for four months during 2005, then the study was terminated because of drought conditions. Even though we had included extra pastures in the study, the severe dry weather resulted in almost no available forage for grazing by August. During 2006, there was adequate rainfall and plenty of grass for the entire season and the calves were weaned after about six and one-half months on the study.

**Results:** The Forage Systems Research Center is an excellent site for this type of research. We were able to locate adequate numbers of low to moderate soil P pastures on the farm to accommodate this large scale study. This farm has a large cow herd and the genetics of the calves were top-notch, plus facilities were readily available for weighing the cows and calves frequently. Also, agronomists and animal scientists were extremely helpful in collecting forage samples, in rotating pastures and weighing the cattle. One difference between this study and the preliminary study that we conducted at the SW Center near Mt. Vernon was that cows calved earlier at FSRC, therefore calves went into the P study when they were over one month of age. At the SW Center, calves were actually born on or around the day the experiment began. The major problem with this study the first year was the lack of rainfall, which may have nullified the usefulness of the P fertilization, plus by July, soil test K levels were low in many of the pastures (Table 2). Soil test K levels are often low during drought since K is “fixed” in the clay. There were no P treatment differences in rate of gain or final weight of calves in 2005 (Tables 2 & 3). The 2006 calves on the +P pastures weighed 8 lbs more than calves from the -P pastures on 9-5-06 and 6 lbs more at termination on 9-20-06 (Table 5). The trends for calf weight gain in 2006 were consistently in favor of the +P pastures, but the difference in weight gain was not as great as expected based on our preliminary experiment at the SW Center.

**Conclusions:** After a good summer of grazing, with good quality grass and great cattle, the calf weight response to P fertilization was positive but the 6lbs of final weight gain was not as great as expected. There could be at least two possible reasons for this, one is that calves were over one month of age before cow and calves were put on the treated pastures. The second reason could be that the low to moderate soil P levels in pastures were 20+ lbs/P acre (Bray I). Our studies at the SW Center were conducted on pastures that had only 7-8 lbs P/acre (Bray I). The 12+ lbs P/acre in the current study may be enough to maintain normal levels of calf weight gain by promoting adequate milk production by the cow.

Table 1. March 27, 2005 soil test data from pastures used in the phosphorus cow/calf study at the Forage Systems Research Center. Each value is the mean of data from all of the pastures within a particular treatment group, usually at least four different pastures.

<b>P Treatment</b>	<b>pH</b>	<b>Bray I P lbs/acre</b>	<b>Bray II P lbs/acre</b>	<b>Ca lbs/acre</b>	<b>Mg lbs/acre</b>	<b>K lbs/acre</b>
Low 1	5.50	19	78	4012	468	268
Low 2	5.53	23	144	4259	518	276
Low 3	5.90	25	172	3339	329	291
High 1	5.78	33	199	3706	420	331
High 2	5.55	50	225	3599	408	315
High 3	6.35	26	215	4016	388	315

Table 2. July 27, 2005 soil test data from the pastures used in the phosphorus cow/calf study at the Forage Systems Research Center. Note that soil K levels are markedly lower in most of the pastures as a result of the drought. Each value is the mean of data from all of the pastures within a particle treatment group, usually at least four different pastures.

<b>P Treatment</b>	<b>pH</b>	<b>Bray I P lbs/acre</b>	<b>Bray II P lbs/acre</b>	<b>Ca lbs/acre</b>	<b>Mg lbs/acre</b>	<b>K lbs/acre</b>
Low 1	5.35	12	67	3701	382	124
Low 2	5.38	15	129	4147	445	138
Low 3	5.90	33	192	3541	330	255
High 1	5.65	37	237	3870	418	339
High 2	5.45	54	274	3709	380	237
High 3	6.30	48	297	4139	365	253

Table 3. The 2005 calf performance on high and low phosphorus pastures at the Forage Systems Research Center. Start weight was on April 14, Period 1 weight was on May 12, Period 2 was on June 9, Period 3 was on July 5, and Period 4 weights were taken on August 9 and again on August 10. At the end of the experiment, the calves and cows were weighed on two consecutive days. Values are means of weight from 75 calves in the treatment.

<b>Treatment</b>	<b>Period 1</b>			<b>Period 2</b>			<b>Period 3</b>			<b>Period 4</b>			
	<b>Start Wt lbs</b>	<b>Wt lbs</b>	<b>Wt Gain lbs</b>	<b>ADG lbs/day</b>	<b>Wt lbs</b>	<b>Wt Gain lbs</b>	<b>ADG lbs/day</b>	<b>Wt lbs</b>	<b>Wt Gain lbs</b>	<b>ADG lbs/day</b>	<b>Wt lbs</b>	<b>Wt Gain lbs</b>	<b>ADG lbs/day</b>
Low P	201	293	92	3.30	366	73	2.61	436	69	2.47	514	78	2.34
High P	202	286	86	3.07	364	78	2.77	425	61	2.18	502	74	2.47

Table 4. The 2005 cow performance on high and low phosphorus pastures at the Forage Systems Research Center. Periods 1, 2, 3 and 4 are the same as those described in the legend of Figure 3. Values are means of weight from 75 cow in the treatment.

<b>Treatment</b>	<b>Period 1</b>			<b>Period 2</b>			<b>Period 3</b>			<b>Period 4</b>			
	<b>Start Wt lbs</b>	<b>Wt lbs</b>	<b>Wt Gain lbs</b>	<b>ADG lbs/day</b>	<b>Wt lbs</b>	<b>Wt Gain lbs</b>	<b>ADG lbs/day</b>	<b>Wt lbs</b>	<b>Wt Gain lbs</b>	<b>ADG lbs/day</b>	<b>Wt lbs</b>	<b>Wt Gain lbs</b>	<b>ADG lbs/day</b>
Low P	1099	1275	176	6.28	1304	28.3	1.01	1267	-37	-1.31	1302	36	1.27
High P	1118	1290	172	6.14	1328	38.2	1.36	1293	-36	-1.28	1331	38	1.37

Table 5. Cow and calf weight gain and average daily gains for summer of 2006.

<b>COWS</b>	START WT	5-16-06 WT	GAIN (34 DAY)	ADG (34 DAY)	6-12-06 WT	GAIN (27 DAY)	ADG (27 DAY)	7-11-06 WT	GAIN (29 DAY)	ADG (29 DAY)
134N LO-P	1258	1367	108	3.19	1363	-4	-0.15	1370	7	0.26
214N LO-P	1252	1384	132	3.89	1400	16	0.58	1428	28	0.97
24 LO-P	1243	1350	107	3.15	1350	0	0.00	1396	46	1.59
AVERAGE	1251	1367	116	3.41	1371	4	0.14	1398	27	0.94
38W HI-P	1205	1306	101	2.97	1287	-19	-0.72	1352	65	2.24
WP20 HI-P	1237	1363	127	3.73	1362	-1	-0.04	1387	25	0.85
31E HI-P	1230	1389	160	4.69	1356	-33	-1.23	1357	1	0.03
AVERAGE	1224	1353	129	3.80	1335	-18	-0.66	1365	30	1.04

<b>COWS</b>	8-8-06 WT	GAIN (28 DAY)	ADG (28 DAY)	9-5-06 WT	GAIN (28 DAY)	ADG (28 DAY)	9-20-06 WT	GAIN (15 DAY)	ADG (15DAY)
134N LO-P	1373	3	0.12	1368	-5.29	-0.19	1379	11.38	0.76
214N LO-P	1406	-21	-0.76	1387	-19.92	-0.71	1405	18.15	1.21
24 LO-P	1352	-45	-1.59	1372	20.54	0.73	1350	-22.40	-1.49
AVERAGE	1377	-21	-0.74	1376	-1.56	-0.06	1378	2.37	0.16
38W HI-P	1329	-22	-0.79	1328	-1.21	-0.04	1323	-4.92	-0.33
WP20 HI-P	1344	-43	-1.53	1377	32.21	1.15	1373	-3.42	-0.23
31E HI-P	1372	15	0.52	1390	18.00	0.64	1345	-44.58	-2.97
AVERAGE	1348	-17	-0.60	1365	16.33	0.58	1347	-17.64	-1.18

<b>CALVES</b>	START WT	5-16-06 WT	GAIN (34 DAY)	ADG (34 DAYS)	6-12-06 WT	GAIN (27 DAY)	ADG (27 DAY)	7-11-06 WT	GAIN (29 DAY)	ADG (29 DAY)
134N LO-P	199	290	91	2.67	355	65	2.40	428	73	2.52
214N LO-P	208	305	96	2.83	376	72	2.66	456	80	2.75
24 LO-P	197	290	94	2.75	352	61	2.27	432	80	2.76
AVERAGE	202	295	94	2.75	361	66	2.44	439	78	2.68
38W HI-P	203	297	94	2.76	361	64	2.38	441	80	2.76
WP20 HI-P	206	303	96	2.84	363	60	2.23	448	85	2.95
31E HI-P	196	297	101	2.96	356	59	2.19	432	76	2.61
AVERAGE	202	299	97	2.85	360	61	2.27	440	80	2.77

<b>CALVES</b>	8-8-06 WT	GAIN (28 DAY)	ADG (28 DAY)	9-5-06 WT	GAIN (28 DAY)	ADG (28 DAY)	9-20-06 WT	GAIN (15 DAY)	ADG (15DAY)
134N LO-P	493	65	2.31	548	55	1.96	577	29.29	1.95
214N LO-P	513	57	2.04	569	55	1.98	603	34.22	2.28
24 LO-P	483	51	1.83	553	70	2.51	572	18.19	1.21
AVERAGE	496	58	2.06	557	60	2.15	584	27.23	1.82
38W HI-P	498	58	2.06	551	52	1.88	583	32.46	2.16
WP20 HI-P	505	57	2.04	574	69	2.45	606	32.04	2.14
31E HI-P	497	65	2.33	569	72	2.57	582	12.71	0.85
AVERAGE	500	60	2.14	565	64	2.30	590	25.74	1.72

# **Potassium Management**

## **Progress Reports**

### **Use of Pre-plant or Foliar-Applied Potassium Chloride with Fungicides to Improve Soybean Response and Disease Resistance**

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#### **Introduction:**

An increased occurrence of K deficiency in soybeans and the potential widespread onset of Asian rust (SBR) (*Phakopsora pachyrhiza*) in soybeans have stimulated interest in new management practices that may improve K nutrition and lower incidence of disease. In 2004, SBR was reported in nine states including Louisiana, other Gulf-coast and southeastern states, and Missouri (APHIS, 2005). Yield loss estimates for this fungal disease range from 10 to 80% in areas where rust is established and could result in economic losses between \$640 to \$1,341 million the first year of infestation (Sweets et al., 2004). Since current soybean varieties grown in the U.S. have little or no resistance to SBR, a primary method of controlling the spread of the disease has been use of fungicides. Currently, four families of fungicides are available for SBR management: triazoles, strobilurins, chloronitriles, and carboxamides. In addition, extensive research has established a link between plant nutrition and disease incidence including the disease suppressing effects of K, Cl, Mn, B and P (Fixen et al, 2004). Therefore, combining K, Cl and other nutrients either as a pre-plant or foliar application with a fungicide may improve disease management. Recent research by Bradley and Sweets (2005) in Missouri indicates that several fungicides can be tank mixed with glyphosate without significant injury or reduction in yields of soybeans, but the limited penetration of the combined spray into the plant canopy may reduce potential SBR control. Nelson et al. (2004) has also established the KCl and several other K fertilizer sources can be combined with glyphosate without reducing weed control or causing significant foliar injury. This “weed and feed” system could also serve as an example for a system that combines disease control and nutrient management. The possible benefits of this approach include reduction in application costs, improved disease suppression and nutrient response, and flexibility in management response to environmental conditions during the growing season.

The objectives of this study were:

4. Determine soybean yield response, disease incidence and K and Cl tissue concentrations from application of KCl alone or in combination with several fungicides.
5. Examine the effects of application timing of KCl or the fungicides on crop response and disease incidence.
6. Evaluate the cost-effectiveness of applying KCl with fungicides for soybean production.

#### **Materials and Methods:**

This study evaluated the effects of either pre-plant or foliar-applied KCl fertilizer sources and rates of application on glyphosate-resistant soybean response and weed control. The first of two site-year field trials was established at the Greenley and Delta Centers on soils with medium to low soil test K.

Roundup-Ready<sup>®</sup> soybeans were no-till planted at 180,000 seeds/acre in 15 inch rows. The study was arranged as a randomized complete block design with four replications. Treatments consisted of a non-treated control, a recommended pre-plant rate of KCl based on soil test, or a foliar application of 16 lb K/acre (as KCl) in a factorial arrangement combined with and without fungicide applications of 6 oz/acre

of pyraclostrobin (Headline<sup>®</sup>), 6.4 oz/acre of azoxystrobin (Quadris<sup>®</sup>) or 6.4 oz/acre Quadris<sup>®</sup> + 2.6 oz/acre of Warrior<sup>®</sup> (lambda-cyhalothrin insecticide) applied either at V4 or R4 growth stages.

Foliar injury was rated 3, 7, and 28 days after foliar application. Treatments were evaluated for the incidence of Septoria brown spot (*Septoria glycines*), frogeye leaf spot (*Cercospora sojina*), sudden death syndrome (*Fusarium solani*), and Asian rust. Soybeans were harvested and data analyzed to determine the influence of the treatments on crop response and grain yield. Data were subjected to an analysis of variance and means separated at  $p=0.05$  unless otherwise specified. Main effects were generally presented in the absence of interactions.

### **Results and Discussion:**

**Injury.** Soybean injury was minimal except when fungicides were tank mixed with KCl at Portageville (Table 1). Leaf necrosis was the primary symptom and plants recovered by 10 days after treatment.

Table 1. Soybean response to tank mixture combinations of foliar applied K with fungicide treatments averaged over application timing.

