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Wayne E. Sabbe Arkansas Soil Fertility Studies 2013

Nathan A. Slaton
University of Arkansas, Fayetteville

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ARKANSAS
SOIL FERTILITY STUDIES
• 2013 •

Nathan A. Slaton, Editor

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Cover: Corn was planted and harvested on an estimated 970,000 acres in 2013, the highest corn acreage harvested in Arkansas since 1950. The photograph shows nitrogen deficient corn (corn that appears to be light green or yellow) surrounded by corn (dark green corn) that received various amounts and/or sources of nitrogen fertilizer in a nitrogen fertilization research trial located in Clay County, Ark. during 2012. (photograph by Russ DeLong, Program Associate II, University of Arkansas System Division of Agriculture, Department of Crop, Soil, and Environmental Sciences).

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WAYNE E. SABBE ARKANSAS SOIL FERTILITY STUDIES – 2013–

Nathan A. Slaton, Editor

Department of Crop, Soil, and Environmental Sciences

Arkansas Agricultural Experiment Station
University of Arkansas System
Division of Agriculture
Fayetteville, Arkansas 72701

SUMMARY

Rapid technological changes in crop management and production require that the research efforts be presented in an expeditious manner. The contributions of soil fertility and fertilizers are major production factors in all Arkansas crops. The studies described within will allow producers to compare their practices with the university's research efforts. Additionally, soil-test data and fertilizer sales are presented to allow comparisons among years, crops, and other areas within Arkansas.

INTRODUCTION

The 2013 Soil Fertility Studies include research reports on numerous Arkansas commodities and several disciplines. For more information on any topic, please contact the author(s). Also included is a summary of soil-test data from samples submitted during 2012. This set of data includes information for counties, soil associations, physiographic areas, and selected cropping systems.

Funding for the associated soil fertility research programs came from commodity check-off funds, state and federal sources, various fertilizer industry institutes, and lime vendors. The fertilizer tonnage fee provided funds not only for soil testing but also for research and publication of this research series.

Mention of a trade name is for facilitating communication only. It does not imply any endorsement of a particular product by the authors or the University of Arkansas System Division of Agriculture, or exclusion of any other product that may perform similarly.

Extended thanks are given to the staff at state and county extension offices, as well as at research centers and stations; farmers and cooperators; and fertilizer industry personnel who assisted with the planning and execution of the programs.

This publication is available as a web-only research series book online at http://arkansasagnews.uark.edu/1356.htm.

Nathan A. Slaton, Editor
Department of Crop, Soil, and
Environmental Sciences
University of Arkansas
Fayetteville, Ark.

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CONTRIBUTORS

P. Ballantyne, Program Technician, Cooperative Extension Service, Little Rock
S.D. Carroll, Research Associate, Soil Testing and Research Lab, Marianna
L.A. Clark, Graduate Assistant, Department of Crop, Soil, and Environmental Sciences, Fayetteville
R.E. DeLong, Program Associate I, Department of Crop, Soil, and Environmental Sciences, Fayetteville
R.J. Dempsey, Graduate Assistant, Department of Crop, Soil, and Environmental Sciences, Fayetteville
L. Espinoza, Extension Soil Scientist, Cooperative Extension Service, Little Rock
M.S. Fryer, Graduate Assistant, Department of Crop, Soil, and Environmental Sciences, Fayetteville
C.E. Greub, Graduate Assistant, Department of Crop, Soil, and Environmental Sciences, Fayetteville
J. Hedge, Program Technician III, Pine Tree Research Station, Colt
C. Herron, Research Specialist, Soil Testing and Research Lab, Marianna
S. Hayes, Program Technician II, Rohwer Research Station, Rohwer
M. Ismanov, Program Technician, Lon Mann Cotton Research Station, Marianna
J.R. Kelley, Extension Agronomist, Cooperative Extension Service, Little Rock
C.G. Massey, Program Associate I, Department of Crop, Soil, and Environmental Sciences, Fayetteville
M. Mozaffari, Research Assistant Professor, Soil Testing and Research Lab, Marianna
R.J. Norman, Professor, Department of Crop, Soil, and Environmental Sciences, Fayetteville
M.R. Parvej, Graduate Assistant, Department of Crop, Soil, and Environmental Sciences, Fayetteville
T.L. Roberts, Research Assistant Professor, Department of Crop, Soil, and Environmental Sciences, Fayetteville
J. Shafer, Program Associate, Pine Tree Research Station, Colt
N.A. Slaton, Professor, Department of Crop, Soil, and Environmental Sciences, Fayetteville

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Soil Test and Fertilizer Sales Data: Summary for the 2012 Growing Season

R.E. DeLong, S.D. Carroll, N.A. Slaton, M. Mozaffari, and C.G. Herron

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Soil-test data from samples submitted to the University of Arkansas System Division of Agriculture Soil Testing and Research Laboratory in Marianna between 1 January 2012 and 31 December 2012 were categorized according to geographic area (GA), county, soil association number (SAN), and selected cropping systems. The GA and SAN were derived from the General Soil Map, State of Arkansas (Base 4-R-38034, USDA, and University of Arkansas Agricultural Experiment Station, Fayetteville, Ark., December, 1982). Descriptive statistics of the soil-test data were calculated for categorical ranges for pH, phosphorus (P), potassium (K), and zinc (Zn). Soil pH and Mehlich-3 extractable (analyzed using inductively coupled argon plasma spectroscopy, ICAP) soil nutrient (i.e., P, K, and Zn) availability index values indicate the relative level of soil fertility.

RESULTS AND DISCUSSION

Crop Acreage and Soil Sampling Intensity

Between 1 January 2012 and 31 December 2012, 211,656 soil samples were analyzed by the University of Arkansas System Division of Agriculture Soil Testing and Research Laboratory in Marianna. After removing standards and check soils measured for quality assurance (17,670), the total number of client samples was 193,986. A total of 55,100 of the submitted soil samples were collected using the field average sampling technique, representing 1,631,246 acres for an average of 30 acres/sample, and had complete data for county, total acres, and soil pH, P, K, and Zn. The cumulative number of samples and acres from information listed in Tables 1 to 4 may vary somewhat because not all samples included SAN, GA, and/or previous crop. The difference of 138,886 samples between the total samples and those with reported acreage were grid samples collected primarily from row-crop fields (133,470) or special or research samples (5,416). The total acreage value does not include the acreage of grid soil samples, but each grid sample likely represents 2.5 to 5.0 acres.

Soil samples from the Bottom Lands and Terraces and Loessial Plains, primarily row-crop areas, represented 49% of the total field average samples and 80% of the total acreage (Table 1). The average number of acres represented by each field-average soil sample submitted from county offices ranged from 1 to 59 acres/sample (Table 2). Clients from Craighead (33,237, 65% from three clients); Crittenden (23,376, 94% from two clients); Clay (Corning and Piggott offices, 20,679, 67% from three clients); Mississippi (14,564, 51% from two clients); and Little River (8,480, 100% from two clients) counties submitted the most grid soil samples for analyses. The large percentage of the total samples processed through the Craighead, Crittenden, Clay, Mississippi, and Little River offices was submitted by only a few clients and likely represents commercial grid soil sample collection services.

Soil association numbers show that most samples were taken from soils common to row-crop and pasture production areas (Table 3). The soil associations having the most samples submitted were 44 (Calloway-Henry-Grenada-Calhoun), 4 (Captina-Nixa-Tonti), 24 (Sharkey-Alligator-Tunica), and 45 (Crowley-Stuttgart). However, the soil associations representing the largest acreage were 24, 44, 45, and 22 (Foley-Jackport-Crowley) which represented 28%, 19%, 12%, and 5% of the total sampled acreage, respectively. Crop codes listed on the field average samples indicate that land used for i) row crop production accounted for 82% of the sampled acreage and 53% of submitted samples, ii) hay and pasture production accounted for 16% of the sampled acreage and 23% of submitted samples, and iii) home lawns and gardens accounted for 1% of sampled acreage and 18% of submitted samples (Table 4). In row-crop producing areas, 63% of the soil samples are collected following soybean in the crop rotation. The cumulative acreage soil sampled following soybean represents about 25% of the annual soybean acreage.

Soil-Test Data

Information in Tables 5, 6, and 7 pertains to the fertility status of Arkansas soils as categorized by GA, county, and the crop grown prior to collecting field average soil samples (i.e., grid samples not included, except by county), respectively. The soil-test levels and median (Md) nutrient availability index values relate to the potential fertility of a soil, but not necessarily to the productivity of the soil. The median is the value that has an equal number of higher and lower observations and may be a better overall indicator of a soil's fertility status than a mean value. Therefore, it is not practical to compare soil-test values among SAN without knowledge of factors such as location, topography, and cropping system. Likewise, soil-test values among counties cannot be realistically compared without knowledge of the SAN and a profile of the local agricultural production systems. Soil-test results for cropping systems can be carefully compared by recognizing that specific agricultural production systems often indicate past fertilization practices or may be unique to certain soils that would influence the current soil-test values. The median pH of most soils in Arkansas ranges from 5.5 to 6.5; however, the predominant soil pH range varies among GA (Table 5), county (Table 6), and last crop produced (Table 7).

Table 7 summarizes the percentage of acreage from field-average soil samples that falls within selected soil-test levels (as defined by concentration ranges) and the median concentrations for each of the cropping system categories. Soil-test nutrient availability index values can be categorized into soil-test levels of Very Low, Low, Medium, Optimum, and Above Optimum. Among row crops, the lowest median concentrations of P and K occur in soils used for the production of rice and soybean; whereas soils used for cotton production have among the highest median concentrations of P and K. Median soil K availability is lowest in soils used for hay production. The median soil-test P and K values for the hay crop codes has decreased for several years and suggests that P and K inputs as fertilizer or manure have declined and K, but not P, is now likely limiting forage yields. The highest median concentrations of P and Zn occur in soils used for non-agricultural purposes (e.g., home garden and landscape/ornamental).

Fertilizer tonnage sold by county (Table 8) and by fertilizer nutrient, formulation, and use (Table 9) illustrates the wide use of inorganic fertilizer predominantly in row-crop production areas. The greatest fertilizer tonnage was sold in Arkansas, Craighead, Clay, Phillips, and Poinsett counties. Fertilizer tonnage does not account for the use of fresh animal manures or other by-products as a source of nutrients that may be applied to the land. Only processed manures or biosolids (e.g., pelleted poultry litter) are quantified in fertilizer tonnage data and are normally reported in the category of Organic.

PRACTICAL APPLICATIONS

The data presented, or more specific data, can be used in county- or commodity-specific educational programs on soil fertility and fertilization practices. Comparisons of annual soil-test information can also document trends in fertilization practices or areas where nutrient management issues may need to be addressed. Of the soil samples submitted in 2012, 82% of the samples and 99% of the represented acreage had commercial agricultural/farm crop codes. Likewise, 98% of the fertilizer and soil amendment tonnage sold was categorized for farm use. Five counties in eastern Arkansas (Arkansas, Craighead, Clay, Phillips, and Poinsett) accounted for 31% of the total fertilizer sold.

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Financial support for routine soil-testing services offered to Arkansas citizens is provided by a proportion of Fertilizer Tonnage Fees and the University of Arkansas System Division of Agriculture.

Table 1. Sample number and total acreage by geographic area for soil samples submitted to the Soil Testing and Research Laboratory in Marianna from 1 January 2012 through 31 December 2012.

Geographic area	Acres sampled	No. of samples	Acres/ sample
Ozark Highlands - Cherty Limestone and Dolomite	124,195	9,137	14
Ozark Highlands - Sandstone and Limestone	8,065	565	14
Boston Mountains	27,281	2,537	11
Arkansas Valley and Ridges	59,278	4,873	12
Ouachita Mountains	27,954	3,007	9
Bottom Lands and Terraces	731,955	14,322	51
Coastal Plain	36,056	3,578	10
Loessial Plains	463,421	10,249	45
Loessial Hills	16,620	1,455	11
Blackland Prairie	4,051	224	18
Total	1,498,879	49,947	30

Table 2. Sample number (includes grid samples) and total acreage by county for soil samples submitted to the Soil Testing and Research Laboratory in Marianna from 1 January 2012 through 31 December 2012.