Treatment	Injury			
	Novelty		Portageville	
	3 DAT	7 DAT	3 DAT	10 DAT
	----- % -----			
Non-treated	1	0	15	7
Quadris at 6.4 oz/a	1	1	13	7
Quadris at 6.4 oz/a + Warrior at 2.6 oz/a	1	1	17	6
Headline at 6 oz/a	3	1	14	5
LSD ( $p=0.05$ )	0.4	0.3	4	2

Abbreviations: DAT, days after treatment; LSD, least significant difference.

**Incidence of disease.** Asian soybean rust was not present at either location in 2006. The incidence of Septoria brown spot, Frogeye leaf spot, or sudden death syndrome was less than 10% in 2006. Interactions between application timing and fungicide treatment were common. However, KCl fertility did affect the incidence of Septoria brown spot and frogeye leaf spot at Novelty in 2006.

Septoria brown spot was present at Novelty and Portageville. A lower incidence of Septoria brown spot was present in treatments with preplant KCl (Table 2). Foliar applied KCl plus Headline slightly reduced the incidence of Septoria brown spot at this location. At Portageville, Septoria brown spot was reduced when Quadris or Headline were applied at the V4 stage; however, no differences were observed at the R4 application timing.

The incidence of frogeye leaf spot was ranked non-treated = foliar applied KCl > preplant KCl ( $P=0.0003$ ) when averaged over fungicides and application timings (data not presented). All fungicide treatments when averaged over application timing and KCl fertility treatments reduced the incidence of frogeye leaf spot when compared to the non-treated control ( $P=0.0007$ ) at Novelty (data not presented). Slight differences in the incidence of frogeye leaf spot among application timings were observed for fungicide treatments at this location (Table 3). At Portageville, the V4 application timing had a lower incidence of disease than the R4 timing ( $P=0.026$ ) (data not presented). Sudden death syndrome was sporadic and none of the treatments reduced the incidence of this plant disease when compared to the non-treated control (Table 3).

Table 2. Effect of K fertility and fungicide on the incidence of Septoria brown spot at Novelty in 2006.

Treatment	Non-treated	Preplant KCl at 455 lb K/a	Foliar KCl at 16 lb K/a	
			%	
Non-treated	10	5	11	
Quadris at 6.4 oz/a	9	4	11	
Quadris at 6.4 oz/a + Warrior at 2.6 oz/a	9	4	9	
Headline at 6 oz/a	9	4	8	
LSD (p=0.05)	-----		2 -----	

Table 3. Effect of fungicide and application timing on the incidence of Septoria brown spot, frogeye leaf spot, and sudden death syndrome in 2006.

Treatment	Septoria brown spot		Frogeye leaf spot	Sudden death syndrome
	Novelty	Portageville	Novelty	Portageville
V4 application timing				
Non-treated	9	6	7	0
Quadris at 6.4 oz/a	9	4	7	3
Quadris at 6.4 oz/a + Warrior at 2.6 oz/a	8	5	5	2
Headline at 6 oz/a	9	3	6	1
R4 application timing				
Non-treated	8	6	6	0
Quadris at 6.4 oz/a	8	7	5	0
Quadris at 6.4 oz/a + Warrior at 2.6 oz/a	7	6	5	0
Headline at 6 oz/a	6	6	3	2
LSD (p=0.05)	NS	2	1.3	1

**Yield.** Grain yield at Novelty and Portageville increased 5.5 to 6.5 bu/a with preplant KCl when compared with the non-treated control and foliar applied KCl (Table 4). At Novelty, fungicide treatments increased yields 2.3 to 3.2 bu/acre, but there was no yield increase when Warrior was added to Quadris. The R4 application timing was 2.6 bu/a greater than the V4 timing in 2006.

**Summary and Conclusions:**

This research indicates that KCl fertility reduced the incidence of Septoria brown spot and frogeye leaf spot at Novelty, but no differences were observed at Portageville. Preplant KCl increased yield when compared to the non-treated control and foliar applied KCl at Novelty and Portageville which could be related to the combined effects of disease tolerance and fertility. Fungicide treatments applied at the R4 stage of development increased grain yield at Novelty, but had no effect on grain yields at Portageville in 2006. The cost-effectiveness of the treatments will be determined following research in 2007.

Table 4. Seed yield of KCl application timing, fungicide, and application timing main effects at Novelty and Portageville in 2006.

Treatment	Yield	
	Novelty	Portageville
	----- bu/acre -----	
KCl application timing		
Non-treated	65.8	62.0
Preplant at 455 lb K/a	72.3	67.6
Foliar at 16 lb K/a	66.8	61.6
LSD (p=0.10)	3.9	5.1
Fungicide		
Non-treated	66.1	62
Quadris at 6.4 oz/a	69.3	64
Quadris at 6.4 oz/a + Warrior at 2.6 oz/a	69.3	61
Headline at 6 oz/a	68.4	67
LSD (p=0.10)	2.0	NS
Application timing		
V4	67.2	64
R4	69.8	64
LSD (p=0.10)	0.4	NS

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# **Miscellaneous Tests**

# Final Reports

## P and K Fixation by Missouri Soils: Final Report

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### **Objectives:**

- Evaluate whether P and K fixation differ widely between Missouri soils.
- If differences are found, determine whether these differences can be predicted by soil region and by easily measured chemical properties of soils.
- Consider whether the buildup component of University of Missouri fertilizer recommendations should be modified to account for differences between soils.
  - Currently, one buildup equation is applied to all Missouri soils, even though soil properties are known to vary widely in Missouri.

### **Procedures:**

- Forty-two Missouri soils were collected for this study, representing many major agricultural soil types (see map and table).
- Laboratory incubations of these soils with and without fertilizer were carried out to see how much soils differed in the size of the soil test increase from fertilization.
  - Each soil received three treatments:
    - P fertilizer added (215 lb P<sub>2</sub>O<sub>5</sub>/acre)
    - K fertilizer added (300 lb K<sub>2</sub>O/acre)
    - no fertilizer added
  - All soils were incubated moist (water was added periodically to maintain soil moisture at field capacity) in the laboratory for three months, then they were sampled and dried.
- Increase in soil test P and soil test K was calculated for all soils as the (soil test with P or K addition) minus the (soil test with no fertilizer added).
- Analysis of covariance was used to determine whether soil region or soil properties consistently affect the size of the soil test increase.
  - Soil regions used were Bootheel, Claypan, Loess & Drift, Osage Plains, Ozarks, and River Bottom.
  - Soil properties measured and related to soil test increase were:
    - initial soil test levels
    - % sand, silt, and clay
    - % organic matter
    - pH and neutralizable acidity
    - extractable iron and aluminum

### **Results for potassium:**

- K was added to the soils at a rate equivalent to 300 lb K<sub>2</sub>O/acre. This K rate resulted in increases in soil test K values ranging from 98 to 240 lb K/acre (Table 1). This range matches well with the current University of Missouri equation, which predicts that 300 lb K<sub>2</sub>O/acre will raise soil test K values by about 100 lb/acre on low-testing soils and 200 lb K/acre on very high-testing soils. However, when used by itself, the initial soil test K value was a very poor predictor of how much soil test K would increase. Only when combined with the region that the soil came from and the amount of clay in the soil were predictions

somewhat accurate.

- Soil test K increased less in soils with higher clay content. The clay component of the soil is responsible for the process of K fixation (tie-up in forms not available to crops). We may need to recommend more K for soils with higher clay contents. This is partly accounted for by current University of Missouri recommendations, which recommend higher soil test K target levels for soils with higher CEC (cation exchange capacity) values, which are closely related to clay content. The end result is that more K is recommended on soils with more clay.
- The only clearly distinguishable regional effect is that soil test K increased more for Ozark soils (average increase = 182 lb K/acre) than for other Missouri soils (average increase = 151 lb/acre). Lower K rates may be appropriate during the buildup period in the Ozarks compared to other regions. We had suspected that we might get this result based on lower concentrations of 2:1 type clays (K-fixing) in Ozark soils.
- Other regions were fairly similar to each other in terms of average soil test K increase observed.
- By combining initial soil test K, clay content, and soil region, we are able to explain 56% of the variability in how much soil test K increased.

### **Results for phosphorus:**

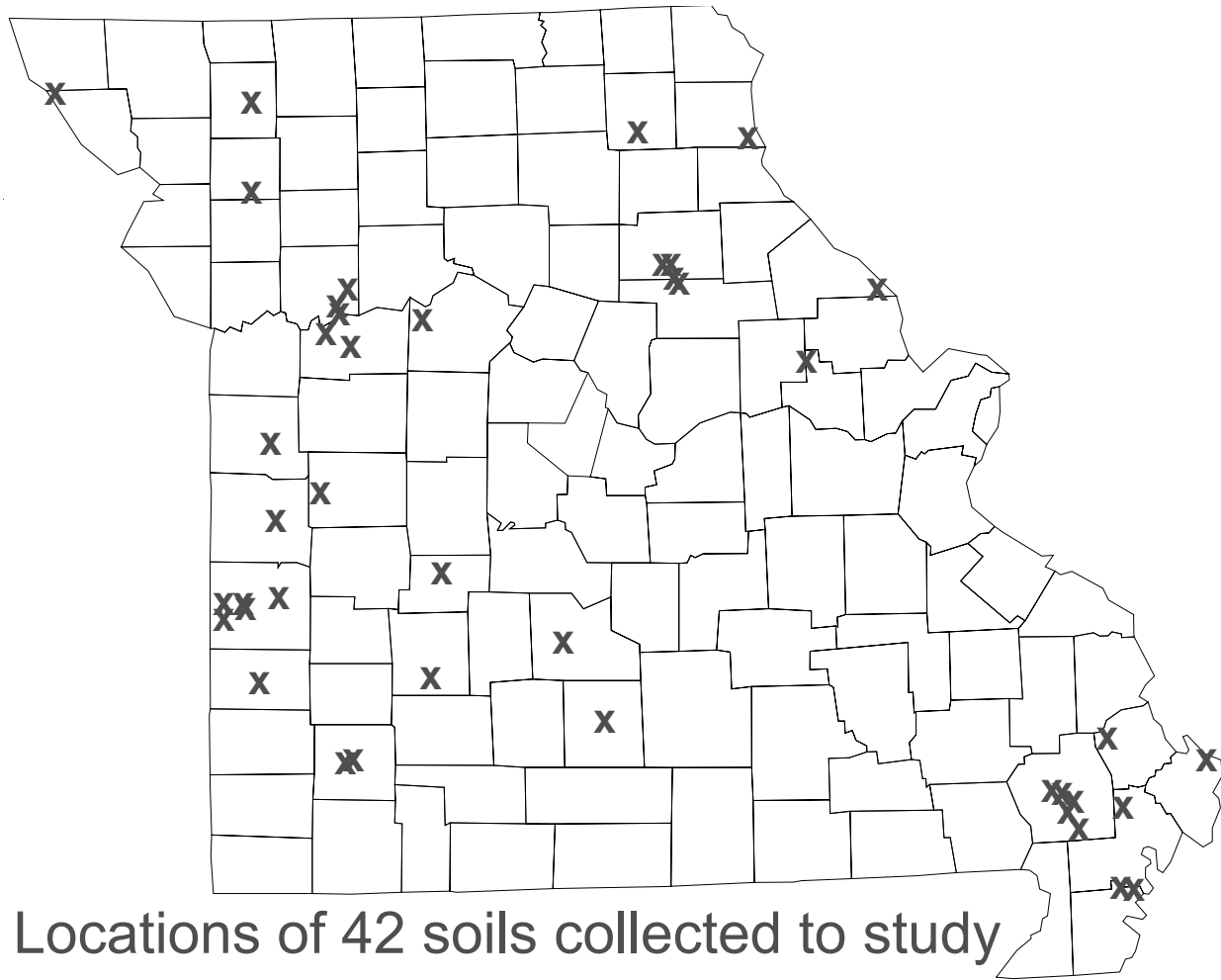
- P was added to the soils at a rate equivalent to 215 lb  $P_2O_5$ /acre. This P rate resulted in increases in soil test P values ranging from 23 to 76 lb P/acre (see table). This range is higher than the current University of Missouri equation, which predicts that 215 lb  $P_2O_5$ /acre will raise soil test P values by about 15 lb/acre on low-testing soils and 45 lb P/acre on very high-testing soils.
- We found weak support for the concept (built into current Missouri recommendations) that a given fertilizer rate gives a larger increase in soil test P on high-testing soils than on low-testing soils. When used by itself, the initial soil test P value explained only 7% of the variation in the size of the increase in soil test P.
  - Although this concept is widely believed, it should be interpreted cautiously. Several other recent studies have found that when different P rates are applied, each increase in the amount of P added gives the same increase in soil test P.
  - For soils above 40 lb P/acre soil test value in this study there was no relationship between initial test value and soil test increase.
  - For soils below 40 lb P/acre, average increase in soil test P was 80% of the increase observed in soils above 40 lb P/acre.
- The combination of initial soil test P value, the region that the soil came from, the amount of clay in the soil, and the neutralizable acidity of the soil explained 58% of the variation in the size of the increase in soil test P.
- As with K, soil test P increased less in soils with higher clay content. The clay component of the soil is responsible for the process of P fixation, which is tie-up in forms not available to crops. We may need to recommend more P for soils with higher clay contents. Currently we do not have a system in place to account for differences in soil clay content in our P recommendations.
- The most clearly distinguishable regional effect is that soil test P increased less for claypan region soils (average increase = 33 lb P/acre) than for other Missouri soils (average increase = 50 lb P/acre). This is true even after correcting for clay contents of all soils, indicating that there is some property of claypan soils in addition to high clay content that results in lower

soil test P increases. Higher P rates may be appropriate for claypan soils (relative to other soil regions), at least during the buildup phase of management.