County	Acres sampled	No. of samples	Acres/ sample	County	Acres sampled	No. of samples	Acres/ sample
Arkansas, DeWitt	137,016	2,351	58	Lee	420,790	10,015	42
Arkansas, Stuttgart	6,384	621	10	Lincoln	8,086	258	31
Ashley	5,576	426	13	Little River	13,096	8,664	2
Baxter	3,233	510	6	Logan, Booneville	713	140	5
Benton	19,637	1,550	13	Logan, Paris	4,295	331	13
Boone	19,174	967	20	Lonoke	108,662	3,855	28
Bradley	929	107	9	Madison	8,163	558	15
Calhoun	263	32	8	Marion	3,396	223	15
Carroll	38,273	1,608	24	Miller	5,266	453	12
Chicot	11,596	258	45	Mississippi	17,052	15,338	1
Clark	2,182	261	8	Monroe	56,425	1,582	36
Clay, Corning	17,901	7,142	3	Montgomery	2,324	176	13
Clay, Piggott	16,514	14,669	1	Nevada	1,028	77	13
Cleburne	6,634	524	13	Newton	2,721	229	12
Cleveland	10,393	2,709	4	Ouachita	280	141	2
Columbia	1,440	214	7	Perry	773	145	5
Conway	17,901	547	27	Phillips	8,954	868	10
Craighead	31,203	34,605	1	Pike	1,483	120	12
Crawford	14,594	677	22	Poinsett	71,514	3,707	19
Crittenden	28,740	24,534	1	Polk	12,465	620	20
Cross	105,282	1,788	59	Pope	7,107	643	11
Dallas	471	123	4	Prairie, Des Arc	17,031	459	37
Desha	30,025	2,502	12	Prairie, De Valls Bluff	10,786	217	50
Drew	5,497	333	17	Pulaski	8,740	1,385	6
Faulkner	10,433	1,059	10	Randolph	16,794	2,078	8
Franklin, Charleston	850	95	9	Saline	1,148	410	3
Franklin, Ozark	5,798	372	15	Scott	4,018	211	18
Fulton	3,334	270	12	Searcy	1,487	178	8
Garland	3,094	1,168	3	Sebastian	4,977	547	9
Grant	186	68	3	Sevier	6,614	308	22
Greene	32,621	3,174	10	Sharp	3,539	274	13
Hempstead	9,439	784	12	St. Francis	5,917	5,015	1
Hot Spring	1,559	202	8	Stone	2,936	411	7
Howard	9,750	422	23	Union	2,836	288	10
Independence	11,025	1,061	10	Van Buren	4,553	323	14
Izard	3,418	272	13	Washington	24,603	3,168	8
Jackson	12,950	7,027	2	White	6,718	1,527	11
Jefferson	56,276	3,773	15	Woodruff	8,620	215	40
Johnson	7,734	444	17	Yell, Danville	6,309	438	14
Lafayette	2,748	129	21	Yell, Dardanelle	402	37	11
Lawrence	36,552	7,307	5	Sum or average	1,631,246	192,317	9

Table 3. Sample number, total acreage by soil association number (SAN), average acreage per sample, and median soil pH and Mehlich-3 extractable P, K, and Zn values by soil association for soil samples submitted to the Soil Testing and Research Laboratory in Marianna from 1 January 2012 through 31 December 2012.

SAN	Soil association	Acres sampled	No. of samples	Acres/ sample	Median pH	Median P	Median K	Median Zn
						------------(ppm)	-----------	
1.	Clarksville-Nixa-Noark	21,166	1,297	16	6.1	68	124	5.0
2.	Gepp-Doniphan-Gassville-Agnos	7,671	866	9	6.6	53	135	6.7
3.	Arkana-Moko	45,648	2,146	21	6.0	118	168	10.5
4.	Captina-Nixa-Tonti	46,177	4,630	10	6.2	114	155	9.4
5.	Captina-Doniphan-Gepp	825	27	31	6.5	49	116	3.2
6.	Eden-Newnata-Moko	759	67	11	6.0	73	132	4.8
7.	Estate-Portia-Moko	690	49	14	5.8	44	80	2.8
8.	Brockwell-Boden-Portia	7,370	511	14	6.2	35	99	3.8
9.	Linker-Mountainburg-Sidon	4,866	291	17	5.9	67	132	5.7
10.	Enders-Nella-Mountainburg-Steprock	22,418	2,246	10	5.9	77	112	5.7
11.	Falkner-Wrightsville	1,179	27	44	6.6	52	137	3.5
12.	Leadvale-Taft	22,832	2,306	10	5.8	53	121	5.9
13.	Enders-Mountainburg-Nella-Steprock	7,551	417	18	5.7	48	102	3.8
14.	Spadra-Guthrie-Pickwick	3,369	169	20	5.6	162	134	11.8
15.	Linker-Mountainburg	24,347	1,954	13	5.7	66	113	5.9
16.	Carnasaw-Pirum-Clebit	4,348	564	8	5.7	70	109	6.0
17.	Kenn-Ceda-Avilla	11,141	590	19	5.7	140	120	8.3
18.	Carnasaw-Sherwood-Bismarck	8,063	1,508	6	5.8	92	120	6.7
19.	Carnasaw-Bismarck	949	33	29	5.9	45	108	2.9
20.	Leadvale-Taft	1,329	127	11	5.6	72	102	6.9
21.	Spadra-Pickwick	2,124	185	12	5.7	31	99	4.3
22.	Foley-Jackport-Crowley	79,601	2,287	35	6.4	28	101	3.3
23.	Kobel	18,240	488	37	6.1	32	109	3.7
24.	Sharkey-Alligator-Tunica	420,034	4,419	95	6.0	43	210	3.6
25.	Dundee-Bosket-Dubbs	39,890	1,581	25	6.4	37	143	4.1
26.	Amagon-Dundee	27,376	934	29	6.4	56	147	4.3
27.	Sharkey-Steele	1,646	77	21	6.4	55	298	5.5
28.	Commerce-Sharkey-Crevasse-Robinsonville	11,118	317	35	6.3	50	185	4.5
29.	Perry-Portland	27,564	946	29	6.1	43	173	3.4
30.	Crevasse-Bruno-Oklared	2,967	68	44	5.9	83	130	5.6
31.	Roxana-Dardanelle-Bruno-Roellen	13,603	308	44	6.2	50	131	3.8
32.	Rilla-Hebert	60,445	2,289	26	6.4	45	137	3.4
33.	Billyhaw-Perry	9,284	187	50	6.3	39	186	2.6
34.	Severn-Oklared	12,831	162	79	6.9	48	140	3.2
35.	Adaton	3,625	96	38	5.8	55	109	3.5
36.	Wrightsville-Louin-Acadia	3,643	152	24	5.7	41	130	3.4
37.	Muskogee-Wrightsville-McKamie	88	11	8	5.3	72	116	5.8
38.	Amy-Smithton-Pheba	1,402	190	7	5.7	52	80	3.3
39.	Darco-Briley-Smithdale	569	19	30	5.6	16	83	2.9
40.	Pheba-Amy-Savannah	4,088	268	15	6.0	57	124	3.6
41.	Smithdale-Sacul-Savannah-Saffell	10,254	1,028	10	5.7	81	97	6.7
42.	Sacul-Smithdale-Sawyer	11,379	1,651	7	5.8	58	92	5.5
43.	Guyton-Ouachita-Sardis	8,364	422	20	5.6	90	112	7.7
44.	Calloway-Henry-Grenada-Calhoun	286,484	6,577	44	6.7	29	99	3.1
45.	Crowley-Stuttgart	176,937	3,672	48	6.4	26	102	2.9
46.	Loring	1,030	59	18	6.1	38	90	2.9
47.	Loring-Memphis	14,307	1,317	11	6.1	40	126	3.9
48.	Brandon	1,283	79	16	6.1	28	104	3.7
49.	Oktibbeha-Sumter	4,051	224	18	6.2	57	133	9.2
	Sum or average	1,496,925	49,838	30	6.0	59	127	5.0

Table 4. Sample number and total acreage by previous crop for soil samples submitted to the Soil Testing and Research Laboratory in Marianna from 1 January 2012 through 31 December 2012.

Crop	Acres sampled	No. of samples	Acres/ sample
Corn	144,330	3,032	48
Cotton	133,428	3,155	42
Grain sorghum, non-irrigated	1,459	39	37
Grain sorghum, irrigated	20,444	280	73
Rice	91,732	2,526	36
Soybean	807,510	16,630	49
Wheat	55,594	941	59
Cool-season grass hay	11,031	643	17
Native warm-season grass hay	3,967	245	16
Warm-season grass hay	44,805	2,038	22
Pasture, all categories	185,257	8,804	21
Home garden	6,670	5,010	1
Turf	4,746	1,296	4
Home lawn	6,033	4,024	1
Small fruit	855	566	2
Ornamental	4,847	1,299	4
Sum or average	1,522,708	50,708	30

Table 5. Soil-test data (% of sampled acres) and median (Md) values by geographic area for soil samples submitted to the Soil Testing and Research Laboratory in Marianna from 1 January 2012 through 31 December 2012.

Geographic area	Soil pH[a] <5.4	5.4-5.7	5.8-6.2	6.3-6.9	>6.9	Md[c]	Mehlich-3 soil P[b] (ppm) <16	16-25	26-35	36-50	>50	Md	Mehlich-3 soil K[b] (ppm) <61	61-90	91-130	131-175	>175	Md	Mehlich-3 soil Zn[b] (ppm) <1.6	1.6-3.0	3.1-4.0	4.1-8.0	>8.0	Md
	---(% of sampled acreage) ---						--(% of sampled acreage) --					(ppm)	-- (% of sampled acreage)---					(ppm)	---- (% of sampled acreage) ----					(ppm)
Ozark Highlands	12	21	26	26	15	6.1	4	7	7	10	72	98	9	13	19	19	40	150	4	12	9	24	51	8.6
Ozark Highlands	14	16	27	27	16	6.2	20	18	12	14	36	36	20	24	24	15	17	98	10	29	20	23	18	3.8
Boston Mountains	22	27	22	24	5	5.9	6	8	9	12	65	76	17	19	21	15	28	115	6	20	11	27	36	5.7
Arkansas Valley and Ridges	27	28	22	19	4	5.8	12	12	10	12	54	59	14	19	21	17	26	117	8	20	11	25	36	5.8
Ouachita Mountains	27	29	23	18	3	5.7	6	8	8	10	68	89	16	19	24	16	25	115	4	17	13	25	41	6.6
Bottom Lands and Terraces	12	18	25	32	13	6.2	6	14	19	26	35	41	4	13	23	21	39	150	7	34	21	32	6	3.6
Coastal Plain	31	25	18	18	8	5.7	14	10	8	9	59	67	25	21	19	13	22	97	9	22	11	20	38	5.7
Loessial Plains	9	13	18	27	33	6.6	15	28	22	18	17	28	9	30	38	15	8	100	11	42	18	23	6	3.0
Loessial Hills	20	18	23	24	15	6.1	13	17	15	16	39	39	10	17	27	22	24	124	6	33	16	26	19	3.9
Blackland Prairie	21	17	16	16	30	6.2	10	7	16	12	55	57	11	18	19	17	35	133	5	13	7	22	53	9.2
Average	20	21	22	23	14	6.1	11	13	13	14	49	59	14	19	24	17	26	120	7	24	14	25	30	5.6

[a] Analysis by electrode in 1:2 soil volume:deionized water volume.
[b] Analysis by inductively coupled argon plasma spectroscopy (ICAP) in 1:10 soil volume:Mehlich-3 volume.
[c] Md = median.

Table 6. Soil-test data (% of sampled acres) and median (Md) values by county for soil samples submitted to the Soil Testing and Research Laboratory in Marianna from 1 January 2012 through 31 December 2012.