- Another likely regional effect is that soil test P increased more for Ozark soils than for soils from other regions. When we started this experiment, we thought that the opposite might be true due to the clay minerals in these soils, which are the most highly-weathered clays found in Missouri. Highly-weathered clay minerals in tropical parts of South America are known to bind P tightly, making it unavailable to plants, but this does not appear to be true for the Ozarks.
- We also thought that Osage Plain soils might need more P for the same reason. We found weak evidence that this might be true, but the effect is small: average soil test increase for Osage Plain soils was 43 lb P/acre, and for Bootheel, Loess & Drift, and River Bottom soils combined it was 49 lb P/acre.
- Another key finding was that the more neutralizable acidity a soil has, the lower the increase in soil test P. This was expected and has been part of our Extension teaching for some time—good lime management helps applied P to be more available. For most parts of Missouri, economics probably favor good lime management rather than applying more P to compensate for inadequate liming.

#### **Outcomes:**

- We will bring up with the Soil Fertility Working Group the possibility of changing the University of Missouri K buildup equation based on our results to reflect regional differences.
- We will bring up with the Soil Fertility Working Group the possibility of changing the University of Missouri P buildup equation based on our results:
  - to reflect that the soil test P increases that we found were larger than what would be predicted by current University of Missouri buildup equations
  - to incorporate regions, soil texture, and possibly soil neutralizable acidity
- Results of this study were used in planning greenhouse experiments to understand how soil properties affect the plant's reaction with fertilizer. Emphasis was placed on studying differences in soil regions and soil clay contents.



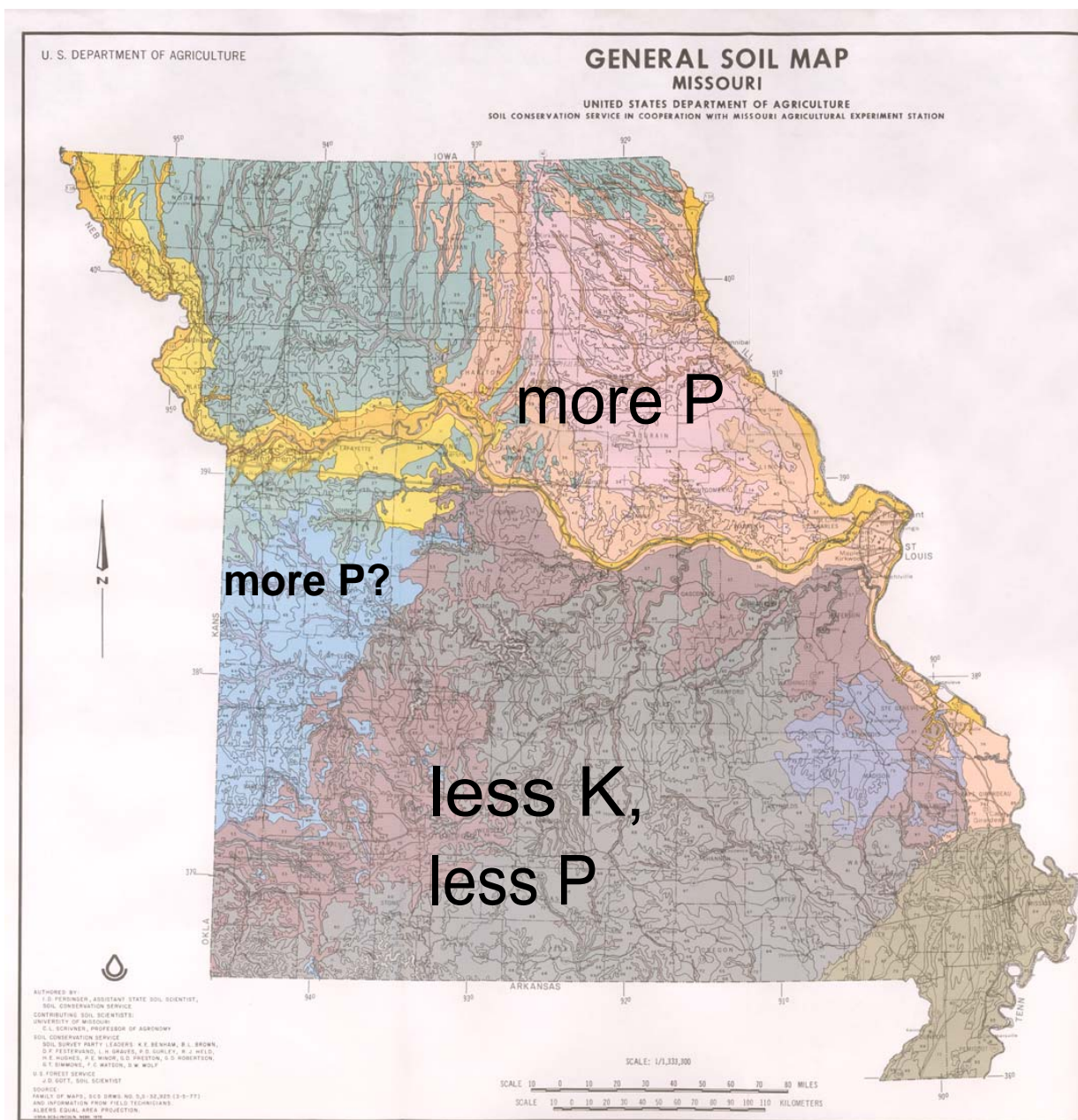
Locations of 42 soils collected to study P and K fixation by Missouri soils

**Table 1. Increase in soil test K for 42 Missouri soils with K added at a rate of 300 lb K<sub>2</sub>O/acre.**

<b>Region</b>	<b>Soil Type</b>	<b>Increase in soil test K</b> lbs/acre
Bootheel	Commerce Silty Clay Loam	98
Claypan	Mexico Silt Loam 1	105
Loess and Drift	Lagonda Silt Loam	107
Bootheel	Portageville Clay	111
Loess and Drift	Marshall Silt Loam	115
Claypan	Putnam Silt Loam 1	117
Loess and Drift	Grundy Silt Loam 1	120
Osage	Barden Silt Loam 1	125
Osage	Barco Loam 1	126
Bootheel	Sharkey Silty Clay Loam	127
Osage	Kenoma Silt Loam	131
Bootheel	Sharkey Clay	132
Bootheel	Loring Silt Loam 1	132
Bootheel	Commerce Silty Clay Loam 1	133
Claypan	Mexico Silt Loam 2	134
Claypan	Mexico Silt Loam 3	136
Osage	Barden Silt Loam 2	139
Claypan	Putnam Silt Loam 2	140
Osage	Barden Silt Loam 3	140
Bootheel	Loring Silt Loam 2	141
Claypan	Mexico Silt Loam 4	142
Ozarks	Cedargap Cherty Silty Loam	142
River Bottom	Haynie Silt Loam	147
Osage	Barco Loam 2	148
River Bottom	Westerville Silt Loam	150
Loess and Drift	Sharpsburg Silt Loam	152
Loess and Drift	Grundy Silt Loam 2	152
Ozarks	Huntington Silt Loam	153
River Bottom	Leta Silty Clay	154
Osage	Hartwell Silt Loam	158
Bootheel	Lilbourn Sandy Loam	163
Loess and Drift	Higginsville Silt Loam	164
Osage	Osage Clay	165
Ozarks	Viraton Silt Loam	167
Osage	Parsons Silt Loam	173
Bootheel	Lilbourn Fine Sandy Loam	177
Ozarks	Goss Gravelly Silt Loam	179
Ozarks	Keeno Cherty Silt Loam	179
Ozarks	Creldon Silt Loam	198
Ozarks	Clarksville Very Cherty Silt Loam	198
Loess and Drift	Haig Silt Loam	221
Claypan	Putnam Silt Loam 3	240

**Table 2. Increase in soil test P for 42 Missouri soils with P added at a rate of 215 lb P<sub>2</sub>O<sub>5</sub>/acre.**

Region	Soil Type	Increase in soil test P lbs/acre
Bootheel	Sharkey Clay	23
Claypan	Mexico Silt Loam 3	28
Bootheel	Loring Silt Loam 2	29
Loess and Drift	Lagonda Silt Loam	30
Claypan	Putnam Silt Loam 1	31
Osage Plains	Barco Loam 2	33
Bootheel	Loring Silt Loam 1	34
Claypan	Mexico Silt Loam 4	35
Claypan	Putnam Silt Loam 2	36
Bootheel	Portageville Clay	36
Osage Plains	Barco Loam 1	37
Osage Plains	Hartwell Silt Loam	37
Claypan	Putnam Silt Loam 3	38
Osage Plains	Barden Silt Loam 1	39
Osage Plains	Osage Clay	40
Osage Plains	Kenoma Silt Loam	43
Claypan	Mexico Silt Loam 1	44
Loess and Drift	Grundy Silt Loam 1	44
Ozarks	Viraton Silt Loam	45
River Bottom	Westerville Silt Loam	49
Ozarks	Keeno Cherty Silty Loam	50
Loess and Drift	Marshall Silt Loam	51
Loess and Drift	Sharpsburg Silt Loam	51
Ozarks	Creldon Silt Loam	52
River Bottom	Haynie Silt Loam	52
Osage Plains	Barden Silt Loam 2	52
Ozarks	Clarksville Cherty Silty Loam	53
Ozarks	Huntington Silt Loam	53
River Bottom	Leta Silty Clay	54
Osage Plains	Barden Silt Loam 3	54
Bootheel	Commerce Silty Clay Loam 1	56
Ozarks	Cedargap Cherty Silty Loam	58
Bootheel	Sharkey Silty Clay Loam	58
Bootheel	Commerce Silty Clay Loam 2	59
Loess and Drift	Haig Silt Loam	64
Loess and Drift	Grundy Silt Loam 2	64
Ozarks	Goss Gravelly Silt Loam	64
Bootheel	Lilbourn Fine Sandy Loam	66
Loess and Drift	Higginsville Silt Loam	68
Osage Plains	Parsons Silt Loam	70
Bootheel	Lilbourn Sandy Loam	76



Map of Missouri soil regions with regional differences in fertilizer needs for soil test buildup as suggested by this research. The claypan region soils required more P than soils from other regions to produce the same soil test increase. This may also be true for the Osage Plains soils. Ozark soils, on the other hand, required less K and probably less P than soils from other regions to produce the same soil test increase. Regional differences in the soil test buildup equations are probably justified.

# **Spectral radiometer to control variable-rate N applications for corn: Final report**

Peter Scharf, Eduardo Souza, and Ken Sudduth

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## **Objectives/relevance:**

- Develop correction formulas so that the spectral radiometer will give the same color reading (and same N rate recommendation) for the same plants regardless of time of day or cloud conditions.
- This objective is in support of variable-rate N applications based on on-the-go crop measurements with the spectral radiometer.
- Our previous research has shown that crop color measurements gives more reliable N rate recommendations than other ways of diagnosing N need.

## **Procedures:**

- We measured reflectance from corn with the Crop Circle passive spectral radiometer at four different wavelengths (460, 550, 670, 800 nm)
- Spectral radiometers were mounted in a stationary position above corn plants and readings were taken every two seconds throughout the day. Corn plants were anywhere from 1 to 6 feet tall at the time that readings were taken.
  - Readings started in May with corn grown in the greenhouse and moved in pots to Sanborn Field.
  - Readings continued from June to October on corn planted at MU's Bradford Farm east of Columbia. Corn was planted about every two weeks starting at normal planting time and continuing throughout the summer and fall. Thus we had knee-high to head-high corn all season long on which to make measurements.
  - We ended up with over 60 days of readings from morning until night.
  - Mathematical correction functions were developed using regression analysis.

## **Results:**

- Analyses focused on the green (550 nm) and near-infrared (NIR) (800 nm) bands, since these wavelengths have been shown in previous research to be the best predictors of N rate needed.
- Reflectance measured with the spectral radiometer tended to be highest in the morning and evening and lower in mid-day.
  - The size of the fluctuations was enough to change N rates substantially based on the prediction equations that we have developed.
  - Thus there is a need for correction factors to produce sound N rate predictions.
- Correction factors for these two bands and indices combining them were developed and are shown in Table 1.
- Applying these correction factors considerably reduced the variability in green and near-infrared reflectance and their combinations (Table 2 and Figure 1).
- Most researchers and industry have moved toward sensors that have their own pulsed light source as a way to reduce variability in reflectance readings as sun conditions (angle, clouds) change.
  - Thus the need for the correction factors that we developed has gone down.
  - However, no one has shown that active-light sensors are stable over the course of a day. Our preliminary evidence shows that correction factors are probably needed.

Table 1 - Regression coefficients for corn reflectance measured in the green band (R550) and the near-infrared (NIR) band (R800) and for two indices combining green and NIR [NIR/Green and the Green Normalized Difference Vegetative Index (GNDVI)] as a function of time, sun angle ( $\psi$ ), and sky clearness (instantaneous clearness index or ICI). N Input was 180 kg/ha. All coefficient estimators were significant at a 99.9% probability by F test.

	<b>R<sub>550</sub></b>	<b>R<sub>800</sub></b>	<b>NIR/Green</b>	<b>GNDVI</b>
<b>Intercept</b>	<b>0.039439</b>	<b>-0.355467</b>	<b>-15.925667</b>	<b>-0.588222</b>
<b>t<sub>C</sub></b>	<b>0.001758</b>	<b>-0.008466</b>	<b>-1.090882</b>	<b>-0.064520</b>
<b>t<sub>C</sub><sup>2</sup></b>	<b>-0.002853</b>	<b>0.051488</b>	<b>2.627776</b>	<b>0.157035</b>
<b>ψ<sub>C</sub></b>	<b>0.001611</b>	<b>-0.026595</b>	<b>-1.341824</b>	<b>-0.080509</b>
<b>ψ<sub>C</sub><sup>2</sup></b>	<b>0.000021</b>	<b>-0.000300</b>	<b>-0.016406</b>	<b>-0.000980</b>
<b>ICI<sub>550</sub></b>	<b>0.017537</b>	<b>0.111122</b>		
<b>ICI<sub>550</sub><sup>2</sup></b>	<b>-0.013960</b>	<b>-0.093015</b>	<b>-1.129808</b>	<b>-0.065197</b>
<b>t<sub>C</sub> X ψ<sub>C</sub></b>	<b>-0.000010</b>	<b>-0.000110</b>	<b>-0.002055</b>	<b>-0.000129</b>
<b>t<sub>C</sub> X ICI<sub>550</sub></b>	<b>-0.002501</b>	<b>-0.006937</b>	<b>0.629987</b>	<b>0.037257</b>
<b>ψ<sub>C</sub> X ICI<sub>550</sub></b>			<b>-0.040053</b>	<b>-0.002080</b>
<b>R<sup>2</sup></b>	<b>0.824</b>	<b>0.868</b>	<b>0.736</b>	<b>0.734</b>

Table 2 - Descriptive statistics of uncorrected and corrected reflectance for green (R550), near-infrared (R800), NIR/Green, and GNDVI. Indices are thought to change less with changing conditions, but clearly they benefited greatly from correction for time, sun angle, and clearness since correction reduced variability in both indices by 48%. The individual wavebands green and NIR benefited even more from correction, with a 58 to 64% reduction in variability.

	<b>Mean</b>	<b>Minimum</b>	<b>Maximum</b>	<b>Standard Deviation</b>	<b>Coefficient Of Variation</b>	<b>Coefficient Of Variation Reduction</b>
<b>R<sub>550</sub></b>	<b>0.0206</b>	<b>0.0118</b>	<b>0.0363</b>	<b>0.0044</b>	<b>21.5%</b>	
<b>CorrR<sub>550</sub></b>	<b>0.0206</b>	<b>0.0128</b>	<b>0.0257</b>	<b>0.0019</b>	<b>9.0%</b>	<b>58.0%</b>
<b>R<sub>800</sub></b>	<b>0.0980</b>	<b>0.0619</b>	<b>0.1795</b>	<b>0.0211</b>	<b>21.6%</b>	
<b>CorrR<sub>800</sub></b>	<b>0.0980</b>	<b>0.0587</b>	<b>0.1177</b>	<b>0.0077</b>	<b>7.8%</b>	<b>63.7%</b>
<b>NIR/Green</b>	<b>4.7942</b>	<b>3.8602</b>	<b>6.4519</b>	<b>0.5133</b>	<b>10.7%</b>	
<b>CorrNIR/Green</b>	<b>4.7942</b>	<b>4.0263</b>	<b>5.6473</b>	<b>0.2639</b>	<b>5.5%</b>	<b>48.6%</b>
<b>GNDVI</b>	<b>0.6521</b>	<b>0.5885</b>	<b>0.7316</b>	<b>0.0306</b>	<b>4.7%</b>	
<b>CorrGNDVI</b>	<b>0.6521</b>	<b>0.6096</b>	<b>0.7022</b>	<b>0.0158</b>	<b>2.4%</b>	<b>48.5%</b>

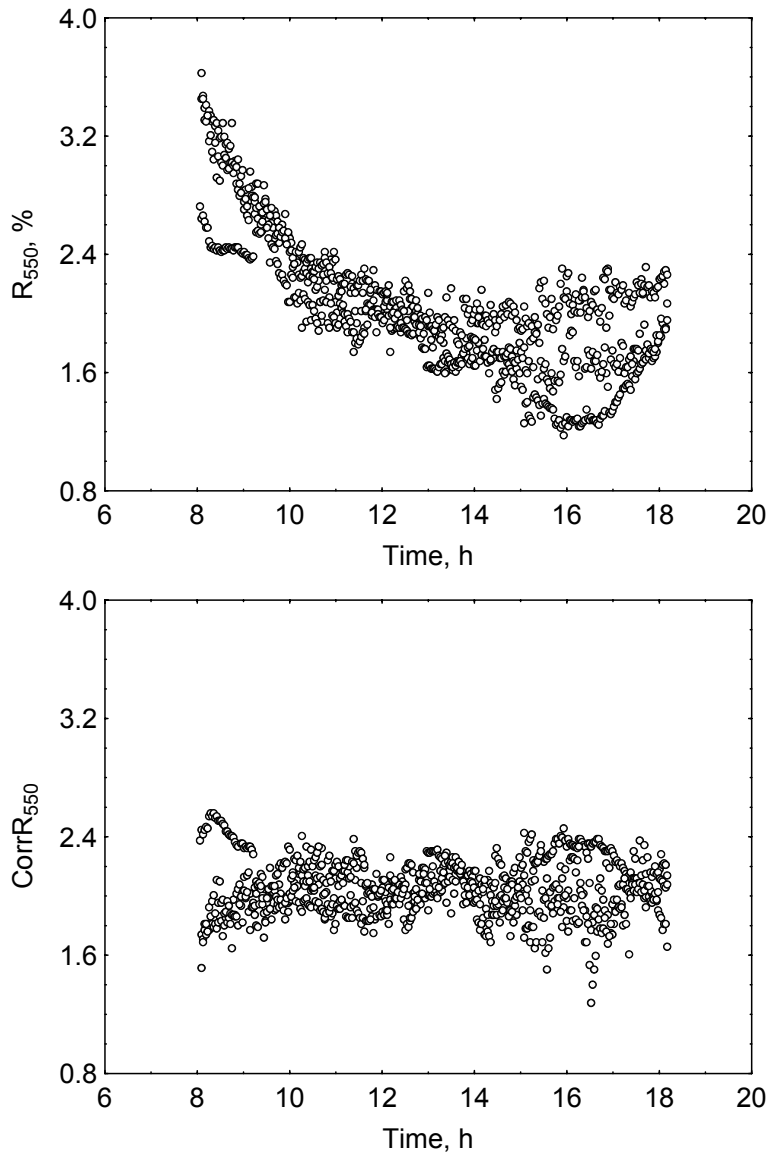


Figure 1- Corn reflectance measured in the green band ( $R_{550}$ ) (top) can change by a factor of two during the day. Usually highest values occur in the morning, drop till afternoon, then go back up as evening approaches. Several days worth of data are shown. Applying correction functions from Table 1 to the data in the top graph results in much more stable data over the course of the day (bottom). This makes the use of these spectral radiometer reflectance measurements much more practical for variable-rate N application.

## **Evaluation of Modified Mehlich Buffer Tests for Determining Lime Requirement in Missouri Soils (2005-2006)**

Manjula Nathan, Peter Scharf, Yichang Sun, and David Dunn

### **Objectives:**

1. To compare the Modified Woodruff Buffer test method with the Modified Mehlich Buffer test for determining the lime requirement for Missouri soils.
2. To determine if the Modified Mehlich Buffer is an effective alternative to the Modified Woodruff Buffer test for Missouri soils.
3. Compare the Lime Recommendations using Modified Mehlich and Modified Woodruff Buffer for Missouri soils.
4. To Determine the Lime Recommendations Equations for Modified Mehlich Buffer for Missouri Soils for the pH ranges of 5.5 to 6.0; 6.0 to 6.5 and 6.5 -7.0.
5. Implementing the Change in Lime Recommendation Test in the University of Missouri Soil Testing Labs.

### **Importance of Research:**

In Missouri, the Modified Woodruff Buffer test is used to determine the lime requirement in soils. Though this method has been proven to work for Missouri soils it uses para-nitrophenol as one of the reagents which is a hazardous substance. Para-nitrophenol can cause serious health effects on humans when breathed in or when absorbed by skin. Thus the waste produced by the Woodruff buffer test needs to be treated as a hazardous waste. Also, since Missouri is the only state in the nation which uses the Woodruff Buffer test, by evaluating the other buffer tests used, data and lime recommendations developed for Missouri can be compared with similar information from the other states.

The SMP buffer test is commonly used throughout the U.S. for determining lime requirement. This is the method listed as the recommended procedure for lime requirement in the publication: *Recommended Chemical Soil Test Procedures by the North Central Region*. This method also uses para-nitrophenol. In addition, even though the SMP buffer test is commonly used throughout the U.S. for determining lime requirement, the SMP buffer solution contains potassium chromate, a carcinogen, and poses a health risk to laboratory technicians who perform this test. Additionally, all waste generated by the test must be collected for proper disposal. An alternative to the SMP test is the Mehlich Buffer test. Although the Mehlich buffer contains barium chloride, another toxic and regulated compound, calcium chloride ( $\text{CaCl}_2$ ) has been shown to be an effective and safe substitute.

Studies have been conducted to develop alternative methods for making lime recommendations without the use of hazardous chemicals. Hoskins from University of Maine evaluated the Mehlich Buffer for Maine soils (Hoskins, 2005) and the modification of the buffer to replace the  $\text{BaCl}_2$  with a non-hazardous chemical. He found  $\text{CaCl}_2$  to be a suitable substitute for  $\text{BaCl}_2$  and developed the Modified Mehlich Buffer (Hoskins, 2005) for evaluating lime requirement in soils. A recent study carried out at Pennsylvania State University by Wolf and Beegle (2005) compared SMP buffer with Modified Mehlich buffer and concluded that the Mehlich buffer is a better predictor of lime requirement on Pennsylvania soils than the SMP buffer and, additionally, does not contain any hazardous components. They also reported that the Mehlich buffer calibration on Pennsylvania soils was similar to Mehlich buffer calibrations in North Carolina and Maine. They concluded that the Mehlich buffer test is a feasible

alternative to the SMP buffer test for determining lime requirement on acid soils of the Northeast and other regions of the U.S.

Similar studies on comparisons of Modified Woodruff with Modified Mehlich buffers for Missouri Soils (Nathan, Sun and Scharf, 2005); SMP and Modified Mehlich buffers for Wisconsin Soils (Laboski and Peters, 2005) and evaluation of Modified Mehlich buffer for Virginia Soils (Mullins, 2005) have been conducted. Research findings from these researchers strongly suggest Modified Mehlich buffer to be a better alternative to the other buffers used in these states.

### **Methodology**

- Twenty soil samples collected from different soil regions in Missouri that represent major agricultural areas were used in the soil incubation study. Lime requirement in the soils selected for incubation study was estimated by the Modified Woodruff Buffer test (method currently used) and the Modified Mehlich Buffer test method.
- *Incubation Study:*  
Soils were amended with reagent grade  $\text{CaCO}_3$  at rates of 0, 1/3, 2/3, 1 and 1 1/3 and 2 times the estimated lime requirement from the Modified Woodruff Buffer test to raise the soil pH for target of 5.5 -6.0, 6.1 -6.5, and 6.6- 7.0 ranges.
- The soils were then incubated in the dark for a total duration of three months, with a three week interval wetting and drying cycle. 3 weeks with the following wetting and drying cycle.
- Soil pH was regressed with  $\text{CaCO}_3$  added to all 20 soils, and the actual lime requirement was estimated for each soil to raise the soil pHs to target levels of 5.8, 6.3 and 6.8. Woodruff and Mehlich buffer pHs were regressed against actual lime requirement for all 20 soils to evaluate effectiveness of each test for estimating the lime requirement in Missouri soils. Soil characteristics of the soils used in this study are presented in Table 1.
- Run Modified Mehlich and Woodruff Buffer tests for soils received from throughout the state of Missouri by the University of Missouri Soil testing labs and find the relationship between the two tests for Missouri soils.

### *Data Analysis:*

Woodruff and Mehlich buffer pH were regressed against actual lime requirement to evaluate effectiveness of each test for estimating the lime requirement for Missouri soils.

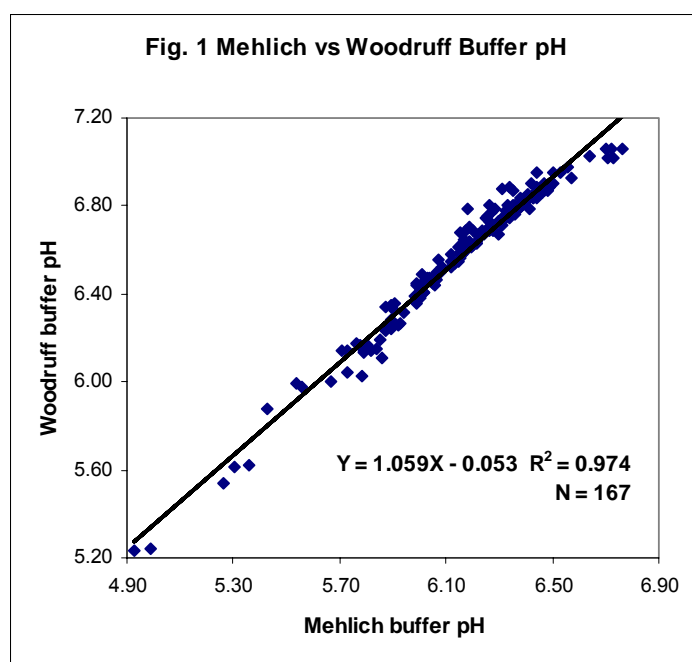
Based on the lime requirement equations obtained to raise the soil pH for Missouri soils for target pHs of 5.8; 6.3 and 6.8, lime requirement was calculated for both buffer tests and compared by linear regression. Regression analysis was run on bulked data to predict lime requirement from buffer pH alone (simple linear) and from pHs (salt pH) and buffer pH (multi linear).