	Soil pH[a]						Mehlich-3 soil P[b] (ppm)						Mehlich-3 soil K[b] (ppm)						Mehlich-3 soil Zn[b] (ppm)					
County	<5.4	5.4-5.7	5.8-6.2	6.3-6.9	>6.9	Md[c]	<16	16-25	26-35	36-50	>50	Md	<61	61-90	91-130	131-175	>175	Md	<1.6	1.6-3.0	3.1-4.0	4.1-8.0	>8.0	Md
	---(% of sampled acreage) ---						--(% of sampled acreage) --					(ppm)	-- (% of sampled acreage)---					(ppm)	---- (% of sampled acreage) ----					(ppm)
Arkansas, DeWitt	4	9	15	27	45	6.8	16	31	22	19	12	27	8	30	38	14	10	101	9	35	22	32	2	3.4
Arkansas, Stuttgart	8	12	23	34	23	6.4	28	36	21	9	6	20	4	40	42	10	4	95	32	34	12	19	3	2.4
Ashley	11	15	19	35	20	6.4	13	14	8	15	50	50	13	21	27	16	23	112	16	33	11	22	18	3.2
Baxter	5	9	13	21	52	7.0	6	12	11	14	57	69	5	10	24	21	40	149	5	8	8	23	56	10.5
Benton	11	21	25	29	14	6.1	2	4	4	7	83	136	8	11	20	20	41	153	1	7	8	25	59	10.5
Boone	8	18	35	27	12	6.1	2	8	9	12	69	90	12	12	17	16	43	153	4	18	12	25	41	6.9
Bradley	17	29	15	28	11	6.0	4	5	2	4	85	139	19	22	14	15	30	120	1	13	9	26	51	8.5
Calhoun	34	22	16	28	0	6.0	3	3	6	13	75	102	16	44	9	3	28	83	6	22	16	19	37	5.2
Carroll	12	27	30	26	5	6.0	1	5	4	8	82	139	8	9	14	15	54	188	1	31	5	20	43	12.4
Chicot	16	19	18	27	20	6.3	10	12	15	11	52	55	7	15	14	10	54	193	9	30	13	31	17	4.1
Clark	25	22	18	23	12	5.9	10	7	8	6	69	97	15	22	25	10	28	112	9	22	12	20	37	6.0
Clay, Corning	3	11	27	40	19	6.4	9	21	25	24	21	33	9	28	39	18	6	102	11	23	11	34	21	4.7
Clay, Piggott	8	11	19	37	25	6.5	4	10	13	20	53	52	4	13	24	24	35	146	8	34	22	33	3	3.6
Cleburne	25	25	23	24	3	5.9	10	12	12	13	53	59	24	20	21	15	20	99	13	27	10	23	27	4.3
Cleveland	12	16	28	34	10	6.2	4	6	6	12	72	73	3	7	13	15	62	215	8	37	20	28	7	3.5
Columbia	39	24	16	18	3	5.5	14	6	9	17	54	58	38	29	17	8	8	71	13	22	11	24	30	4.9
Conway	37	30	20	13	0	5.6	17	12	9	10	52	53	27	23	18	14	18	91	14	21	9	23	33	4.8
Craighead	6	9	17	33	35	6.7	12	18	16	18	36	39	10	21	25	19	25	120	7	34	23	30	6	3.6
Crawford	17	25	23	21	14	6.0	10	8	10	14	58	61	10	15	25	15	35	130	5	15	8	32	40	6.6
Crittenden	10	13	20	34	23	6.4	6	16	21	27	30	39	3	9	16	19	53	185	6	30	26	38	0	3.7
Cross	8	8	11	24	49	7.0	13	27	23	21	16	29	9	28	29	15	19	105	5	41	21	28	5	3.4
Dallas	34	16	20	18	12	5.8	7	9	16	10	58	69	32	20	17	16	15	88	15	24	7	18	36	4.6
Desha	6	13	27	36	18	6.4	5	12	16	27	40	45	1	6	22	26	45	167	11	34	21	33	1	3.4
Drew	28	16	20	23	13	5.9	18	16	12	17	37	38	15	20	20	16	29	121	12	31	12	20	25	3.6
Faulkner	29	28	19	21	3	5.7	17	19	13	15	36	36	14	22	27	18	19	112	11	30	16	23	20	3.6
Franklin, Charleston	19	40	13	20	8	5.7	20	18	13	10	39	33	14	32	18	16	20	100	15	17	12	32	24	5.1
Franklin, Ozark	32	36	22	10	0	5.6	8	11	7	8	66	85	14	16	21	15	34	127	3	15	11	27	44	7.0
Fulton	14	23	21	24	18	6.1	11	14	16	13	46	45	8	24	23	20	25	124	13	24	13	26	24	4.2
Garland	22	25	26	22	5	5.8	3	7	7	13	70	82	11	18	29	19	23	120	4	17	14	27	38	6.0
Grant	40	22	10	13	15	5.5	15	21	9	4	51	52	32	18	15	18	17	88	7	34	12	18	29	4.0
Greene	11	13	21	35	20	6.4	16	21	15	16	32	34	10	20	29	21	20	117	13	36	19	27	5	3.2
Hempstead	31	25	13	15	16	5.7	25	15	10	9	41	36	30	18	16	12	24	96	9	24	7	20	40	5.9
Hot Spring	32	25	20	22	1	5.7	11	15	9	10	55	58	29	17	15	14	25	104	16	25	9	19	31	4.8
Howard	25	30	24	14	7	5.7	8	6	6	9	71	118	19	13	17	18	33	135	6	16	11	23	44	7.2
Independence	10	13	12	17	48	7.0	28	29	14	9	20	23	18	31	30	12	9	91	9	29	24	29	9	3.7
Izard	17	28	27	20	8	5.9	8	17	12	19	44	45	22	28	26	11	13	90	11	32	13	23	21	3.7
Jackson	5	12	21	39	23	6.5	28	20	15	15	22	27	16	29	29	16	10	95	19	46	15	18	2	2.5
Jefferson	10	16	23	33	18	6.3	4	15	20	27	34	41	6	16	29	21	28	129	13	42	21	19	5	2.9
Johnson	24	25	23	23	5	5.8	10	15	15	13	47	47	7	23	28	20	22	117	8	30	13	23	26	4.3
Lafayette	35	31	18	13	3	5.5	12	11	13	11	53	53	13	13	30	22	22	119	19	30	9	18	24	3.2
Lawrence	5	12	25	38	20	6.4	21	26	22	19	12	27	13	29	31	16	11	99	10	45	18	18	9	2.9
Lee	11	14	23	32	20	6.4	4	12	19	31	34	42	2	12	29	25	32	140	18	47	16	19	0	2.5
Lincoln	23	19	28	26	4	6.0	3	6	10	20	61	63	4	18	27	25	26	134	17	24	12	25	22	4.3
Little River	11	16	23	28	22	6.3	10	16	16	20	38	41	1	9	23	29	38	156	19	53	16	12	0	2.4

continued

Table 6. Continued.

County	Soil pH[a]						Mehlich-3 soil P[b] (ppm)						Mehlich-3 soil K[b] (ppm)						Mehlich-3 soil Zn[b] (ppm)					
	<5.4	5.4-5.7	5.8-6.2	6.3-6.9	>6.9	Md[c]	<16	16-25	26-35	36-50	>50	Md	<61	61-90	91-130	131-175	>175	Md	<1.6	1.6-3.0	3.1-4.0	4.1-8.0	>8.0	Md
	---(% of sampled acreage) ---						--(% of sampled acreage) --					(ppm)	-- (% of sampled acreage)---					(ppm)	---- (% of sampled acreage) ----					(ppm)
Logan, Booneville	16	30	26	19	9	5.8	7	4	6	16	67	78	9	11	16	24	40	162	3	14	13	29	41	7.0
Logan, Paris	27	42	23	8	0	5.6	9	10	10	11	60	73	19	19	19	14	29	117	2	16	11	26	45	7.1
Lonoke	13	22	30	32	3	6.1	14	25	22	18	21	30	8	23	36	18	15	111	20	49	15	13	3	2.4
Madison	18	28	29	23	2	5.9	2	5	7	10	76	111	11	14	20	15	40	149	1	13	13	28	45	7.6
Marion	12	19	15	27	27	6.4	5	5	8	12	70	81	10	20	20	13	37	130	1	12	13	30	44	7.3
Miller	30	24	20	17	9	5.8	8	12	9	10	61	72	20	19	26	14	21	107	6	22	11	23	38	5.6
Mississippi	6	11	25	40	18	6.4	1	4	8	21	66	60	1	4	16	30	49	175	2	24	29	41	4	4.1
Monroe	5	10	15	31	39	6.7	36	21	15	15	13	22	13	28	30	18	11	102	10	44	18	24	4	3.0
Montgomery	23	26	21	21	9	5.9	5	6	6	7	76	112	13	17	19	16	35	133	5	9	7	26	53	9.1
Nevada	27	33	17	23	0	5.7	7	10	11	12	60	65	10	20	20	22	28	128	5	21	6	27	41	5.5
Newton	23	28	26	19	4	5.9	9	11	11	14	55	57	25	18	19	16	22	104	22	25	15	21	17	3.2
Ouachita	45	23	17	15	0	5.5	14	11	10	8	57	59	30	30	22	10	8	83	14	18	12	21	35	5.6
Perry	35	28	27	10	0	5.5	18	16	10	8	48	45	24	18	16	10	32	103	9	19	20	25	27	5.2
Phillips	8	11	16	39	26	6.5	2	9	23	33	33	42	2	14	34	24	26	130	16	45	19	18	2	2.7
Pike	40	37	10	13	0	5.5	3	5	9	3	80	112	18	19	21	18	24	113	3	12	8	24	53	8.8
Poinsett	4	9	18	31	38	6.7	9	21	25	25	20	33	6	19	25	14	36	130	4	21	19	43	13	4.5
Polk	28	31	19	17	5	5.7	5	4	5	6	80	140	19	15	18	14	34	126	4	14	8	23	51	8.5
Pope	26	26	23	19	6	5.8	11	9	7	6	67	91	10	19	29	16	26	120	6	19	10	21	44	7.3
Prairie, Des Arc	6	16	29	33	16	6.3	14	31	24	16	15	27	5	30	38	17	10	107	15	37	22	22	4	3.1
Prairie, De Valls Bluff	6	7	18	36	33	6.7	18	35	24	12	11	25	15	32	34	14	5	93	11	33	19	31	6	3.4
Pulaski	27	18	16	23	16	6.0	10	12	8	11	59	67	14	24	25	18	19	107	6	18	10	22	44	6.9
Randolph	7	11	23	36	23	6.5	11	21	21	22	25	34	11	26	32	19	12	105	8	23	6	36	17	4.7
Saline	27	21	19	19	14	5.9	12	8	10	12	58	61	22	21	24	14	19	103	11	21	11	21	36	5.4
Scott	30	36	23	11	0	5.6	6	12	7	9	66	88	21	17	21	9	32	107	4	10	11	21	54	9.2
Searcy	26	26	21	19	8	5.8	4	10	6	15	65	72	8	23	20	17	32	128	16	25	7	25	27	4.4
Sebastian	23	24	23	19	11	5.9	10	16	12	9	53	55	9	17	26	22	26	125	1	11	11	32	45	7.2
Sevier	31	36	18	8	7	5.6	5	9	7	6	73	123	17	17	18	11	37	126	4	12	9	25	50	8.3
Sharp	10	12	26	28	24	6.3	12	19	12	12	45	43	21	18	22	13	26	108	13	26	17	19	25	3.8
St. Francis	8	12	21	40	19	6.4	2	8	14	26	50	51	1	6	13	19	61	207	15	46	17	20	2	2.7
Stone	33	26	19	18	4	5.7	6	9	10	21	54	56	15	27	27	15	26	101	8	32	17	23	20	3.8
Union	37	25	20	17	1	5.6	12	9	7	12	60	76	22	24	23	15	16	99	8	14	10	23	45	7.5
Van Buren	26	35	18	21	0	5.7	12	13	10	18	47	48	20	21	21	14	24	106	17	35	11	16	21	3.0
Washington	12	20	25	28	15	6.2	4	6	6	9	75	105	5	11	19	22	43	158	2	10	9	25	54	9.4
White	23	21	21	29	6	6.0	8	13	13	14	52	53	20	23	24	15	18	102	9	27	14	27	23	4.3
Woodruff	10	22	27	27	14	6.1	12	29	24	15	20	28	10	36	30	10	14	95	10	42	17	24	7	3.1
Yell, Danville	30	40	20	10	0	5.6	8	6	7	5	74	123	11	17	20	15	37	133	2	12	9	22	55	9.7
Yell, Dardanelle	18	34	18	29	1	5.9	13	5	13	13	56	72	13	32	24	8	23	93	11	13	13	29	34	5.8
Average	19	22	21	24	14	6.1	10	13	12	14	51	62	14	20	23	16	27	121	9	26	14	25	26	5.2

[a] Analysis by electrode in 1:2 soil weight:deionized water volume.
[b] Analysis by inductively coupled argon plasma spectroscopy (ICAP) in 1:10 soil weight:Mehlich-3 volume.
[c] Md = median.

Table 7. Soil-test data (% of sampled acres) and median (Md) values by previous crop for soil samples submitted to the Soil Testing and Research Laboratory in Marianna from 1 January 2012 through 31 December 2012.

	Soil pH[a]						Mehlich-3 soil P[b] (ppm)						Mehlich-3 soil K[b] (ppm)						Mehlich-3 soil Zn[b] (ppm)					
Geographic area	<5.4	5.4-5.7	5.8-6.2	6.3-6.9	>6.9	Md[c]	<16	16-25	26-35	36-50	>50	Md	<61	61-90	91-130	131-175	>175	Md	<1.6	1.6-3.0	3.1-4.0	4.1-8.0	>8.0	Md
	---(% of sampled acreage) ---						--(% of sampled acreage) --					(ppm)	-- (% of sampled acreage)---					(ppm)	---- (% of sampled acreage) ----					(ppm)
Corn	8	14	26	36	16	6.3	5	14	23	27	30	39	3	16	30	22	29	132	7	37	21	31	4	3.4
Cotton	9	10	19	37	25	65	2	7	14	30	47	48	0	10	29	28	33	145	14	40	18	28	0	3.0
Grain sorghum, non-irrigated	23	13	36	28	0	6.0	18	10	21	13	38	38	13	18	31	18	20	114	15	36	23	21	5	3.1
Grain sorghum, irrigated	33	25	20	18	4	5.7	5	15	18	38	24	39	3	20	23	18	36	139	5	42	25	28	0	3.2
Rice	10	16	21	32	21	6.4	22	33	23	14	8	24	8	26	26	13	27	111	10	41	24	25	0	3.0
Soybean	7	14	23	31	35	6.4	4	25	23	23	25	31	6	24	32	16	22	113	10	41	20	27	2	3.1
Wheat	25	30	28	17	0	5.7	6	11	25	30	28	39	3	15	24	19	39	149	13	45	21	30	1	2.8
Cool-season grass hay	19	23	31	26	1	5.9	9	11	8	10	62	72	21	22	19	14	24	103	10	19	12	24	35	5.4
Native warm-season grass hay	28	36	22	11	3	5.6	20	23	13	9	35	32	32	27	21	8	12	78	19	28	14	25	14	3.4
Warm-season grass hay	26	31	22	20	1	5.7	10	11	10	13	56	64	28	22	20	13	17	91	9	23	12	24	32	5.0
Pasture, all categories	23	32	26	18	1	5.8	10	10	8	10	62	79	15	15	19	15	36	132	7	18	10	23	42	6.8
Home garden	11	12	16	28	33	6.6	4	4	5	7	80	144	6	11	18	18	47	170	3	9	7	18	63	12.5
Turf	15	16	20	36	13	6.3	7	8	7	12	66	70	25	17	22	17	19	106	4	16	9	30	41	7.2
Home lawn	29	22	20	21	8	5.8	7	11	13	16	53	54	8	20	29	24	19	120	4	18	17	36	25	5.2
Small fruit	28	19	17	28	8	6.0	2	8	8	15	67	84	10	20	28	14	28	117	5	16	9	22	48	7.9
Ornamental	16	12	17	29	26	6.4	8	8	8	10	66	77	11	20	27	19	23	117	3	9	9	22	57	10.0
Average	19	20	23	26	12	6.1	9	13	14	17	47	58	12	19	25	17	27	121	9	27	16	25	23	5.3

[a] Analysis by electrode in 1:2 soil weight:deionized water volume.
[b] Analysis by inductively coupled argon plasma spectroscopy (ICAP) in 1:10 soil weight:Mehlich-3 volume.
[c] Md = median.

Table 8. Fertilizer tonnage sold in Arkansas counties from 1 July 2012 through 30 June 2013[a].

County	Fertilizer sold	County	Fertilizer sold	County	Fertilizer sold
	(tons)		(tons)		(tons)
Arkansas	87,088	Garland	1,211	Newton	619
Ashley	18,807	Grant	3,088	Ouachita	108
Baxter	1,657	Greene	32,892	Perry	621
Benton	10,096	Hempstead	2,565	Phillips	58,329
Boone	3,338	Hot Spring	901	Pike	424
Bradley	718	Howard	722	Poinsett	56,027
Calhoun	228	Independence	9,090	Polk	1,146
Carroll	2,317	Izard	1,172	Pope	2,365
Chicot	39,315	Jackson	23,999	Prairie	33,240
Clark	1,076	Jefferson	41,032	Pulaski	9,686
Clay	59,867	Johnson	1,134	Randolph	17,751
Cleburne	1,490	Lafayette	9,184	Saline	1,401
Cleveland	24	Lawrence	25,178	Scott	282
Columbia	997	Lee	38,320	Searcy	1,509
Conway	5,686	Lincoln	5,996	Sebastian	2,710
Craighead	67,393	Little River	4,784	Sevier	929
Crawford	4,454	Logan	1,443	Sharp	1,305
Crittenden	17,993	Lonoke	54,759	St. Francis	30,069
Cross	41,943	Madison	3,923	Stone	1,145
Dallas	196	Marion	1,620	Union	1,581
Desha	32,839	Miller	9,134	Van Buren	8,012
Drew	11,123	Mississippi	54,505	Washington	6,227
Faulkner	3,453	Monroe	38,371	White	22,505
Franklin	1,770	Montgomery	345	Woodruff	36,422
Fulton	1,597	Nevada	436	Yell	923

[a] Arkansas Distribution of Fertilizer Sales by County, 1 July 2012 to 30 June 2013, Arkansas State Plant Board, Division of Feed and Fertilizer, Little Rock, Ark., and University of Arkansas System Division of Agriculture, Arkansas Agricultural Experiment Station, Fayetteville, Ark.

Table 9. Fertilizer nutrient, formulation, and use category sold in Arkansas from 1 July 2012 through 30 June 2013[a].

	Container			Use		
Fertilizer	Bag	Bulk	Liquid	Farm	Non-farm	Totals
	------	------	------ (tons) ------	------	------	------
Multi-nutrient	23,330	338,460	9,378	359,805	11,363	371,168
Nitrogen	4,804	538,407	105,699	641,013	7,897	648,910
Phosphate	558	32,531	13	32,580	522	33,102
Potash	379	89,945	98	89,018	1,405	90,423
Organic	28	160	0	161	28	189
Micronutrient	1,447	736	108	2,273	17	2,290
Lime	562	3,958	10	4,317	212	4,529
Miscellaneous	5,381	6,326	5,282	16,529	460	16,989
Totals	73,190	970,929	119,947	1,140,662	23,404	1,164,066

[a] Arkansas Distribution of Fertilizer Sales by County, 1 July 2011 to 30 June 2012, Arkansas State Plant Board, Division of Feed and Fertilizer, Little Rock, Ark., and University of Arkansas System Division of Agriculture, Arkansas Agricultural Experiment Station, Fayetteville, Ark.

The Effect of Nitrogen Fertilizer Rate and Application Time on Winter Wheat Yield on a Poorly Drained Silt Loam Soil

L.A. Clark, T.L. Roberts, N.A. Slaton, R.J. Norman, J.R. Kelley, and C.E. Greub

BACKGROUND INFORMATION AND RESEARCH PROBLEM

United States wheat (*Triticum aestivum* L.) owes a significant portion of its production to the mid-South, namely, Mississippi, Louisiana, and Arkansas. Approximately 450,000 acres of soft red winter wheat were harvested in Arkansas in 2012, and acreage increased to 615,000 in 2013 (National Agricultural Statistics Service, 2014). Although wheat is best suited for well-drained soils, a significant amount of wheat is produced on Arkansas' poorly drained loamy and clayey-textured soils. Without adequate drainage, increased concentrations of aluminum and manganese can lead to toxicity and reduce wheat yields (Carver and Ownby, 1995). Compensation for these challenges is achieved by planting wheat on raised beds or incorporating drainage ditches to prevent extended periods of surface ponding.

Nitrogen (N) is one of the most limiting nutrients in cereal crop production and must be applied to most fields in order to maximize yield. Consequently, N fertilizer is one of the greatest input costs associated with Arkansas wheat production. Nitrogen fertilizer costs producers approximately $0.68/lb or $81.60/acre (120 lb N/acre is the current recommendation for the majority of the wheat production acreage), which accounts for 31% of total input costs associated with Arkansas wheat production (University of Arkansas Cooperative Extension Service, 2012).

Overapplication of N fertilizer can lead to yield decreases and profit losses by both increased cost and yield losses due to lodging and increased disease pressure. Current N fertilizer recommendations for Arkansas wheat grain production range from 90 to 120 lb N/acre on loamy-textured soils following crops other than fallow (less N) or rice (more N). Producers participating in the program were applying approximately 120 to 130 lb N/acre, which is within the recommendation guidelines (J. Kelley, personal communication, 2013).. The cost of production associated with N fertilization coupled with environmental concerns increases the need for research identifying the yield-maximizing N rate. Our research objective was to determine how soft red winter wheat yield in Arkansas is influenced by N rate and time of application on a poorly-drained soil.

PROCEDURES

Two field experiments, one in 2012 and one in 2013 were conducted to evaluate the responsiveness of wheat to N fertilizer. Trials took place at the Pine Tree Research Station near Colt, Ark., on a Calloway silt loam (fine-silty, mixed, active, thermic Aquic Fraglossudalfs) in 2012 and a Calhoun silt loam (fine-silty, mixed, active, thermic Typic Glossaqualfs) in 2013. Soil series and classification were defined using the Web Soil Survey, by the Natural Resources Conservation Service (Soil Survey Staff, 2010). The Calloway and Calhoun soil series are both classified as poorly drained soils and representative of the standard production setting for wheat produced on poorly drained silt loam soils in the Eastern Arkansas Delta Region.

Soil samples were collected to a 4-inch depth prior to planting and submitted to the University of Arkansas Diagnostic Lab (Fayetteville, Ark.). Samples were subjected to Mehlich-3 extractable nutrients analysis (Helmke and Sparks, 1996) to ensure P, K, S, and other micronutrients were not limiting wheat growth (Table 1). Prior to planting, 50 lb P_2O_5 and 60 lb K_2O/acre were broadcast and incorporated at each location.

Weeds, insects, and diseases were controlled using best management practices according to University of Arkansas wheat production recommendations. Wheat cultivar Ricochet was drill-seeded at a rate of 100 lb/acre and recommended management practices were followed (Johnson, 1992).

Three different N-fertilizer application times for each rate were carried out as follows: Early-single (Feekes stage 3), Late-single (Feekes stage 6), and Split application (one-half of the N applied at Feekes stage 3 followed by one-half of the N applied at Feekes stage 6). The yield study was conducted in 16-ft long by 5.7-ft wide plots that received six different N-fertilizer rates ranging from 0 to 200 lb N/acre using urea (46% N) as the N-fertilizer source. Fertilizer treatments were applied by hand, and fertilizer was treated with the urease inhibitor n-(n-butyl) thiophosphoric triamide, trade name Agrotain® Ultra (Koch Fertilizer LLC, Wichita, Kansas), at a rate of 3 qt/ton in order to reduce ammonia volatilization.

Analysis of variance (ANOVA) was carried out using JMP PRO 9.0 (SAS Institute, Inc., Cary, N.C.). Each experiment was a randomized complete block design with a three by six factorial treatment structure. Each treatment was replicated four times and year was included in the model statement as a random effect. Means were separated using the least significant difference (LSD) test, assessing significance at $P < 0.05$.

RESULTS AND DISCUSSION

The ANOVA indicated that there was a significant N application time by rate interaction ($P = 0.0058$). Overall, the minimum yield-maximizing N rate and application method was 120 lb N/acre applied as an Early-single or Split application (Table 2). Yield tended to increase as N rate increased within the Split-application treatments until N rate reached 120 lb N/acre at which time grain yield reached a plateau and declined when N rate exceeded 160 lb N/acre. Wheat receiving N as the Split application had similar yields as the equivalent amount of N applied as an Early-single, but the Late-single N application produced yields that were numerically and sometimes statistically lower for each N rate >40 lb N/acre. Overfertilization with N can have an adverse effect on grain yield due to increased lodging, delayed maturity, and increased disease (Wells et al., 1995). Split application of N rates greater than 160 lb N/acre reduced wheat yield. For the Early-single application, yield tended to increase as N rate increased until yield reached a plateau at rates of 120 to 200 lb N/acre. Although this study indicated that the Early-single N application timing could produce similar yields to the Split application at rates of 80 to 160 lb N/acre, N from the Early-single application could suffer substantial loss in years with greater rainfall increasing the risk associated with applying all the N prior to the Feekes 3 growth stage.

For the Late-single application, the soil inorganic-N content was too low to produce significant tillering before fertilizer N was applied, and the N fertilizer was applied late enough that the wheat could not regain all of the yield potential exhibited by the treatments that received at least a portion of the N prior to the Feekes 6 growth stage. Except for the 40 and 80 lb N/acre rates, wheat yields for the Late-single application were statistically lower within a N rate than wheat yields from either the Early-single or Split-application. The greatest yields for the Late-single application were not achieved until 160 lb N/acre was applied, and even then grain yield was ~12 bu/acre lower than the maximum yields attained with the Early-single and Split treatments. However, it is surprising that the Late-single applications were able to provide sufficient N to achieve the yields that they did. Previous work on a silty clay soil has shown that N fertilizer applied as late as Feekes stage 10 can significantly increase wheat yield (Mascagni et al., 1990). In light of these findings, it might be deduced that wheat yield is less affected by tillering than other yield components (number of spikes per square ft., number of kernels per spike, and kernel weight).