**Results:**

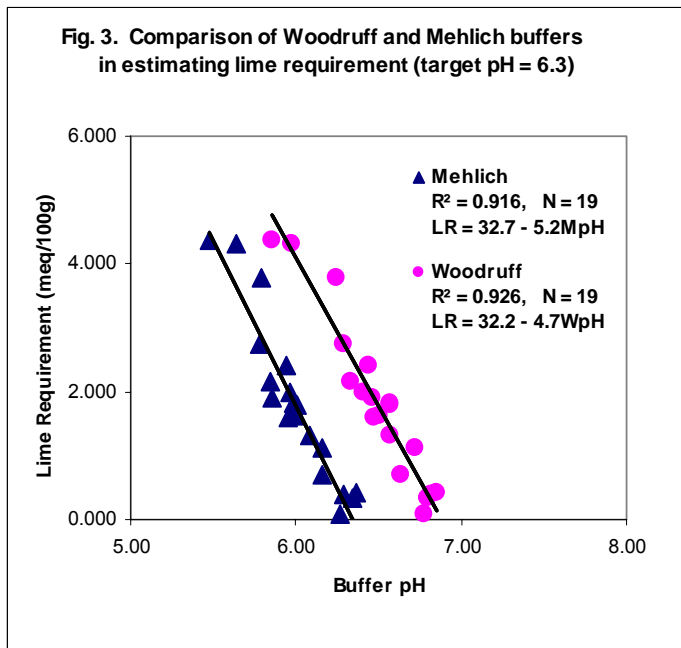
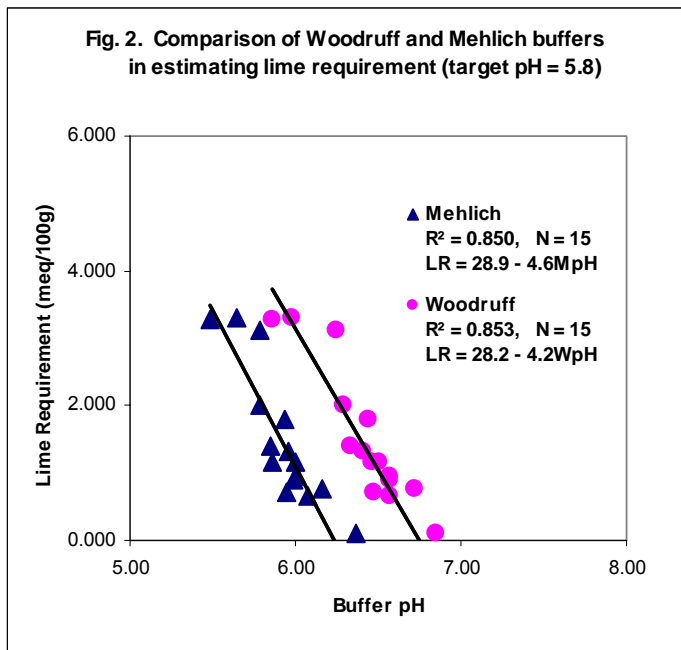
**Table 1. Soil Characteristics**

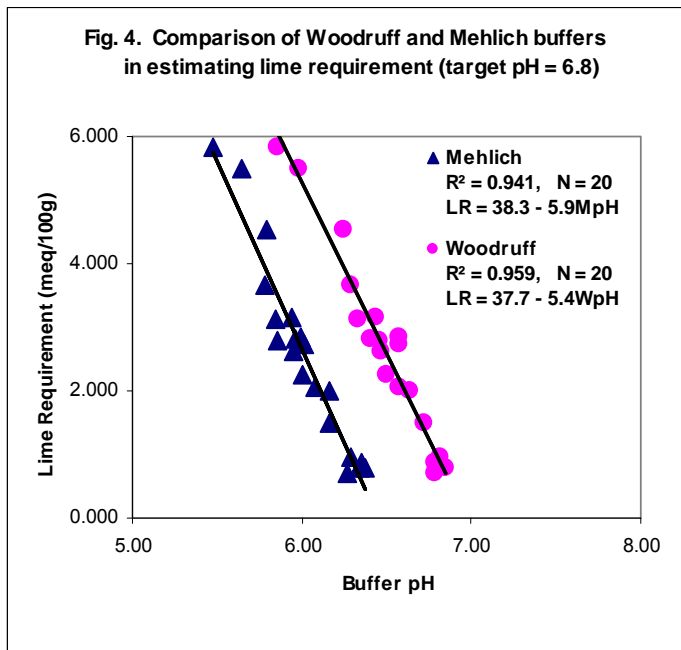
ID	County	Location	Soil Series	Soil pH	Woodruff pH	Mehlich pH	OM %
1	Boone	Bradford Farm	Mexico silt loam	4.6	6.3	5.8	2.7
2	Boone	South farm	Mexico silt loam	5.9	6.6	6.2	4.1
3	Knox	Novelty	Kilwinning silt loam	5.4	6.6	6.1	3.2
4	Holt	Corning	Salix silty clay loam	5.1	6.5	5.9	3.4
5	Linn	Linneus	Lagonda silty clay loam	5.4	6.6	6.0	5.2
6	Lawrence	Mount Vernon	Credon silt loam	4.7	6.4	6.0	2.1
7	Webster	Springfield	Tonti silt loam	4.2	5.9	5.5	3.7
8	Gentry	Albany	Grundy silt loam	5.4	6.5	6.0	4.0
9	Saline	Marshall	Higginsville silt loam	6.0	6.8	6.3	3.2
10	Mississippi	Hwy K	Commerce silt loam	5.1	6.7	6.2	1.8
11	Oregon	Alton	Fanchon silt loam	4.5	6.4	5.9	2.6
12	Pemiscot	Portageville	Tiptonville silt loam	4.2	6.3	5.8	2.4
13	Dunklin	Qulin	Crowley silt loam	5.9	6.9	6.4	1.5
14	Barton	Lamar	Parson's silt loam	4.5	6.5	6.0	1.7
15	Pemiscot	Portageville	Tiptonville silt loam	5.9	6.8	6.3	1.9
16	New Madrid	Morehouse	Sharkey clay	5.4	6.6	6.0	3.7
17	Osage	Linn	Union silt loam	6.0	6.8	6.4	1.9
19	Pike	Annada	Tice silt loam	6.0	6.8	6.3	2.1
20	Ray	Camden	Colo Silt loam	5.0	6.3	5.9	3.0

The 167 soil samples collected through out the state of Missouri were used in comparing the modified Woodruff and modified Mehlich buffer tests (Fig. 1). The two buffer tests were found to be well correlated in Missouri soils. ( $R^2=0.974$ ).



Relationship between the buffer pH and lime requirement for both buffers after incubating the soil with different  $\text{CaCO}_3$  treatments to achieve target pHs of 5.8, 6.3 and 6.8 are presented in Fig 2, 3 and 4.





Lime requirement regression equations for modified Woodruff and modified Mehlich buffer tests for target pHs of 5.8, 6.3 and 6.8 are presented in Table 2.

**Table 2: Lime Requirement Linear Regression Equations using Buffer pH, meq/100 g of soil**

Buffer Test	Target pH	Regression Equation	R <sup>2</sup>	n
Modified Woodruff	5.8	L. R = 28.2 – 4.2 W pH	0.853	15
Modified Mehlich	5.8	L. R = 28.9 – 4.6 M pH	0.850	15
Modified Woodruff	6.3	L. R = 32.2 – 4.7 W pH	0.926	19
Modified Mehlich	6.3	L. R = 32.7 – 5.2 M pH	0.916	19
Modified Woodruff	6.8	L. R = 37.7 – 5.4 W pH	0.959	20
Modified Mehlich	6.8	L. R = 38.3 – 5.9 M pH	0.941	20

L.R – Lime Requirement in meq/100 g of soil

W pH – Modified Woodruff buffer pH

M pH - Modified Mehlich buffer pH

### **Conclusions:**

Both buffers (Mehlich and Woodruff) were found to be equally good in predicting the lime requirement for Missouri soils. (Fig 2, 3, and 4). Modified Mehlich buffer was found to be a viable alternative to Woodruff buffer. However, the modified Mehlich buffer has limitations as it cannot be stored beyond two weeks without any microbial growth. The short bench life of Mehlich buffer (about 14 days) makes it not acceptable for use by commercial soil testing labs. Additional research is warranted to develop a new buffer test that would eliminate hazardous waste and would preferably have no effect in agronomic interpretations.

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## **Progress Reports**

### **Nutrient Removal Values for Major Agronomic Crops in Missouri Report for 2006**

Manjula V. Nathan and Yichang Sun, and David Dunn

#### **Introduction:**

Currently the soil Fertility Group is working on revising the University of Missouri (MU) Fertilizer and Lime Recommendations for Missouri. At this time, there is no research based values for nutrient removal available for major agronomic crops in Missouri. Since the source of nutrient removal values currently used by the MU fertilizer and Lime Recommendations is unknown, it was suggested that we replace the existing values in MU recommendations with data on nutrient removal values from the National Beef Research Council and National Dairy Research council. Since the crop nutrient removal values vary depending on yields, variety grown, and environmental conditions, it would be more appropriate to use nutrient uptake values from Missouri rather than using the national values reported by the National Beef and Dairy Research Councils.

#### **Objective:**

- To obtain nutrient removal values for major agronomic crops in Missouri and use them in refining University of Missouri Fertilizer Recommendations.

#### **Current Status:**

Table 1 provides a comparison of the current removal rates, the proposed removal rates based on National Beef Research Council and National Dairy Research Council, and the rates recommended by the Potash and Phosphate Institute (PPI, 2002).

Preliminary work was done in year 2006 by collecting grain and forage samples for major agronomic crops in the state of Missouri. The samples were collected throughout the state of Missouri by working in collaboration with Missouri Department of Agriculture Grain Inspection Service Centers, MFA grain elevators, Agricultural Experiment Station Research Center and Farms and researchers. We collected 326 grain samples and 76 forage samples from the state of Missouri. At this time, we have completed N, P, K and moisture analysis on 182 grain samples and the results are presented in Table 2.

Table 2 provides the grain nutrient removal values for major agronomic crops in Missouri in 2006. The N, P and K nutrient removal values for grain crops in Missouri for year 2006 didn't match with the nutrient values provided by the National Beef and Dairy Research Council. (Table 3). The values used by them are from a national data base and it doesn't truly represent the Missouri conditions. This suggests that additional data for grain nutrient removal values should be collected over years for agronomic crops in Missouri to come up with appropriate values to refine MU Fertilizer recommendations.

**Need for Future Research:**

Since the nutrient removal values vary with weather conditions, yields, management and soil type, we need to collect data over multiple years to have a larger data base to develop appropriate and realistic nutrient removal values representing the growing conditions in Missouri. Samples will be collected from grain inspection services, grain elevators, variety trials, agriculture experiment station farms, and researchers from all parts of the state to get a representative sample pool. There is a dire need for this data before making changes in nutrient removal values for agronomic crops in Missouri. Other states use the data collected from their states to come up with the appropriate values for nutrient removal that represent the growing conditions in their state.

**Table 1: Comparison of current University of Missouri, proposed (National Research Council), and Phosphate Potash Institute nutrient removal values for agronomic crops.**

Crop	Yield Unit	N removal			P <sub>2</sub> O <sub>5</sub> removal			K <sub>2</sub> O removal		
		Current	NRC	PPI	Current	NRC	PPI	Current	NRC	PPI
Barley	bushel	0.96	0.87	1.1	0.38	0.33	0.4	0.24	0.29	0.35
Corn Grain	bushel	0.9	0.74	0.75	0.45	0.32	0.44	0.30	0.25	0.29
Corn Silage	ton	9.0	9.9	8.3	3.6	4.1	3.6	9.0	10	8.3
Oats	bushel	0.64	0.6	0.8	0.26	0.26	0.25	0.19	0.17	0.2
Rice	pound	0.013	-	-	0.0065	-	-	0.004	-	-
Sorghum grain	pound	0.014	0.018	0.015	0.0093	0.0067	0.0075	0.006	0.0047	0.0038
Sorghum silage	ton	13.0	10	-	4.6	3.5	-	10	15	-
Soybean	bushel	-	3.4	4.0	0.84	0.80	0.80	1.44	1.30	1.40
Wheat	bushel	1.26	1.18	1.5	0.60	0.50	0.5	0.30	0.30	0.35
Alfalfa-grass hay	ton	-	54	50	10.0	11	14	45	53	54
Bermuda grass hay	ton	50	30	41	9.0	11	11	34	40	45
Clover-grass hay	ton	-	55	45	8.2	13	14	38	57	54
Cool season grass hay	ton	40	38	34	9.0	12	16	34	47	47
Lespedeza-grass hay	ton	-	-	-	8.8	-	-	20	-	-
Sudan grass hay	ton	40	27	36	6.9	8	14	19	52	52
Warm season grass hay	ton	-	-	-	2.0	-	-	14.6	-	-

**Table 2: Survey Report of the Grain Nutrient Removal Values for Major Agronomic Crops in Missouri – Year 2006**

<u>CORN</u> County	<u>N</u> %	<u>P</u> %	<u>K</u> %	<u>Nutrient</u> lbs N/bu	<u>Removal</u> lbs P <sub>2</sub> O <sub>5</sub> /bu	<u>Values</u> lbs K <sub>2</sub> O/bu
Gentry	1.395	0.490	0.579	0.660	0.527	0.330
Montgomery	1.491	0.474	0.705	0.706	0.510	0.402
Audrain	1.222	0.300	0.440	0.578	0.323	0.251
Warren	1.407	0.333	0.541	0.666	0.358	0.308
Warren	1.448	0.450	0.620	0.685	0.484	0.353
Audrain	1.265	0.439	0.576	0.598	0.472	0.328
Morgan	1.317	0.468	0.599	0.623	0.503	0.342
Boone	1.555	0.561	0.672	0.736	0.603	0.383
Grundy	1.224	0.284	0.440	0.579	0.305	0.251
Bates	1.252	0.408	0.515	0.592	0.438	0.293
Barton	1.288	0.414	0.522	0.609	0.445	0.298
Saline	1.305	0.391	0.484	0.618	0.420	0.276
St. Francois	1.326	0.412	0.604	0.627	0.443	0.344
Chariton	1.170	0.408	0.564	0.554	0.439	0.322
Randolph	1.205	0.420	0.569	0.570	0.452	0.325
Lafayette	1.295	0.433	0.582	0.613	0.466	0.332
Lafayette	1.209	0.401	0.548	0.572	0.432	0.313
Audrain	1.145	0.419	0.597	0.542	0.451	0.341
Livingston	1.539	0.469	0.679	0.728	0.504	0.387
St. Genevieve	1.350	0.466	0.579	0.639	0.501	0.330
St. Louis	1.485	0.389	0.635	0.703	0.419	0.362
Lafayette	1.176	0.340	0.464	0.556	0.366	0.264
Cape Girardeau	1.362	0.448	0.643	0.644	0.481	0.367
Mississippi	1.551	0.439	0.681	0.734	0.472	0.388
St. Charles	1.319	0.362	0.588	0.624	0.389	0.335
Clark	1.486	0.457	0.742	0.703	0.492	0.423
New Madrid	1.208	0.298	0.468	0.571	0.321	0.267
Scott	1.769	0.545	0.679	0.837	0.586	0.387
Livingston	1.536	0.493	0.711	0.727	0.530	0.405
Lafayette	1.296	0.480	0.661	0.613	0.516	0.377
Randolph	1.487	0.339	0.582	0.703	0.364	0.332
Nodaway	1.484	0.429	0.662	0.702	0.462	0.377
Howard	1.358	0.344	0.581	0.643	0.370	0.332
Cape Girardeau	1.324	0.441	0.614	0.627	0.475	0.350
Mississippi	1.246	0.394	0.585	0.590	0.424	0.333
St. Charles	1.546	0.465	0.657	0.731	0.501	0.375
Clark	1.324	0.387	0.596	0.626	0.416	0.340
New Madrid	1.342	0.404	0.514	0.635	0.435	0.293
Scott	1.342	0.468	0.583	0.635	0.503	0.332
Lafayette	1.328	0.367	0.541	0.628	0.395	0.309
Livingston	1.281	0.404	0.565	0.606	0.434	0.322
Lafayette	1.596	0.412	0.643	0.755	0.443	0.366
Randolph	1.529	0.331	0.608	0.723	0.355	0.347
Nodaway	1.588	0.441	0.708	0.751	0.474	0.404
Howard	1.346	0.334	0.550	0.637	0.359	0.313
Bates	1.515	0.381	0.594	0.717	0.410	0.339

<b>CORN</b>	<b>N</b>	<b>P</b>	<b>K</b>	<b>Nutrient</b>	<b>Removal</b>	<b>Values</b>
Cape Girardeau	1.414	0.486	0.675	0.669	0.523	0.385
St. Charles	1.307	0.325	0.534	0.618	0.350	0.304
Stoddard	1.493	0.378	0.704	0.706	0.406	0.402
Scott	1.612	0.516	0.631	0.763	0.555	0.360
St. Charles	1.656	0.432	0.605	0.784	0.465	0.345
Stoddard	1.472	0.485	0.717	0.697	0.522	0.409
New Madrid	1.674	0.628	0.742	0.792	0.676	0.423
Scott	1.611	0.582	0.673	0.762	0.626	0.384
Stoddard	1.691	0.521	0.837	0.800	0.560	0.477
New Madrid	1.622	0.517	0.702	0.768	0.556	0.400
Scott	1.293	0.531	0.642	0.612	0.571	0.366
Stoddard	1.578	0.489	0.698	0.747	0.526	0.398
New Madrid	1.486	0.518	0.633	0.703	0.557	0.361
Scott	1.144	0.443	0.576	0.541	0.477	0.328
New Madrid	1.392	0.504	0.661	0.659	0.542	0.377
Scott	1.362	0.457	0.584	0.645	0.492	0.333
New Madrid	1.776	0.643	0.753	0.840	0.692	0.429
New Madrid	1.344	0.424	0.630	0.636	0.456	0.359
<b>Mean</b>	<b>1.409</b>	<b>0.436</b>	<b>0.614</b>	<b>0.667</b>	<b>0.469</b>	<b>0.350</b>
<b>STD</b>	<b>0.157</b>	<b>0.075</b>	<b>0.079</b>	<b>0.074</b>	<b>0.081</b>	<b>0.045</b>
<b>N</b>	<b>64</b>	<b>64</b>	<b>64</b>	<b>64</b>	<b>64</b>	<b>64</b>

<b>SOYBEANS</b>	<b>N</b>	<b>P</b>	<b>K</b>	<b>Nutrient</b>	<b>Removal</b>	<b>Values</b>
<b>County</b>	<b>%</b>	<b>%</b>	<b>%</b>	<b>lbs N/bu</b>	<b>lbs P<sub>2</sub>O<sub>5</sub>/bu</b>	<b>lbs K<sub>2</sub>O/bu</b>
Mississippi	4.708	0.405	1.603	2.458	0.481	1.008
Gentry	4.691	0.440	1.516	2.449	0.522	0.954
Atchison	5.256	0.473	1.784	2.744	0.561	1.122
Andrew	6.301	0.464	1.825	3.289	0.551	1.148
Buchanan	5.633	0.550	1.952	2.940	0.653	1.228
Clinton	4.967	0.459	1.794	2.593	0.545	1.129
Pike	4.771	0.450	1.794	2.490	0.534	1.129
Macon	4.603	0.439	1.805	2.403	0.521	1.135
Scott	5.065	0.455	1.805	2.644	0.540	1.135
Warren	5.349	0.477	1.536	2.792	0.566	0.966
Stoddard	4.615	0.425	1.734	2.409	0.504	1.091
Boone	4.500	0.414	1.652	2.349	0.491	1.039
Pemiscot	4.741	0.444	1.859	2.475	0.527	1.169
Barton	5.504	0.448	1.747	2.873	0.531	1.099
Morgan	5.241	0.464	1.502	2.736	0.551	0.945
Boone	4.566	0.456	1.545	2.383	0.541	0.971
Grundy	4.367	0.481	1.651	2.280	0.571	1.038
Barton	4.767	0.435	1.607	2.488	0.516	1.011
St. Francois	3.499	0.431	1.280	1.826	0.511	0.805
Livingston	4.188	0.407	1.492	2.186	0.483	0.938
Chariton	3.774	0.433	1.447	1.970	0.514	0.910
Audrain	4.002	0.434	1.516	2.089	0.515	0.953
St. Genevieve	5.429	0.505	1.743	2.834	0.599	1.096
Livingston	4.693	0.401	1.446	2.450	0.476	0.909
Pemiscot	5.005	0.427	1.665	2.613	0.507	1.047

<u>SOYBEANS</u>	<u>N</u>	<u>P</u>	<u>K</u>	<u>Nutrient</u>	<u>Removal</u>	<u>Values</u>
Holt	4.485	0.502	1.694	2.341	0.596	1.066
Dekalb	5.093	0.467	1.761	2.659	0.554	1.107
Gentry	5.198	0.431	1.655	2.713	0.511	1.041
Nodaway	5.025	0.431	1.727	2.623	0.511	1.086
Saline	4.514	0.385	1.215	2.356	0.457	0.764
Lafayette	3.965	0.467	1.640	2.070	0.554	1.032
Randolph	4.270	0.442	1.350	2.229	0.524	0.849
Nodaway	4.296	0.408	1.603	2.242	0.484	1.008
New Madrid	4.923	0.440	1.631	2.570	0.522	1.026
New Madrid	4.897	0.436	1.619	2.556	0.517	1.018
Pemiscot	5.030	0.423	1.633	2.626	0.502	1.027
Holt	5.175	0.462	1.719	2.701	0.549	1.081
Dekalb	5.028	0.533	1.714	2.625	0.632	1.078
Gentry	4.831	0.349	1.571	2.522	0.414	0.988
Nodaway	5.381	0.449	1.793	2.809	0.532	1.128
Saline	4.753	0.415	1.472	2.481	0.492	0.926
Lafayette	3.985	0.465	1.600	2.080	0.551	1.006
Randolph	4.520	0.417	1.556	2.359	0.495	0.978
Nodaway	4.711	0.447	1.681	2.459	0.530	1.057
New Madrid	4.876	0.426	1.645	2.545	0.505	1.035
Pemiscot	4.853	0.419	1.629	2.533	0.497	1.024
Holt	5.013	0.461	1.772	2.617	0.547	1.114
Gentry	5.470	0.485	1.658	2.855	0.575	1.043
Nodaway	5.344	0.443	1.744	2.789	0.526	1.097
New Madrid	4.956	0.429	1.671	2.587	0.508	1.051
Pemiscot	5.342	0.435	1.672	2.789	0.517	1.052
<b>Mean</b>	<b>4.827</b>	<b>0.445</b>	<b>1.642</b>	<b>2.520</b>	<b>0.528</b>	<b>1.033</b>
<b>STD</b>	<b>0.510</b>	<b>0.034</b>	<b>0.144</b>	<b>0.266</b>	<b>0.041</b>	<b>0.090</b>
<b>N</b>	<b>51</b>	<b>51</b>	<b>51</b>	<b>51</b>	<b>51</b>	<b>51</b>

<u>WHEAT</u>	<u>N</u>	<u>P</u>	<u>K</u>	<u>Nutrient</u>	<u>Removal</u>	<u>Values</u>
<u>County</u>	<u>%</u>	<u>%</u>	<u>%</u>	<u>lbs N/bu</u>	<u>lbs P<sub>2</sub>O<sub>5</sub>/bu</u>	<u>lbs K<sub>2</sub>O/bu</u>
New Madrid	2.007	0.366	0.618	1.042	0.432	0.386
Gentry	1.779	0.309	0.436	0.923	0.365	0.272
Warren	1.759	0.356	0.438	0.913	0.420	0.274
Audrain	1.380	0.286	0.357	0.716	0.337	0.223
Boone	2.116	0.288	0.433	1.098	0.340	0.270
St. Francois	1.909	0.304	0.419	0.991	0.359	0.262
Grundy	1.751	0.245	0.376	0.909	0.289	0.235
Boone	1.747	0.386	0.544	0.907	0.455	0.340
Boone	1.811	0.365	0.546	0.940	0.430	0.341
Boone	1.619	0.332	0.517	0.840	0.391	0.324
Boone	1.542	0.335	0.487	0.800	0.395	0.304
Boone	1.822	0.356	0.533	0.946	0.420	0.333
Boone	1.721	0.357	0.561	0.893	0.421	0.351
Knox	1.558	0.357	0.499	0.809	0.421	0.312
Knox	1.580	0.285	0.342	0.820	0.336	0.214
Knox	1.621	0.307	0.355	0.841	0.362	0.222
Knox	1.539	0.274	0.308	0.799	0.323	0.192

<u>WHEAT</u>	<u>N</u>	<u>P</u>	<u>K</u>	<u>Nutrient</u>	<u>Removal</u>	<u>Values</u>
Knox	1.667	0.299	0.335	0.865	0.352	0.209
Knox	1.689	0.367	0.351	0.877	0.433	0.220
Carroll	1.601	0.326	0.431	0.831	0.385	0.270
Chariton	1.721	0.321	0.495	0.893	0.379	0.310
Randolph	1.602	0.316	0.399	0.831	0.373	0.250
Audrain	1.871	0.382	0.554	0.971	0.451	0.346
Livingston	1.592	0.326	0.465	0.826	0.384	0.291
St. Genevieve	1.971	0.401	0.646	1.023	0.473	0.404
Cape Girardeau	2.067	0.334	0.639	1.073	0.394	0.399
Mississippi	1.624	0.308	0.519	0.843	0.363	0.325
Cape Girardeau	1.799	0.326	0.526	0.934	0.385	0.329
Mississippi	1.734	0.314	0.484	0.900	0.370	0.303
Mississippi	1.638	0.302	0.479	0.850	0.357	0.299
Grundy	2.104	0.315	0.512	1.092	0.372	0.320
Bates	1.625	0.268	0.337	0.843	0.317	0.211
Grundy	1.585	0.326	0.428	0.823	0.385	0.268
Randolph	1.493	0.326	0.427	0.775	0.385	0.267
Montgomery	1.599	0.300	0.433	0.830	0.354	0.271
Audrain	1.774	0.349	0.507	0.920	0.411	0.317
Montgomery	1.628	0.297	0.452	0.845	0.350	0.282
Audrain	1.858	0.347	0.517	0.964	0.409	0.324
Bates	1.836	0.312	0.408	0.953	0.368	0.255
Montgomery	1.648	0.301	0.440	0.855	0.355	0.275
Audrain	1.743	0.372	0.536	0.905	0.439	0.335
Audrain	1.786	0.323	0.480	0.927	0.382	0.300
Barton	2.598	0.396	0.609	1.348	0.467	0.381
<b>Mean</b>	<b>1.747</b>	<b>0.327</b>	<b>0.469</b>	<b>0.907</b>	<b>0.386</b>	<b>0.293</b>
<b>STD</b>	<b>0.210</b>	<b>0.035</b>	<b>0.085</b>	<b>0.109</b>	<b>0.041</b>	<b>0.053</b>
<b>N</b>	<b>45</b>	<b>45</b>	<b>45</b>	<b>45</b>	<b>45</b>	<b>45</b>
<u>SORGHUM</u>	<u>N</u>	<u>P</u>	<u>K</u>	<u>Nutrient</u>	<u>Removal</u>	<u>Values</u>
<b>County</b>	<b>%</b>	<b>%</b>	<b>%</b>	<b>lbs N/bu</b>	<b>lbs P<sub>2</sub>O<sub>5</sub>/bu</b>	<b>lbs K<sub>2</sub>O/bu</b>
Gentry	1.590	0.885	1.019	0.775	0.980	0.598
Audrain	1.819	0.760	0.833	0.886	0.841	0.489
Morgan	2.166	0.868	1.106	1.055	0.961	0.649
Boone	1.932	0.877	1.000	0.941	0.971	0.587
Barton	1.767	0.782	0.872	0.861	0.866	0.512
Livingston	1.856	0.848	1.044	0.904	0.939	0.613
Ray	1.650	0.884	0.994	0.804	0.979	0.583
Grundy	1.469	0.740	0.856	0.716	0.820	0.502
Audrain	1.712	0.948	1.006	0.834	1.050	0.591
Livingston	1.570	0.892	1.083	0.765	0.987	0.636
Audrain	1.602	0.844	1.036	0.781	0.934	0.608
Audrain	1.658	0.870	1.034	0.808	0.964	0.607
Audrain	1.547	0.822	0.979	0.754	0.911	0.575
Audrain	1.522	0.734	0.876	0.742	0.813	0.514
<b>Mean</b>	<b>1.704</b>	<b>0.840</b>	<b>0.981</b>	<b>0.830</b>	<b>0.930</b>	<b>0.576</b>
<b>STD</b>	<b>0.189</b>	<b>0.064</b>	<b>0.087</b>	<b>0.092</b>	<b>0.071</b>	<b>0.051</b>
<b>N</b>	<b>14</b>	<b>14</b>	<b>14</b>	<b>14</b>	<b>14</b>	<b>14</b>