PRACTICAL APPLICATION

Wheat grain yields were maximized by application of 120 to 160 lb N/acre as an Early-single or Split application. The Early-single N fertilizer application method is perhaps a less economically sound decision due to the potential for significant N loss in one or multiple events following application of all of the N fertilizer. The Late-single N fertilizer application method does not provide enough N to optimize early plant development on N-deficient soils. Although the results averaged across two years of research do not show clear differences between the Early-single and Split application N-fertilization methods, applying the total N rate in two splits may increase N recovery and reduce N loss compared to an Early-single application with little or no additional costs if N is applied by airplane. The results also support previous research, which suggests that the initial N fertilizer application should be applied no later than Feekes stage 5.

ACKNOWLEDGMENTS

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Table 1. Selected soil chemical property means from 0 to 4-inch deep soil samples (n = 4) collected from N-fertilization trials located at the Pine Tree Research Station, near Colt, Ark., during 2012 and 2013.

Soil series	Soil OM[a]	Soil pH	Mehlich-3 soil nutrients								
			P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
	(%)		(ppm)								
Calloway	2.8	7.7	35	112	1801	350	7	290	222	4.7	1.2
Calhoun	2.6	7.1	29	133	2077	363	6	240	267	2.4	1.2

[a] OM = organic matter.

Table 2. Winter wheat yield means, averaged across years, as influenced by N-fertilizer rate and application time at the Pine Tree Research Station, near Colt, Ark., during the 2011-20112 and 2012-2013 growing seasons.

N rate	Application time[a]		
	Early-single	Late-single	Split
(lb N/acre)	(bu/acre)		
0	46[b]		
40	56	56	65
80	73	71	73
120	92	76	98
160	90	86	97
200	98	83	87
		$LSD_{0.05}$ = 9.3 bu/acre	

[a] Early-single applied at Feekes stage 3; Late-single applied at Feekes stage 6; and Split involved applying one-half of the N at Feekes stage 3 followed by one-half of the N applied at Feekes stage 6.

[b] The 0 lb N/acre treatment yields reported as an average across all applications.

Yield Response of Corn to Varying Nitrogen Rates in Clayey-Textured Soils

L. Espinoza, J.R. Kelley, P. Ballantyne, and M. Ismanov

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Corn (*Zea mays* L.) was an important crop in Arkansas during the early 1900s when more than 1 million acres were harvested each year. The acreage declined during the 1950s to less than 200,000 acres due to better prices and demand for soybean, rice, and cotton. Improved prices and higher yield potential have resulted in a considerable increase in corn acreage during the last decade. During the 2012 season, Arkansas farmers harvested nearly 700,000 acres of corn. Fertilization represents one of the largest production costs, especially due to the high nitrogen (N) requirement necessary to produce a high-yielding corn crop. A recent report lists the state of Arkansas as the fifth largest contributor of N to the total nutrient flux delivered to the Gulf of Mexico, with corn and soybean production being listed as the most important sources of N (Alexander et al., 2008).

Current N recommendations for corn grown in clayey soils are 30% to 35% higher than those for corn grown in silt loams to compensate for more prevalent diffusion constraints and greater microbial immobilization. Therefore, any effort to increase fertilizer use efficiency and develop research-based recommendations is important to ensure the economic and agronomic sustainability of corn production in Arkansas. The objective of this study was to assess the yield response of corn, grown in clayey-textured soils, to N rate.

PROCEDURES

Research plots were established at the Northeast Research and Extension Center (NEREC) near Keiser, Ark., and at the Rohwer Research Station (RRS) near Rohwer, Ark., from 2007 to 2012. Soils at both locations were mapped as Sharkey silty clay. Soil samples were collected during the spring of each year, from the shoulder of existing beds or before beds were formed. One composite soil sample from the 0 to 6 and 6 to 12-inch soil depth was collected from each location, each year. The soil was extracted for plant available nutrients using the Mehlich-3 procedure. Nitrate-N was determined with an ion-selective electrode, and pH was measured in a 1:2 soil:water (vol:vol) mixture. Treatments consisted of N rates equivalent to 0, 50, 100, 150, 200, 250, 300, and 350 lb N/acre.

The intended plant population was 31,000 plants/acre every year. A Pioneer and a DeKalb hybrid were planted at each location every year, as separate experiments, to represent different genetic materials. Therefore, for data analysis purposes, each hybrid is considered a site-year, for a total of 24 site-years. Each plot consisted of four 38-inch wide and 25-ft long rows with treatments arranged in a randomized complete block design and replicated five times. For 50, 100, and 150 lb N/acre, N was applied in a 2-way split, with 50% of the total N rate applied at emergence or by the third leaf, and the remaining N applied before the V6 stage. For 200, 250, 300, and 350 lb N/acre, the fertilizer was applied in a 3-way split, with 50% of the total N rate applied at emergence or by the third leaf, 45 lb N/acre applied around 7 days prior to the emergence of the tassel, and the remaining N applied before the V6 stage. Calcium ammonium nitrate (27% N) was the N form used during 2007 and 2008. Urea coated with Agrotain® (a urease inhibitor; Koch Fertilizer LLC, Wichita, Kansas) was the N form used for years 2009-2012. The first N split was applied using a modified Hege plot seeder (Wintersteiger Inc., Salt Lake City, Utah) for uniform fertilizer distribution. The rest of the fertilizer was applied by hand, with the fertilizer incorporated by rainfall, irrigation, or cultivation within 10 days after application. Results of the soil test were used to decide on the need for other nutrients. Furrow irrigation and weed and insect control were done according to University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations.

At maturity, the two middle rows of each plot were harvested with a plot combine equipped with a weigh-system and grain moisture meter. Yields were adjusted to 15.5% moisture content for statistical analysis. To compensate for the variability associated with planting dates and differences in management among site-years, relative yields (RY) were used to develop yield response curves. A number of sigmoidal, logistic, and linear models were tested for goodness of fit using CurveExpert Professional V1.6 (Hyams Development, Inc., Chattanooga, Tenn.). The Akaike Information Criterion (Akaike, 1974) was used to select the Gompertz regression model (Gompertz, 1825) to represent the relationship between RY and N rate.

RESULTS AND DISCUSSION

Selected agronomic practices are presented in Table 1. Plots at the NEREC were typically planted later than normal due to weather conditions. Table 2 shows the average concentration of selected soil nutrients at NEREC and RRS. Soil test results show sufficient levels for potassium, phosphorus and zinc at the study sites.

Table 3 shows the average yield according to N rate for the two hybrids grown at NEREC. Although not statistically compared, yields varied numerically among years and between the two hybrids. The N rate necessary to maximize yield ranged between 200 and 350 lb N/acre, but most commonly (75% of the time) 250 or 300 lb N/acre was required to produce maximum yield for both hybrids. Table 4 shows average yields from RRS according to varying N rate. Similar to NEREC, the amount of N necessary to maximize yield potential ranged from 200 to 350 lb N/acre, but 83% of the time yields were maximized by 250 or 300 lb N/acre.

Figure 1 shows relative corn yield as a function of N rate and the fitted model. Relative yields show significant variation from the regression line for N rates below 250 lb N/acre, and less variation at the higher N rates indicating that N rates ≥250 lb N/acre consistently produce near maximal relative yields. Under the conditions of these trials conducted at two locations from 2007-2012, and using a Gompertz regression model, 95% relative yield was achieved at a N rate close to 280 lb N/acre. Examination of the results in Fig. 1 shows that 95% RY was achieved at N rates lower than 280 lb N/acre for some site-years. Until a soil-N test can be developed for corn, N-fertilizer recommendations will be generic, meaning they simply represent the average yield response to N-fertilizer rate and should be modified by farmers based on their particular growing conditions and yield potential.

Table 5 shows the average RY obtained for selected N rates and the number of times 95% RY was achieved at such N rate. Under the conditions of these studies, a 95% RY was achieved only three times (12%) when 200 lb N/acre was applied, with an average of 92% and 96% RY achieved when 250 and 300 lb N/acre, respectively, were applied. This table shows that 95% RY was achieved 17 of 24 times (71%) when 250 or 300 lb N/acre was applied. This information could be used to assess the risk associated with reducing N-fertilizer rates as a result of low commodity prices or high fertilizer costs.

Results from these studies underscore the importance of N fertilization for optimum corn production. When no N fertilizer was applied, only 13% to 14% of the maximum yield potential was achieved and about 50% of the yield potential was obtained with 100 lb N/acre. In most years, the corn crop required more than 250 lb N/acre to achieve a yield potential above 90%.

Results of these studies showed that 95% RY was obtained at a N rate of about 280 lb N/acre. To estimate the amount of N needed to produce one bushel of corn (56 lb of grain), corn yields were divided into yields below 150 bu/acre, yields between 150 and 175 bu/acre, and yields above 175 bu/acre. On average, 1.3 lb of N was required to produce one bushel of grain for yields under 150 bu/acre. For yields between 150 and175 bu/acre, 1.5 lb of N was required. For yields above 175 bu/acre, 1.2 lb N was required to produce one bushel of grain.

PRACTICAL APPLICATIONS

The development of research-based N recommendations is critical not only due to economic and agronomic reasons, but also due to increased environmental concerns associated with the health of the Gulf of Mexico. Yields obtained with these studies showed significant variation among site-years, probably due to environmental conditions. There appears to be some differences between locations and hybrids. These are some of the reasons why fertilizer recommendations are generic in nature, as they represent the average response to N-fertilizer rates under varying growing conditions. Results from these studies show that around 280 lb N/acre were needed to achieve 95% R.

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Table 1. Planting and harvesting date, and associated crop rotation at the Northeast Research and Extension Center (NEREC) and the Rohwer Research Station (RRS).

	Plant date		Harvest date		Previous crop	
Year	NEREC	RRS	NEREC	RRS	NEREC	RRS
2007	23 Apr	20 Apr	5 Sep	29 Aug	Soybean	Soybean
2008	21 May	14 Apr	2 Oct	22 Sep	Soybean	Soybean
2009	20 May	24 Apr	30 Sep	28 Oct	Soybean	Soybean
2010	8 May	14 Apr	23 Sep	24 Aug	Soybean	Soybean
2011	12 May	13 Apr	26 Sep	8-Sep	Corn	Soybean
2012	4 Apr	28 Mar	29 Aug	22 Aug	Corn	Soybean

Table 2. Selected soil chemical parameter means from the 0 to 6- and 6 to 12-inch soil depths at the Northeast Research and Extension Center (NEREC) and the Rohwer Research Station (RRS). Composite soil samples were collected in the spring, before planting.

		NEREC						RRS					
Year	Depth	pH	NO_3-N	P	K	Zn	Ca	pH	NO_3-N	P	K	Zn	Ca
	(inches)		----------(ppm)----------						----------(ppm)----------				
2007	0-6	6.4	12	81	414	6.1	4780	6.5	12	94	265	4.8	3567
	6-12	6.4	10	68	380	6.0	5154	6.3	8	79	240	3.9	3210
2008	0-6	6.5	7	79	418	7.9	4961	6.4	6	96	307	5.3	3114
	6-12	6.8	7	71	389	7.5	5459	6.8	9	82	301	4.1	2670
2009	0-6	6.1	10	77	376	6.9	5111	6.8	8	88	233	4.8	2842
	6-12	6.3	8	69	312	5.1	4536	6.2	11	66	222	3.9	2786
2010	0-6	6.6	20	63	394	9.6	4681	6.4	9	72	335	5.7	2616
	6-12	6.8	8	60	369	7.7	4973	6.7	8	62	392	3.1	3872
2011	0-6	6.7	19	45	376	4.3	4185	7.0	15	58	354	3.6	4648
	6-12	6.4	9	37	325	4.1	3986	6.5	9	48	277	3.9	4536
2012	0-6	6.1	6	52	277	3.9	3041	6.5	14	53	200	4.2	2593
	6-12	6.0	5	46	255	4.3	2842	6.3	7	45	185	3.1	2842

Table 3. Grain yield means of two corn hybrids as influenced by N-fertilizer rate from 2007 to 2012 at the Northeast Research and Extension Center.

	Yield											
	2007		2008		2009		2010		2011		2012	
N rate	P[a]	D[b]	P	D	P	D	P	D	P	D	P	D
(lb N/acre)	(bu/acre)											
0	23	24	30	29	15	21	21	17	53	44	13	22
50	95	79	61	59	48	54	60	53	87	71	39	49
100	145	121	104	103	94	149	89	79	126	124	85	101
150	167	166	161	140	136	181	136	146	145	145	160	174
200	187	188	173	172	143	201	173	192	153	160	188	204
250	206	204	168	182	163	230	193	215	155	158	231	239
300	207	239	207	189	168	217	213	217	150	156	247	230
350	225	204	181	198	167	223	227	231	156	159	276	254
$LSD_{0.10}$	18.8	18.7	10.4	11.1	11.9	18.4	10.3	10.4	10.7	14.9	21.0	18.7
CV (%)	11.7	11.3	7.2	7.7	9.5	10.7	6.9	6.7	7.8	11.1	12.6	10.9

[a] P = Pioneer.
[b] D = Dekalb.

Table 4. Grain yield means of two corn hybrids as influenced by N-fertilizer rate from 2007 to 2012 at the Rohwer Research Station.

	Yield											
	2007		2008		2009		2010		2011		2012	
N rate	P[a]	D[b]	P	D	P	D	P	D	P	D	P	D
(lb N/acre)	(bu/acre)											
0	9	15	18	11	15	9	46	47	35	51	34	56
50	20	29	52	51	23	21	72	84	61	75	75	98
100	77	81	87	86	56	51	105	116	94	108	114	134
150	98	108	137	143	86	102	143	149	125	159	156	163
200	114	132	170	145	130	120	165	153	150	186	192	207
250	138	144	194	193	144	154	162	157	170	196	223	234
300	148	148	210	227	142	178	154	163	184	201	240	250
350	146	142	226	210	153	183	157	166	199	196	245	261
$LSD_{0.1}$	13.2	13.6	14.4	13.6	12.6	17.7	10.9	11.7	15.7	32.3	15.8	14.6
CV (%)	13.1	12.7	9.8	9.5	12.5	16.1	8.2	8.4	11.5	20.6	9.2	7.7

[a] P = Pioneer.
[b] D = Dekalb.

Table 5. Average predicted relative yield (RY) obtained across site-years at selected N rates and the frequency of achieving 95% RY at such N rates.

N rate	Average RY	Frequency of achieving 95% RY
(lb N/acre)	(%)	(no.)
150	75	0
200	87	3
250	92	7
300	97	10
350	97	4

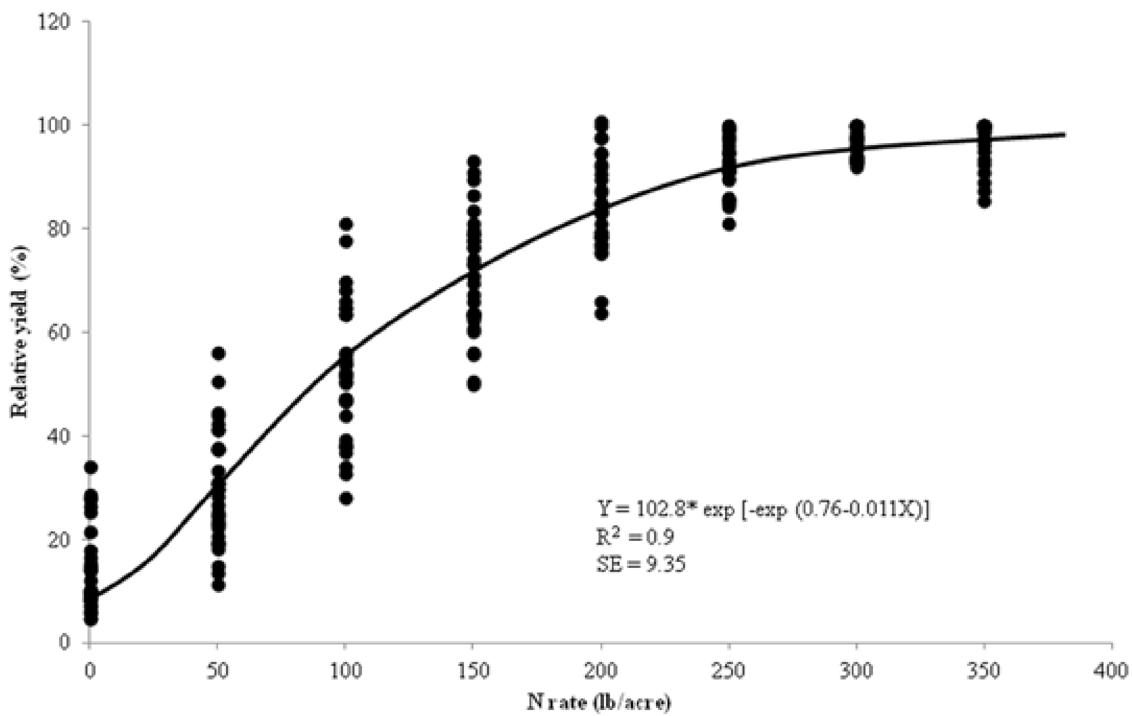

Fig. 1. Regression model and associated model parameters for the relative yield response of corn to varying N-fertilizer rates in clayey soil (Y = relative yield).

Effect of Urea and an Enhanced Efficiency Fertilizer on Cotton and Corn Yields in Arkansas

M. Mozaffari, N.A. Slaton, and J. Hedge

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Nitrogen (N) is the most yield-limiting nutrient for crop production in many Arkansas soils. Soil organic matter is an important source of potentially available N in many cropping systems. Unfortunately, the organic matter content of many Arkansas agricultural soils is low (<2.0%) requiring Arkansas growers to apply relatively high rates of N fertilizer to produce maximal cotton (*Gossypium hirsutum* L.) and corn (*Zea mays* L.) yields. Several biogeochemical and transport processes such as runoff, leaching, and denitrification contribute to the loss of soil and fertilizer N. Reducing N-fertilizer loss to the environment will increase the growers' profit margins and reduce potential environmental risks associated with excessive N fertilization. A polymer-coated urea (44% N, Agrium Advanced Technologies, Loveland, Colo.) is currently being marketed in Arkansas under the trade name of Environmentally Smart Nitrogen or ESN®. According to the manufacturer, the polymer coating protects the urea-N against rapid loss to the environment with the N release rate controlled by temperature and moisture. The objective of this research was to evaluate cotton and corn yield response to ESN and urea in two typical Arkansas soils.

PROCEDURES

Cotton Experiment

An N fertilization experiment was conducted to evaluate cotton yield response to preplant application of urea, ESN, and their combinations at the Lon Mann Cotton Research Station (LMCRS) in Marianna, Ark., on a Memphis silt loam in 2013. Before applying any fertilizer, soil samples were collected from the 0- to 6-inch depth and composited by replication. Soil samples were oven-dried, crushed, and soil pH, organic matter, and Mehlich-3 extractable nutrients were measured. Average soil properties in the 0- to 6-inch depth were 1.6% organic matter, 56 ppm phosphorus (P), 109 ppm potassium (K), and 6.9 pH. Agronomically important information is presented in Table 1.

The cotton experiment was a randomized complete block design with a factorial arrangement of four preplant-applied, urea-ESN combinations that included five rates ranging from 30 to 150 lb N/acre in 30 lb N/acre increments and a no N control. The four urea and ESN-N combinations were: 100% urea-N; 50% urea-N plus 50% ESN-N; 25% urea-N plus 75% ESN-N; and 100% ESN-N. Each treatment was replicated six times. We applied muriate of potash and triple superphosphate to supply 90 lb K_2O and 46 lb P_2O_5/acre to the entire experimental area. All fertilizers including the N-fertilizer treatments were broadcast by hand onto the soil surface and incorporated immediately with a Do-all cultivator. After the fertilizers were incorporated, the beds were pulled with a hipper and the cotton was planted on top of the beds. Each cotton plot was 40-ft long and 12.6-ft wide allowing for four rows of cotton planted in 38-inch wide rows. Cotton was furrow-irrigated as needed and we closely followed the University of Arkansas System Division of Agriculture's Cooperative Extension Service cultural recommendations for irrigated-cotton production. The two center rows of cotton in each plot were harvested with a spindle-type picker equipped with an electronic weight measuring and recording system.

Corn Experiment

The corn N-fertilization trial was conducted at the Pine Tree Research Station (PTRS) near Colt, Ark., on a Calhoun silt loam. The experimental treatments and design for the corn experiments were similar to the cotton experiments. The average soil chemical properties were 2.5% soil organic matter, 15 ppm P, 116 ppm K, and 7.4 pH.

The preplant-applied, N rates for the corn experiment ranged from 60 to 300 lb N/acre and increased in 60 lb N/acre increments and the trial also included a no N control. Each treatment was replicated six times. Applications of muriate of potash, triple superphosphate, and $ZnSO_4$ were made to supply 60 lb K_2O, 60 lb P_2O_5, 10 lb zinc (Zn), and 5.0 lb sulfur (S)/acre. All fertilizers, including the N treatments, were hand applied onto the soil surface, incorporated immediately with a Do-all cultivator, beds were pulled with a hipper, and corn was planted (33,000 seeds/acre) on top of the beds. Corn was furrow-irrigated as needed and the Cooperative Extension Service recommended cultural practices were closely followed. The plots were 25-ft long and 10-ft wide allowing for four rows of corn planted in 30-inch wide rows. Corn plants in the center 2-rows of each plot were harvested with a plot combine and grain yields were adjusted to 15.5% moisture content.

We obtained monthly precipitation data from weather stations at LMCRS and PTRS. Long-term average precipitation data for LMCRS and PTRS were obtained from the Arkansas Variety Testing Site (http://www.arkansasvarietytesting.com/crop/data/2) and Southern Regional Climate Center (http://www.srcc.lsu.edu/index.html), respectively. Analysis of variance (ANOVA) was performed by crop using the GLM procedure of SAS. The data from the control (0 lb N/acre) were not included in the ANOVA. When appropriate, means were separated by the least significant difference (LSD) method and interpreted as significant when $P \leq 0.10$.

RESULTS AND DISCUSSION

At LMCRS monthly precipitation amounts in June, July, and August were lower than the long-term average, but at PTRS the early-season monthly precipitation amount was higher than normal (Table 2). Thus, the weather conditions were not conducive for significant N loss at the cotton test site, but may have been conducive for N loss via leaching, runoff, or denitrification in the corn trial. At both sites N loss could have occurred during irrigation events.

Cotton Experiment

Neither N source, nor the N source × N rate interaction, significantly influenced seedcotton yield at the LMCRS ($P > 0.10$, Table 3). Seedcotton yields were significantly ($P < 0.0001$) affected only by N-fertilizer rate. The significant effect of N rate, but not N source, is consistent with our previous findings (Mozaffari et al., 2013). Seedcotton yield for the cotton that received no N was 2,255 lb/acre, which was numerically (13%) lower than the yield of cotton that received the lowest actual N rate of 30 lb N/acre, averaged across N sources. Averaged across the four urea and ESN blends, seedcotton yield increased numerically and often significantly as N rate increased. Maximum seedcotton yields were produced by applying 90 to 150 lb N/acre. Although the interaction was not significant, when urea was included in the N-fertilizer blend, numerically maximal seedcotton yields were produced with application of 150 lb N/acre; but when ESN was the sole source of N, numerically maximal yields were produced with application of 120 lb N/acre. During the growing season we observed that at N rates of 60 to 120 lb N/acre, ESN-fertilized cotton appeared more vigorous.

Corn Experiment

The grain yield of corn that received no N fertilizer was 18 bu/acre suggesting the soil would be responsive to N fertilization. The main effects of N source and N rate both significantly ($P < 0.0001$) influenced corn grain yield, but their interaction did not (Table 4). Corn grain yields, averaged across the four N sources, significantly increased with each incremental increase in N rate and maximal yields were produced by application of 300 lb N/acre. Averaged across all N rates, corn grain yield increased numerically and often significantly as the proportion of ESN-N in the fertilizer blend increased (Table 4). We have observed comparable trends in previous years (Mozaffari and Slaton, 2011, 2012; Mozaffari et al., 2013).

PRACTICAL APPLICATION

The amount of early-season precipitation during the 2013 growing season was below normal for the cotton test at LMCRS, and was likely conducive for efficient uptake of preplant N regardless of the source. Nitrogen application rate significantly increased seedcotton yields and maximal yields were produced by 90 to 150 lb N/acre. The amount of precipitation during May, June, and July after preplant N was applied and corn was planted at the PTRS was above normal making N loss from wet soil conditions possible. Nitrogen fertilization significantly increased corn grain yield and maximal yields were produced with 300 lb N/acre. Corn grain yields significantly increased with each incremental increase in N rate and tended to increase as the proportion of ESN-N increased suggesting that ESN-N was a more efficient preplant N source than urea-N when early-season precipitation was above normal. Preplant incorporated ESN is a suitable alternative to urea for cotton and corn and may be advantageous as a preplant N source during years of above normal precipitation.

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Table 1. Selected agronomically important information for cotton and corn N-fertilization trials established at the Lon Mann Cotton Research Station (LMCRS), Marianna, Ark., and Pine Tree Research Station (PTRS), near Colt, Ark., during 2013.