**Table 3: Comparison of current University of Missouri, proposed (National Research Council), Phosphate Potash Institute and measured Missouri nutrient removal values, 2006 for major agronomic crops.**

Crop	Yield Unit	N removal				P <sub>2</sub> O <sub>5</sub> removal				K <sub>2</sub> O removal			
		Current	NRC	MO Values 2006	PPI	Current	NRC	MO values 2006	PPI	Current	NRC	MO values 2006	PPI
Corn Grain	bushel	0.9	0.74	0.67	0.75	0.45	0.32	0.46	0.44	0.30	0.25	0.35	0.29
Sorghum grain	pound	0.014	0.018	0.014	0.015	0.0093	0.0067	0.015	0.0075	0.006	0.0047	0.009	0.0038
Soybean	bushel	-	3.4	2.52	4.0	0.84	0.80	0.53	0.80	1.44	1.30	1.03	1.40
Wheat	bushel	1.26	1.18	0.91	1.5	0.60	0.50	0.39	0.5	0.30	0.30	0.29	0.35

## Using Phosphorus, Ammonium-nitrogen and Strip-kill to Increase Tall Fescue Seed Production in Missouri

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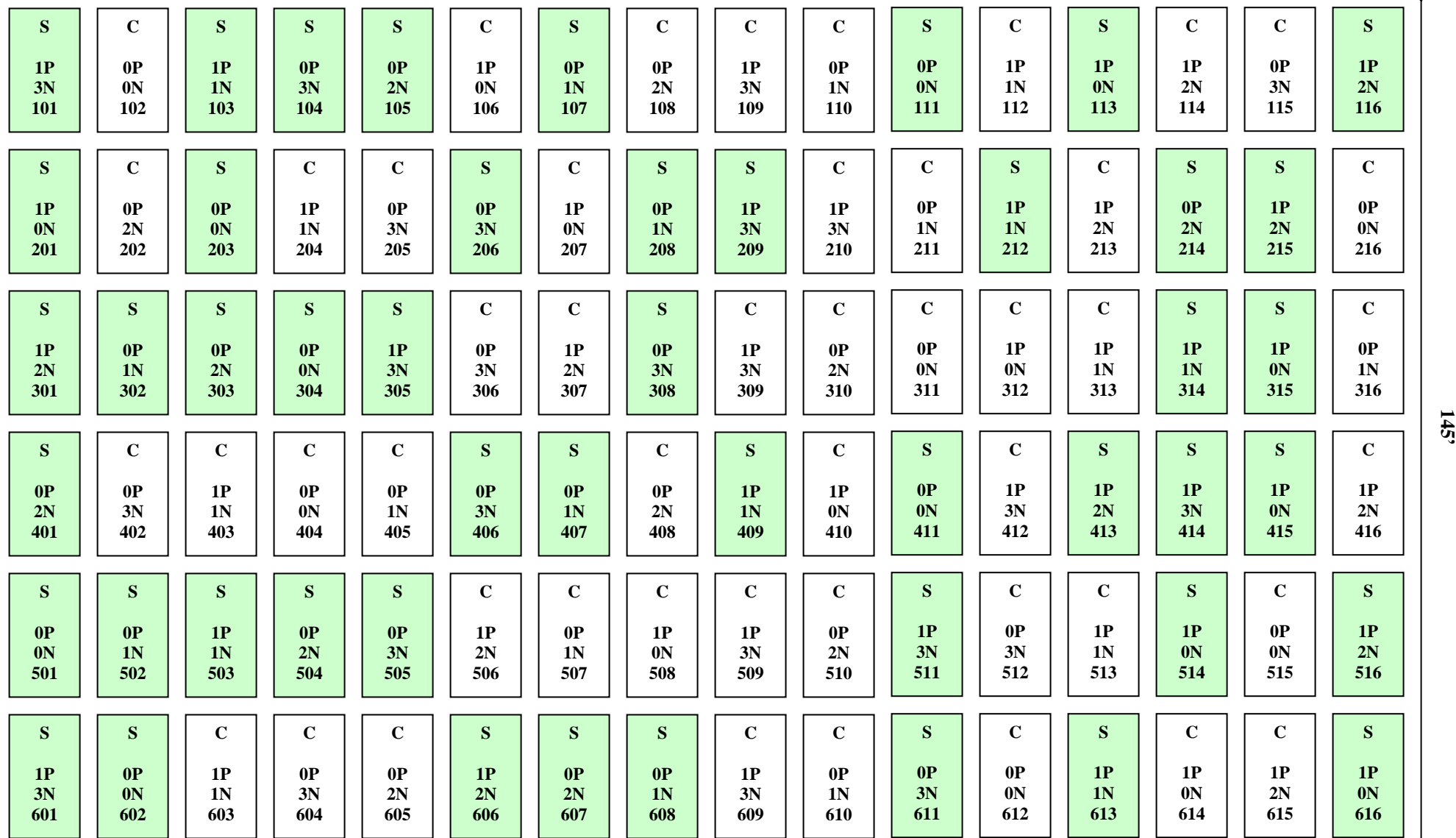
**Objective:** To determine if tall fescue seed production in Missouri can be increased by late summer phosphorus (P) and ammonium ( $\text{NH}_4^+$ ) applications in a strip-kill management system. In several plant species, a fall  $\text{NH}_4^+$  application increased production of the hormone, cytokinin, by root tips, and this hormone triggered reproductive growth that culminated in greater seed production (Marschner 1995). This project is important in that Missouri has 13 million acres of tall fescue pastures, and leads the nation in common tall fescue seed production, however, our seed yields are much lower than those in Oregon, for example. In earlier experiments, we dug tall fescue roots from established pasture monthly from October to April, and found an extremely thick root mass. The mass of roots was so thick that the plant almost looked “root-bound” and pastures needed to be aerated, like lawns, in the fall. Stripkill could be used to renovate the dense root system and restore the new growth. Our stripkill method worked for increasing forage production and our preliminary results indicate that stripkill also improves seed production.

**Procedure:** During the summer of 2006, a PhD student, Will McClain, built a sprayer that will spray Roundup® approximately 7.5” wide strips and leave 7.5” for seed production. The sprayer had a 10’ boom and eight 4002 Tarjet nozzles placed 15” apart. During mid-September 2006, tall fescue (K31, endophyte infected) pastures at the SW Center near Mt. Vernon and at the Bradford Agronomy Research Center near Columbia were selected and forage was removed to a height of 4”. Soil samples were collected and tested for P, Mg, Ca and K concentrations. Plots were flagged at 10’x 20’ (SWC) and 10’ x 25’ (ARC) with 5’ alleys (see Figs. 1 & 2 for the plots maps from SWC and ARC, respectively). Ten days after forage removal, Roundup® was applied in 7.5” strips leaving 7.5” of live tall fescue on stripkill plots. A Roundup® concentration of 1.6 oz/gal of water with 0.5 oz of crop oil/gal and 1.2 oz/gal of a blue tracking dye were used for the strip-kill process (Fig. 3). The total volume of application was 31 gal/acre. One half of the plot area was not treated with Roundup® and these plots will be used for conventional tall fescue seed production (controls). On September 20 (SW Center) and September 25 (ARC), plots were treated with 0 or 100 lbs P/acre from triple super phosphate (0-46-0) and 0 or 100 lbs of N/acre as either ammonium beads (N-guard) from Specialty Fertilizer Products, urea or ammonium nitrate. Therefore, the experimental design consisted of 8 fertilizer treatment combinations, 2 management treatments (stripkill/none), 6 replications, and 2 sites for a total of 192 plots.

**2006 Results:** A sprayer designed to kill 7.5” strips in 10’ wide plots of tall fescue was built and worked well. The tracking dye worked to clearly show the size of the treated strips and the area covered (Fig. 3). The killed strips (Fig. 4) look good at both locations.

**Second year schedule:** Once the seed is mature (early to mid-June 2007), it will be harvested with a plot combine, and yields and specific seed weight will be determined for each plot. The same plots will be used in 2007-08 without further Roundup® treatments. Based on our preliminary work, stripkill plots can be used for two years. By mid-September 2007, nitrogen will be applied as in 2006, and 50 lbs/acre of P will be applied to P-treated plots. In June 2008, the final seed harvest will be completed and the two years of data will be prepared for publication and distribution.

**Figure 1. Stripkill study plot map at Mt. Vernon 2006**



235'

145'

Plots are 10' x 20' with 5' alleys all around. 6 replicate blocks.

The entire area is 235' x 145' or 34075 ft<sup>2</sup> (0.782 acres). The diagonal is 276.13' from corner to corner.

<b>P</b>	<b>0= none</b>
	<b>1= 100lb P/acre</b>
<b>N</b>	<b>0= none</b>
	<b>1= 100lb N beads/acre</b>
	<b>2= 100lb NH<sub>4</sub>NO<sub>3</sub>/acre</b>
	<b>3= 100lb Urea/acre</b>

**Figure 2. Stripkill study plot map at Bradford (ARS) 2006**



235'

175'

Plots are 10' x 25' with 5' alleys all around. 6 replicate blocks.

The entire area is 235' x 175' or 41125 ft<sup>2</sup> (0.94 acres). The diagonal is 293' from corner to corner.

**P** 0= none  
1= 100lb P/acre

**N** 0= none  
1= 100lb N beads/acre  
2= 100lb NH<sub>4</sub>NO<sub>3</sub>/acre  
3= 100lb Urea/acre

**Figure 3. Spraying strips of tall fescue in fall 2006.**



**Figure 4. Killed strips of tall fescue in late fall 2006.**



## Using Magnesium and Phosphorus Fertilization to Improve the Macronutrient Quality of Stockpiled Tall Fescue

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**Objective:** To determine if phosphorus (P) and magnesium (Mg) concentrations in leaves of stockpiled tall fescue during winter can be increased by fertilization with both P and Mg. The acreage involved makes this research important to the Missouri fertilizer industry. Missouri leads the nation in tall fescue production and is second in beef calf production (Missouri Farm Facts, 2005). Of the 13 million acres of tall fescue pasture in Missouri, much of it grows on soils low in plant available P (Bray I). Production of forage on these soils might have an impact on the macronutrient quality of tall fescue. Our previous work has shown that P fertilization of tall fescue pastures improved leaf P and Mg concentrations (Reinbott and Blevins 1997). Currently, it is recommended that cattle producers stockpile tall fescue to reduce winter feeding costs. However, there is very little information available on the macronutrient quality of stockpiled tall fescue and management practice that can be used to improve it.

**Procedure:** During summer 2006, an established stand of tall fescue (K31, endophyte infected) was selected at the University of Missouri Southwest Research Center near Mt. Vernon. Soil samples were taken and sent to the University of Missouri Soil Testing Lab for analysis. The soil test results were used for making the final site selection. On September 20, forage was removed from the plot area and plots of 10' x 25' with 5' foot alleys were treated with combinations of 0, 50, 100, or 200 lbs P/acre (as 0-46-0) and 0 or 50 lbs Mg/acre (K-Mag). The use of K-Mag required that we add potassium (K) and sulfur (S) to all treated plots to balance K and S added in the K-Mag treatments. Each treatment combination was replicated six times. Total number of plots is calculated by multiplying 4 P treatments x 2 Mg treatments x 6 replicates of each treatment = 48 (see plot map, Fig. 1). From mid-October through mid-April, 20 of the most recently collared leaves are being harvested monthly from each plot. Samples are being dried, ground and digested in nitric acid in a microwave accelerated digestion system (CEM Corp.). Digested samples will be filtered, diluted and K will be determined by flame ionization, Mg and Ca by atomic absorption, and P by colorimetric analysis. This study will be completed after two years of harvests. Data will be analyzed by SAS and graphs will be prepared by plotting macronutrient concentrations versus month of the year and treatments. The same treatments will be applied to the same plots in September 2007 for the second year of study.

**2006 Results:** The site was selected, plots were established and the treatments were applied. Leaf samples are being collected monthly from each plot and these samples are being dried, ground, digested and analyzed for macro- and micronutrient concentrations.

**Second year schedule:** Leaf samples will be collected monthly through April 2007 and forage will be harvested for yield determination during the third week of June 2007. Forage will be harvested in early September and fertilizer will be re-applied to the same plots used in 2006. Monthly leaf samples will be collected starting in October (2007 through April 2008), and hay will be harvested for yield determinations in May. All samples will be analyzed for macro- and micronutrients and the effects of P and Mg fertilization will be determined. Of special interest will be fertilization treatment responses of leaf P and Mg concentration during the late winter months.