Site ID	Previous crop	Soil series	Cultivar or hybrid	Planting date	N application date	Harvest date
LMCRS cotton	corn	Memphis	ST5458[a]	28 May	20 May	23 Oct
PTRS corn	soybean	Calhoun	Pioneer 1615HR	1 May	31 April	29 Aug

[a] ST5458 cotton, Bayer Crop Science, Stoneville, Miss.

Table 2. Actual rainfall received by month in 2013 and the long-term (1960-2007) average monthly mean rainfall data at Lon Mann Cotton Research Station (LMCRS), Marianna, Ark., and Pine Tree Branch Station (PTRS), near Colt, Ark.

		Precipitation					
Site ID	Precipitation	May	June	July	August	September	Total
		(inches)					
LMCRS[a]	2013	7.42	0.72	2.79	1.88	4.25	17.06
	Average[b]	5.90	3.90	3.90	2.80	3.20	19.70
PTRS[c]	2013	8.09	5.80	5.41	2.22	2.06	23.58
	Average[b]	5.02	3.42	3.33	3.46	3.02	18.25

[a] At LMCRS, cotton was planted on 28 May and harvested on 23 Oct.
[b] Long-term average for 1960-2007.
[c] At PTRS, corn was planted on 1 May and harvested on 29 Aug.

Table 3. Seedcotton yield as affected by the non-significant N source and non-significant N source × N rate interaction ($P > 0.10$) and the significant N rate (averaged across N sources) effect for a cotton fertility experiment conducted at the Lon Mann Cotton Research Station in Lee County Arkansas during 2013.

	Seedcotton yield						
	N-fertilizer source						
N rate	100% Urea-N	50% Urea-N 50% ESN-N[a]	25% Urea-N 75% ESN-N	100% ESN-N	N rate mean	N fertilizer source	N source mean
(lb N/acre)	(lb/acre)						(lb/acre)
0	2255[b]					None	2255[b]
30	2319	2750	2727	2593	2598	100% Urea-N	2859
60	2804	2473	2725	2802	2707	50%Urea-N, 50%ESN-N	2876
90	3024	2982	2910	2808	2929	25% Urea-N,75% ESN-N	2891
120	3054	2819	2901	3176	2980	100% ESN-N	2839
150	3131	3134	3115	3106	3124		
$LSD_{0.10}$	NS[c] (interaction)				177[d]	$LSD_{0.10}$	NS
P-value	0.4848				<0.0001	*P*-value	0.9147

[a] ESN = Environmentally Smart N, polymer coated urea.
[b] The no N control yield is listed for reference only as it was not included in the analysis of variance.
[c] NS = not significant ($P > 0.10$).
[d] LSD compares the yield of treatments that received N, averaged across N sources.

Table 4. Corn grain yield as affected by the significant main effects of N source and N rate and the non-significant N source × N rate interaction for a corn N-fertilization experiment conducted at the Lon Mann Cotton Research Station in Lee County Arkansas during 2013.

	Corn grain yield						
	N-fertilizer source						
N rate	100% Urea-N	50% Urea-N 50% ESN-N[a]	25% Urea-N 75% ESN-N	100% ESN-N	N rate mean	N fertilizer source	N source mean
(lb N/acre)	(lb/acre)						(lb/acre)
0	18[b]					None	18[b]
60	53	70	71	60	64	100% Urea-N	136
120	103	125	112	124	116	50%Urea-N, 50%ESN-N	145
180	147	172	149	143	153	25% Urea-N,75% ESN-N	148
240	182	197	182	185	186	100% ESN-N	160
300	188	220	219	215	211		
$LSD_{0.10}$	NS[c] (interaction)				10[d]	$LSD_{0.10}$	9[e]
P-value	0.6850				<0.0001	*P*-value	0.0007

[a] ESN = Environmentally Smart N, polymer coated urea.
[b] The no N control yield is listed for reference only as it was not included in the analysis of variance.
[c] NS = not significant ($P > 0.10$).
[d] LSD compares the yield of treatments that received N, averaged across N sources.
[e] LSD compares the yield of treatments that received N, averaged across N rates.

Soil-Applied Phosphorus and Potassium Increase Corn Yield in Arkansas

M. Mozaffari, N.A. Slaton, S. Hayes, and J. Hedge

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Corn (*Zea mays* L.) acreage in Arkansas has increased because of favorable prices and the potential for increasing farm income. In 2012, approximately 695,000 acres of corn were harvested in Arkansas. Between 1992 and 2012, the state average corn grain yield in Arkansas increased from 130 to 178 bu/acre and represents a significant increase in nutrient export from fields. A corn grain yield of 175 bu/acre removes the equivalent of 60 lb P_2O_5 and 45 lb K_2O/acre in the harvested grain (International Plant Nutrition Institute, 2012). Phosphorus (P) and/or potassium (K) deficiency may limit corn yield if the nutrients removed by the harvested grain are not replenished by fertilization.

In recent years, P [and nitrogen (N)] transport from agricultural soils have been implicated as factors contributing to the hypoxic zone in the Gulf of Mexico. Applying the right rate of P and K will enable growers to maximize the net returns from corn production and protect the environment. Reliable soil-test-based fertilizer recommendations are the key to applying the right nutrient rate. Unfortunately, very little information is available describing corn response to P or K fertilization under current Arkansas production practices and the limited data that is available is based on a modified (1:7 soil to solution ratio) Mehlich-3 test, which is no longer in use. In 2010, we initiated replicated field experiments to evaluate corn response to P and K fertilization. The reliability and applicability of such information will increase if the studies are conducted on soils with a wide range of Mehlich-3 extractable P and K concentrations. The specific research objectives were to evaluate the effect of soil-applied P or K fertilizer rates on ear-leaf P or K concentration at silking and grain yield.

PROCEDURES

Phosphorus Experiments

Four replicated P-fertilization trials were conducted in 2013 at the Lon Mann Cotton Research Station in Lee County (LEZ33) and the Pine Tree Research Station in St. Francis County (SFZ31, SFZ33, and SFZ35) on silt loam soils. The soil series and selected agronomic information are listed in Table 1. The previous crop was corn at all sites, except SFZ35 where soybean was planted in 2012. Prior to P application, soil samples were taken from the 0- to 6-inch depth of either the 0 lb P_2O_5/acre plots of P-fertilization trials established in 2011 and the same P-fertilizer rates were applied to the same plots as in 2011 and 2012 (LEZ34, SFZ31, SFZ33) or by replication (SFZ35). Each composite soil sample consisted of a total of 6 to 8 cores with an equal number of cores collected from the top of the bed and bed shoulder. Soil samples were dried, crushed, extracted with Mehlich-3 solution, and the concentrations of elements in the extracts were measured by inductively coupled plasma atomic emission spectroscopy. Soil pH was measured in a 1:2 (volume:volume) soil-water mixture and particle size analysis was performed by the hydrometer method (Arshad et al., 1996). Selected mean soil chemical properties are listed in Table 2.

Phosphorus application rates ranged from 0 to 160 lb P_2O_5/acre in 40 lb P_2O_5/acre increments as triple superphosphate. The experimental design was a randomized complete block where each treatment was replicated three to six times depending on the test. Phosphorus treatments were applied onto the soil surface in a single application before pulling the beds for planting (SFZ35) or shortly after crop emergence (LEZ33, SFZ31, SFZ33). At trial sites established in 2011, the same rates of P were applied to the same plots as in previous years. Blanket applications of muriate of potash and $ZnSO_4$ supplied 60 to 90 lb K_2O, ~5 lb sulfur (S), and ~10 lb zinc (Zn)/acre. All experiments were fertilized with a total of 260 to 290 lb N/acre as urea in a single or split application (e.g., preplant, 3- to 6-leaf stage and/or pre-tassel) depending on the location. Corn was grown on beds and furrow-irrigated as needed. Each plot was 25-ft long and 10- to 12.6-ft wide allowing for four rows of corn, spaced 30 (SFZ31, SFZ33, and SFZ35) or 38 (LEZ33) inches apart. Corn management closely followed University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations for irrigated corn production.

When corn was at the early- to mid-silk stage, ear-leaf samples were collected from10 plants/plot at three of the four sites. Leaf samples were dried in an oven at 70 °C to a constant weight, ground to pass through a 60-mesh sieve and P concentration was measured following wet digestion (Jones and Case, 1990). The middle two rows of each plot were harvested either with a plot combine or by hand with harvested ears placed through a combine later. The calculated grain yields were adjusted to a uniform moisture content of 15.5% before statistical analysis.

Potassium Experiments

Replicated field experiments were conducted at five sites including the Lon Mann Cotton Research Station in Lee County (LEZ34) and the Pine Tree Research Station in St. Francis County (SFZ32, SFZ34), Rohwer Research Station in Desha County (DEZ32), and a commercial production field in Clay County (CLZ32). At LEZ32, the K-rate trial was adjacent to the P-rate study. The agronomic information for K trials is described in Table 1. The previous crop was corn at all sites except at CLZ32 and DEZ32, where soybean was planted in 2012. Prior to K application, soil samples were taken from the 0- to 6-inch depth of the 0 lb K_2O/acre plots at LEZ34, SFZ32, and SFZ34 (established in 2011) or by replication at CLZ32 and DEZ32 and processed as described previously. Mean soil chemical properties are listed in Table 3.

Potassium application rates ranged from 0 to 200 lb K_2O/acre in 40 lb K_2O/acre increments and applied as muriate of potash onto the plot surface at all five sites shortly after crop emergence. At the trial site (SFZ34) established in 2011, the same rates of K were applied to the same plots as in previous years. Triple superphosphate and $ZnSO_4$ were broadcast to supply 40 to 80 lb P_2O_5, ~10 lb Zn, and ~5 lb S/acre. At DEZ32, the plots were 40-ft long and 12.6-ft wide allowing for four rows of corn planted in 38-inch wide rows. At the other four locations, plots were 25-ft long and either 10 (CLZ32, SFZ32, SZ34) or 12.6-ft (LEZ34) wide allowing for four rows of corn planted in 38- or 30-inch wide rows. All experiments were a randomized complete block design and each treatment was replicated five or six times.

Analysis of variance was performed for P and K tests using the GLM procedure of SAS. Each experiment was analyzed separately. When appropriate, significant differences among means were separated by the least significant difference (LSD) test with significance interpreted at the 0.10 level. If corn responded positively to fertilization, we investigated the relation between the nutrient application rate and grain yield or compared the mean of the no P or K control to the mean of a rate close to the recommended rate using orthogonal contrasts.

RESULTS AND DISCUSSION

Phosphorus Experiments

The soil pH ranged from 6.4 to 8.1 and soil texture was silt loam at all four sites (Table 2). Mehlich-3 extractable P ranged from 19 to 26 ppm. According to the current Cooperative Extension Service interpretation, the soil-test P level was Medium (26 to 35 ppm) at SFZ31 and Low (16 to 25 ppm) at the other three sites and would have received recommendations of 60 to 80 and 80 to 110 lb P_2O_5/acre, respectively, depending on corn yield goal.

Ear-leaf P concentrations in corn that received no P fertilizer ranged from 0.27% to 0.40% P compared to 0.27% to 0.42% P for corn treated with 160 lb P_2O_5/acre (Table 4). The established critical corn ear-leaf P concentration is 0.25% (Campbell and Plank, 2000). For site-years where ear-leaf tissue was collected, the ear-leaf P concentrations were lowest at LEZ33 and highest at SFZ31, which had Low and Medium soil-test P levels, respectively (Table 2). Phosphorus fertilization significantly ($P \leq 0.10$) affected corn ear-leaf P concentration at SFZ35, the site with the lowest Mehlich-3 extractable soil-test P, but there was no consistent trend among P rates.

Phosphorus fertilization significantly influenced ($P < 0.10$) corn grain yields at all four sites (Table 4). Orthogonal contrasts indicated a significant ($P \leq 0.0469$) linear (SFZ31, SFZ33, SFZ35) or quadratic (LEZ33) grain yield response to P-fertilizer rate at all four sites. This is consistent with the results of our 2012 research (Mozaffari et al., 2012). At all sites, corn fertilized with ≥ 80 lb P_2O_5/acre produced significantly higher grain yields than corn that did not receive P fertilizer. At two sites, SFZ31 and SFZ33, application of 40 lb P_2O_5/acre produced near maximal yields that were greater than the yield of corn fertilized with no P. The positive response to P fertilization at these four sites with Low and Medium soil-test levels indicate that the current Cooperative Extension Service interpretation of soil-test P can identify soils that benefit from P fertilization.