**Figure 1. Magnesium and phosphorus stockpiled tall fescue study plot map for SW Center 2006.**

<b>Block 1</b>	<b>200P</b> <b>100Mg</b>	<b>0P</b> <b>100Mg</b>	<b>100P</b> <b>0Mg</b>	<b>200P</b> <b>0Mg</b>	<b>0P</b> <b>0Mg</b>	<b>100P</b> <b>100Mg</b>	<b>50P</b> <b>100Mg</b>	<b>50P</b> <b>0Mg</b>
	<b>101</b>	<b>102</b>	<b>103</b>	<b>104</b>	<b>105</b>	<b>106</b>	<b>107</b>	<b>108</b>

<b>Block 2</b>	<b>0P</b> <b>0Mg</b>	<b>50P</b> <b>100Mg</b>	<b>0P</b> <b>100Mg</b>	<b>200P</b> <b>0Mg</b>	<b>200P</b> <b>100Mg</b>	<b>100P</b> <b>100Mg</b>	<b>50P</b> <b>0Mg</b>	<b>100P</b> <b>0Mg</b>
	<b>201</b>	<b>202</b>	<b>203</b>	<b>204</b>	<b>205</b>	<b>206</b>	<b>207</b>	<b>208</b>

<b>Block 3</b>	<b>100P</b> <b>100Mg</b>	<b>0P</b> <b>100Mg</b>	<b>200P</b> <b>0Mg</b>	<b>200P</b> <b>100Mg</b>	<b>0P</b> <b>0Mg</b>	<b>50P</b> <b>0Mg</b>	<b>100P</b> <b>0Mg</b>	<b>50P</b> <b>100Mg</b>
	<b>301</b>	<b>302</b>	<b>303</b>	<b>304</b>	<b>305</b>	<b>306</b>	<b>307</b>	<b>308</b>

<b>Block 4</b>	<b>100P</b> <b>100Mg</b>	<b>200P</b> <b>0Mg</b>	<b>0P</b> <b>100Mg</b>	<b>100P</b> <b>0Mg</b>	<b>200P</b> <b>100Mg</b>	<b>0P</b> <b>0Mg</b>	<b>50P</b> <b>100Mg</b>	<b>50P</b> <b>0Mg</b>
	<b>401</b>	<b>402</b>	<b>403</b>	<b>404</b>	<b>405</b>	<b>406</b>	<b>407</b>	<b>408</b>

<b>Block 5</b>	<b>50P</b> <b>0Mg</b>	<b>50P</b> <b>100Mg</b>	<b>100P</b> <b>0Mg</b>	<b>0P</b> <b>100Mg</b>	<b>200P</b> <b>100Mg</b>	<b>100P</b> <b>100Mg</b>	<b>0P</b> <b>0Mg</b>	<b>200P</b> <b>0Mg</b>
	<b>501</b>	<b>502</b>	<b>503</b>	<b>504</b>	<b>505</b>	<b>506</b>	<b>507</b>	<b>508</b>

<b>Block 6</b>	<b>0P</b> <b>0Mg</b>	<b>50P</b> <b>0Mg</b>	<b>100P</b> <b>100Mg</b>	<b>200P</b> <b>0Mg</b>	<b>200P</b> <b>100Mg</b>	<b>0P</b> <b>100Mg</b>	<b>100P</b> <b>0Mg</b>	<b>50P</b> <b>100Mg</b>
	<b>601</b>	<b>602</b>	<b>603</b>	<b>604</b>	<b>605</b>	<b>606</b>	<b>607</b>	<b>608</b>

**Individual plots are 10' X 25' = 250 ft<sup>2</sup>, with 5' alleys between blocks.  
 Blocks are 25' X 80' = 2,000 ft<sup>2</sup>. Blocks are replicated 6 times.  
 Total area is 14,000 ft<sup>2</sup> (0.32 acres)  
 Mg is applied at 0, & 100 lbs Mg /acre.  
 P is applied at 0, 50, 100 & 200 lbs P/acre.  
 Diagonal is 192.42' from corner to corner.**

**Figure 2. Matt Massie, Agronomist at the University of Missouri Southwest Center (left) applying phosphorus and magnesium treatment on this study in September 2006.**



## Soil Sampling and Fertility Build-up Management

Gene Stevens and David Dunn

Many soil test laboratories allow farmers to select the number of years they want to build low or medium P or K soil levels in fields back to optimum levels. Sometimes this decision has a huge effect on the amount of fertilizer that a farmer will apply in a given year. If a grower does not check an option box on a soil test submission form, MU soil test labs use an 8-year default build-up time to calculate fertilizer recommendations. No field research has been conducted to suggest which buildup option is the most profitable method to manage crop nutrients. Long build-up programs help farmers manage their financial resources by spreading fertilizer costs over many years. However, growers need information concerning the magnitude of yield loss that may occur early in an 8-year build-up as compared to shorter build-up (1 to 4 years).

Soil nutrient buildup from fertilizer is being studied in cropping systems at Qulin, and West Plains, Missouri. Cropping systems includes a rice/soybean rotation, and fescue hay and pasture. All experiments are randomized complete blocks with four replications. Permanent markers were placed to help locate research plots in following years. In the spring before fertilizer applications are made, composite soil samples are collected from each plot and analyzed at the MU Delta Center Soil Lab.

Yield goals being used to calculate P and K fertilizer recommendations are 175 bu/acre for corn, 45 bu/acre for soybean, 6075 lb/acre (135 bu) for rice, 2 tons fescue hay/acre, and 175 cow days/yr for fescue pasture. Standard treatments include an untreated check, 1-year, 4-year, and 8-year buildup fertilizer programs. In the soybean/rice rotation test, treatments are included to compare using soybean versus rice soil test target levels. Current MU target soil P buildup for rice is 35 lb Bray-P/acre and soybeans is 45 lb Bray-P/acre. Target ammonium acetate extractable K is 125+(5XCEC) for rice and 220+(5XCEC) for soybeans. Rice receives 150 lb N/acre (3-way split), and fescue receives 50 lb N/acre in April and 30 lb N/acre in September. In the fescue tests, three S treatments are added to the standard treatments.

### Accomplishments in Year 3

Fertilizer treatments increased soil test levels in rice and soybean plots compared to the untreated checks, but one year P and K buildup applications failed to increase P or K above critical target levels (Table 1). Soil tests on fescue hay and pasture plots were closer to what we expected (Table 2). The general order from high to low was 1 year buildup, 4 year buildup, 8 year buildup, and checks (untreated and N only). Rice and soybeans yields were higher with P and K treatments than untreated checks (Table 3). Averaged across years, no difference was found between 4 and 8 year buildup programs.

Rainfall at West Plains was unusually low in July and August of 2005 and 2006. In 2006, nitrogen fertilizer alone increased fescue dry matter yields 33 percent compared to the no fertilizer check (Table 4). Applying P and K fertilizer with nitrogen increased hay yields an additional 35 percent. Nitrogen content in the hay, an indicator of crude protein, was increase by N but not P or K fertilizer (Table 5). Tissue P content (possibly related to energy) in the 1 year build program was higher than other treatments. Large fescue hay yield increases were found across years from P and K (Table 6). But building up soil P is not profitable low fescue hay prices and high P fertilizer costs.

Table 1. Soil test levels from fields rotated in rice and soybeans at Qulin, Missouri before third year P and K buildup treatments were applied in May 2006.

Buildup program Soil crop target	Soil test level †	
	P	K
<u>Field 4</u>	---lb/acre---	
N only check	14	134
1-year/rice target	35	207
4-year/rice target	24	195
8-year/rice target	19	152
1-year/soybean target	24	153
4-year/soybean target	29	163
8-year/soybean target	17	128
<u>Field 5</u>		
Untreated check	13	90
1-year/rice target	27	103
4-year/rice target	23	106
8-year/rice target	20	102
1-year/soybean target	23	104
4-year/soybean target	22	94
8-year/soybean target	23	100

†In 2004, field 4 was 29 lb P/a, 165 lb K/a, and 9.2 CEC. Field 5 was 37 lb P/a, 249 lb K/a, and 10.4 CEC.

Table 2. Soil test levels from fescue hay and pasture fields at West Plains, Missouri before third year P and K buildup treatments were applied in March 2006.

Treatment	Soil test level †	
	P	K
<u>Hayfield</u>	---lb/acre---	
Check	9	198
N only	8	185
1 yr build	48	252
4 yr build	27	210
8 yr build 0 S	15	228
8 yr build 9 S	14	213
8 yr build 12 S	15	219
8 yr build 24 S	23	272
<u>Pasture</u>		
Check	10	207
N only	12	208
1 yr build	51	311
4 yr build	29	241
8 yr build 0 S	15	235
8 yr build 9 S	26	258
8 yr build 12 S	16	260
8 yr build 24 S	22	293

† Initial average soil test levels in 2004 were 8 lb Bray1-P/a and 162 lb am. acetate extractable K/a.

Table 3. Effect of fertilizer build-up programs on third-year rice and soybean yields on a Crowley silt loam soil at Missouri Rice Research Farm, Quilin, Missouri.

Planted Crop	Buildup program Soil crop target	2006 rates		2004	2005	2006	Avg.
		P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O				
Rice		---lb/acre---		-----bu/acre-----			
	N only check	0	0	168	142	136	149
	1-year/rice target	41†	38†	192	160	133	162
	4-year/rice target	52	69	193	161	136	163
	8-year/rice target	45	67	187	159	143	163
	1-year/soybean target	41†	38	172	149	138	153
	4-year/soybean target	74	130	170	161	150	160
	8-year/soybean target	56	97	165	155	134	151
Soybean	Untreated check	0	0	40	39	53	44
	1-year/rice target	38†	65†	53	47	63	54
	4-year/rice target	38	65	53	49	60	54
	8-year/rice target	38	65	51	45	62	53
	1-year/soybean target	38†	65	58	54	57	56
	4-year/soybean target	58	39	51	46	55	51
	8-year/soybean target	50	32	51	43	57	50

† Only crop removal P and K was applied to 1-yr buildup treatment in 2005 and 2006.

Table 4. Dry matter forage yields from two cuttings of fescue in fertilizer buildup experiment at West Plains, Missouri in 2006.

Trt No.	Buildup program	Sulfur lb/acre	Recommended		2006 Harvest dates		Total
			P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	May 25	Oct 30	
			---lb/acre---		-----ton/acre-----		
1	Untreated check	0	0	0	0.40	0.29	0.68
2	N only	0	0	0	0.60	0.43	1.03
3	1-year	9	18†	68†	1.21	0.37	1.59
4	4-year	9	117	90	1.16	0.40	1.56
5	8-year	9	65	79	1.20	0.35	1.54
6	8-year	0	65	79	1.14	0.49	1.63
7	8-year	12	65	79	1.15	0.34	1.48
8	8-year	24	65	79	1.23	0.40	1.63

† Only crop removal P and K was applied to 1-yr buildup treatment in 2005 and 2006.

Table 5. Nutrient content in fescue hay from May harvests at West Plains, Missouri in 2004-2006.

Treatment	Nitrogen				Phosphorus				Potassium				Sulfur			
	2004	2005	2006	Avg.	2004	2005	2006	Avg.	2004	2005	2006	Avg.	2004	2005	2006	Avg.
	-----%-----				-----%-----				-----%-----				-----ppm-----			
Check	1.5	1.1	0.8	1.1	0.08	0.08	0.05	0.07	2.0	2.2	1.8	2.0	164	170	209	181
N only	2.6	1.0	1.2	1.6	0.13	0.07	0.09	0.09	2.4	1.6	1.9	2.0	121	171	208	167
1 yr buildup	2.1	1.2	1.2	1.5	0.31	0.18	0.18	0.23	3.1	2.2	2.2	2.5	106	205	205	172
4 yr buildup	2.3	0.9	1.2	1.5	0.25	0.16	0.18	0.19	2.7	2.2	2.0	2.3	159	256	235	217
8 yr buildup (0S)	3.1	0.9	0.9	1.6	0.19	0.15	0.15	0.16	2.7	2.3	2.3	2.4	82	190	190	154
8 yr buildup (9S)	2.6	1.2	0.9	1.5	0.20	0.14	0.16	0.17	2.8	2.0	2.4	2.4	134	196	251	193
8 yr buildup (12S)	2.4	1.2	1.5	1.7	0.20	0.16	0.13	0.16	2.7	2.4	1.9	2.3	263	348	322	311
8 yr buildup (24S)	2.6	1.6	1.1	1.8	0.14	0.15	0.14	0.14	3.0	2.5	2.0	2.5	263	278	308	283

Table 6. Cumulative effect of build-up programs (2004+2005+2006) on total fertilizer cost and fescue hay yield in a non-renovated pasture on a Tonti-Hogcreek complex (2% slope) at West Plains, Missouri.

Trt No.	Buildup program	-----Three-year cumulative-----				
		S 1b/acre	P <sub>2</sub> O <sub>5</sub> ---lb/acre---	K <sub>2</sub> O	Cost† per acre	Hay ton/acre
1	Untreated check	0	0	0	\$0	3.1
2	N only	0	0	0	\$89	4.3
3	1-year	27	441	291	\$289	6.6
4	4-year	27	347	270	\$256	6.4
5	8-year	27	195	239	\$204	6.1
6	8-year	0	195	239	\$197	5.8
7	8-year	36	195	239	\$205	6.4
8	8-year	72	195	239	\$223	6.1

† Economics based on \$0.37 per lb N, \$0.30 per lb P<sub>2</sub>O<sub>5</sub>, \$0.21 per lb K<sub>2</sub>O, \$0.41 per lb S. N credit was given to DAP (trt 6-8) and ammonium sulfate and S credit to triple super phosphate (trt 3-5).

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