Potassium Experiments

The soil texture was silt loam at all sites except CLZ32, which was a silty clay (Table 3). The average Mehlich-3 extractable K ranged from 53 to 115 ppm among the five sites. According to the Cooperative Extension Service soil-test interpretation, soil-test K level was Very Low (≤60 ppm) at LEZ34; Low (61 to 90 ppm) at DEZ32 and SFZ32; and Medium (91 to 130 ppm) at CLZ32 and SFZ34. Current fertilization guidelines for corn with a yield goal of >175 bu/acre would have recommended 155, 110, and 75 lb K_2O/acre for the Very Low, Low, and Medium soil-test K levels, respectively. Corn ear-leaf K concentration ranged from 0.85% to 1.60% K for corn that received no K and 1.55% to 1.96 % K for corn fertilized with 200 lb K_2O/acre (Table 5). Corn ear-leaf concentrations <1.80% K indicate possible K deficiency (Campbell and Plank, 2000). Potassium fertilization significantly ($P \leq 0.10$) increased corn ear-leaf K concentration at DEZ32 and LEZ34. Ear-leaf K concentration tended to increase numerically and sometimes statistically with each incremental increase in K-fertilizer rate. Based on the suggested critical ear-leaf K concentration, positive yield increases from K fertilization were expected at DEZ32 and LEZ34.

Potassium fertilization significantly ($P \leq 0.10$) affected corn grain yields at LEZ34 and SFZ32, but had no influence on grain yield at CLZ32, DEZ32, and SFZ34 (Table 5). Lack of response to K fertilization at DEZ32 was not expected because soil-test K was Low (Table 3). The grain yields among K rates at SFZ34 were not numerically consistent (Table 5). At the two responsive sites (LEZ34 and SFZ32), near maximal corn grain yields were produced from application of 40 (SFZ32) or 80 (LEZ34) lb K_2O/acre. There was a significant linear relationship between K-application rate and corn grain yield at LEZ34 and SFZ32 ($P < 0.10$). The mean yield of corn receiving 0 lb K_2O/acre was significantly ($P < 0.10$) lower than the grain yields of corn fertilized with ≥80 lb K_2O/acre at LEZ34 and SFZ32. The positive grain yield response to K fertilization at LEZ34 (Very Low soil-test K) and SFZ32 (Low soil-test K) and the lack of response to K fertilization at CLZ32 and SFZ34 (Medium soil-test K) are consistent with the current Cooperative Extension Service interpretation of Mehlich-3 extractable K for corn production.

PRACTICAL APPLICATIONS

The 2013 results show that P fertilization significantly and linearly increased corn grain yield when Mehlich-3 extractable P in the 0- to 6-inch depth was Low or Medium. Phosphorus fertilization increased corn grain yield by 15% to 37% above the yield of corn receiving no P. Previous research has shown similar responses for corn grown on soils with suboptimal soil-test P levels (Mozaffari and Slaton, 2011, 2012; Mozaffari et al., 2012).

Potassium fertilization significantly increased corn grain yield by 17% to 59% above that of corn receiving no K at two sites, which had either Very Low or Low soil-test K levels, but failed to influence corn yield at another site that also had a Low soil-test K level and two sites that had a Medium soil-test K level. Additional trials on soils with a wide array of soil-test K values are needed to ascertain whether our interpretation of soil-test K needs to be changed. In general, our research suggests that current Cooperative Extension Service soil-test-based P- and K-fertilizer recommendations are able to identify soils that need no P. Potassium recommendations for corn need further evaluation, as there is some variability in the measured responses.

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Table 1. Site identification code, test nutrient(s), soil series, corn hybrid, planting date, fertilizer application, leaf sample collection and harvest dates for P or K fertilization rate trials conducted in Clay (CLZ32), Desha (DEZ32), Lee (LEZ33, LEZ34), and St. Francis (SFZ31-SFZ35) counties during 2013.

Site	Test nutrient	Soil series	Hybrid	Planting date	Fertilizer application date	Ear-leaf sampling date	Harvest date
CLZ21	K	Jackport silty clay	DeKalb DKC6483	18 April	26 April	NC[a]	28 Aug
DEZ22	K	Hebert silt loam	Pioneer 1615HR	26 April	8 May	10 July	23 Sep
LEZ33&LEZ34	P, K	Calloway silt loam	Pioneer 1615HR	16 April	25 April	11 July	21 Aug
SFZ31&SFZ33	P	Calloway silt loam	Pioneer 1615HR	22 April	14 May	11 July	26 Aug
SFZ32&SFZ34	K	Calloway silt loam	Pioneer 1615HR	22 April	14 May	NC	23 Aug
SFZ35	P	Calloway silt loam	Pioneer 1615HR	2 May	2 May	11 July	23 Aug

[a] NC = ear-leaf samples not collected.

Table 2. Selected mean soil properties of samples collected from the 0- to 6-inch depth, before P-fertilizer application, for four P-fertilization trials established in Lee (LEZ33) and St. Francis (SFZ31, SFZ33, SFZ35) counties during 2013.

		Mehlich-3-extractable nutrients							Soil physical properties			
Site ID	Soil pH[a]	P[b]	K	Ca	Mg	Mn	Cu	Zn	Sand	Silt	Clay	Texture
		(ppm)							(%)			
LEZ33	6.4	24	87	756	185	165	1.0	9.6	3	79	18	silt loam
SFZ31	7.9	26	90	2730	323	423	1.3	7.2	1	74	25	silt loam
SFZ33	8.1	20	108	2972	339	357	1.3	11.6	1	74	25	silt loam
SFZ35	7.9	19	72	2377	335	256	1.3	2.4	1	72	27	silt loam

[a] Soil pH was measured in a 1:2 (volume: volume) soil-water mixture.
[b] Standard deviation of soil-test P means: 11 ppm for LEZ33, 6 ppm for SFZ31, 8 ppm for SFZ33, and 2 ppm for SFZ35.

Table 3. Selected soil property means of samples taken from the 0- to 6 inch depths before K-fertilizer application for five K-fertilization trials conducted in Clay (CLZ32), Desha (DEZ32), Lee (LEZ34), and St. Francis (FSZ32, SFZ34) counties during 2013.

		Mehlich-3-extractable nutrients						Soil physical properties			
Site ID	Soil pH[a]	P[b]	K	Ca	Mg	Cu	Zn	Sand	Silt	Clay	Texture
		(ppm)						(%)			
CLZ32	6.8	34	115	1065	687	1.4	4.4	6	67	26	silty clay
DEZ32	6.9	41	72	823	111	0.9	1.3	29	56	15	silt loam
LEZ34	6.7	32	53	880	198	2.2	10.1	2	82	17	silt loam
SFZ32	7.3	26	80	1594	254	1.0	6.3	1	77	24	silt loam
SFZ34	6.9	34	104	1497	261	1.4	9.7	1	74	25	silt loam

[a] Soil pH was measured in a 1:2 (volume: volume) soil-water mixture.
[b] Standard deviation of soil-test K in the 0- to 6-inch depths: 17 ppm for CLZ32; 8 ppm for DEZ22; 5 ppm for LEZ34; 16 ppm for SFZ32; and 16 ppm for SFZ34.

Table 4. Effect of P-fertilization rate on ear-leaf P concentration at the silking stage and corn grain yield for P-fertilization trials established in Lee (LEZ33) and St. Francis (SFZ31, SFZ33 and SFZ35) counties during 2013.

	LEZ33		SFZ31		SFZ33		SFZ35	
P rate	Ear-leaf P	Grain yield	Ear-leaf P	Grain yield	Ear-leaf P	Grain yield	Ear-leaf P	Grain yield
(lb P_2O_5/acre)	(% P)	(bu/acre)	(% P)	(bu/acre)	(% P)	(bu/acre)	(% P)	(bu/acre)
0	0.27	182	0.40	143	ND[a]	141	0.32	133
40	0.27	186	0.42	169	ND	188	0.32	136
80	0.27	209	0.42	167	ND	176	0.35	170
120	0.29	209	0.42	183	ND	159	0.33	178
160	0.27	209	0.42	165	ND	178	0.32	182
C.V.[b]	9.3	8.9	7.8	9.4	-	10.5	3.7	9.4
P value	0.4291	0.0694	0.8900	0.0348	-	0.0095	0.0555	0.0239
$LSD_{0.10}$[c]	NS[d]	19	NS	21	-	22	0.02	26

[a] ND = No data; ear-leaf samples were not collected at this research site.
[b] C.V. = Coefficient of variation.
[c] LSD = Least significant difference at $P = 0.10$.
[d] NS = not significant ($P > 0.10$).

Table 5. Effect of K-fertilization rate on corn ear-leaf K concentration, at the silk stage, and grain yield for five K-fertilization trials conducted in in Clay (CLZ32), Desha (DEZ32), Lee (LEZ32), and St. Francis (SFZ32, SFZ34) counties during 2013.

	CLZ32		DEZ32		LEZ34	SFZ32	SFZ34
K rate	Ear-leaf K	Grain yield	Ear-leaf K	Grain yield	Grain yield	Grain yield	Grain yield
(lb K_2O/acre)	(% K)	(bu/acre)	(% K)	------------(bu/acre)------------			
0	1.60	221	0.85	238	180	132	175
40	1.70	219	1.02	244	194	195	209
80	1.73	242	1.32	242	211	200	190
120	1.83	228	1.35	242	207	197	215
160	1.97	215	1.44	245	210	204	194
200	1.96	246	1.55	247	205	209	224
C.V.[a]	7.8	9.1	14.8	2.6	8.6	8.9	13.2
P value	0.0005	0.2222	<0.0001	0.5676	0.0480	0.0007	0.2385
$LSD_{0.10}$[b]	0.14	NS[c]	0.18	NS	15	23	NS

[a] CV = Coefficient of variation.
[b] LSD = Least significant difference at $P = 0.10$.
[c] NS = not significant ($P > 0.10$).

Dry Matter and Potassium Accumulation and Partitioning in Determinate and Indeterminate Soybean Varieties

M.R. Parvej, N.A. Slaton, T.L. Roberts, R.E. DeLong, C.G. Massey, R.J. Dempsey, and M.S. Fryer

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Understanding the uptake and distribution pattern of nutrients among plant structures during the growing season is required to develop sound fertilization programs and diagnostic information to assess plant nutritional health. For soybean [*Glycine max* (L.) Merr.], a recently matured trifolioliate leaf from one of the topmost plant nodes is recommended for sampling to assess the plant's nutritional status. The potassium (K) concentration in the trifoliolate leaf at the R1 to R2 stage is reportedly well correlated to relative soybean yield potential (Yin and Vyn, 2004; Clover and Mallarino, 2013). However, some scientists have found a poor relationship at the R1 to R2 stage for both determinate (Sartain et al., 1979) and indeterminate (Slaton et al., 2010) varieties and/or reported a better correlation between leaf K concentration at the early (R3; Terman, 1977; Sartain et al., 1979) and full pod (R4; Miller et al., 1961) stages with the yield of determinate soybean varieties.

The relationship between leaf K concentration and seed yield may be different for determinate and indeterminate soybean varieties due to the longer flower and pod set periods of indeterminate varieties coupled with the competition for nutrients between the vegetative and reproductive structures. If so, it is reasonable to assume that critical leaf K concentrations, the proper plant part to sample for tissue analysis, and/or the best plant development stage for sample collection could differ between growth habits. Previous research has not adequately evaluated how determinate and indeterminate glyphosate-resistant soybean varieties having similar or different maturity groups (especially IV and V) allocate nutrients among plant parts under the same or different levels of soil K availability.

The overall research goal is to improve our ability to monitor and assess the nutritional status of determinate and indeterminate soybean varieties by enhancing our knowledge and understanding of aboveground nutrient uptake and allocation patterns during the growing season. Our short-term objective is to evaluate season-long dynamics of dry matter accumulation and nutrient uptake and allocation to aboveground plant parts in representative determinate and indeterminate soybean varieties of different maturity groups under the same growing condition, with emphasis on K.

PROCEDURES

An experiment was performed at the Pine Tree Research Station, near Colt, Ark., on a Calhoun silt loam (fine-silty, mixed, active, thermic Typic Glossaqualfs) in 2012. Before fertilizer application, a composite soil sample was collected from the 0- to 4-inch soil depth from each of four blocks. The soil samples were oven-dried at 55 °C and crushed to pass a 2-mm sieve, extracted with Mehlich-3 solution, and the extract was analyzed for nutrient concentrations by inductively coupled plasma atomic emission spectroscopy (ICP-AES). Soil pH was determined in a 1:2 v:v soil:water mixture. Soil organic matter content was determined using the weight loss-on-ignition method. Selected soil chemical property means for the Calhoun soil include a pH of 7.1, organic matter of 2.2%, and Mehlich-3 nutrient availability indices of 15 ppm P [2.8 ppm standard deviation (SD)], 64 ppm K (6 ppm SD), 1642 ppm calcium (Ca), 302 ppm magnesium (Mg), 8 ppm sulfur (S), and 2.6 ppm zinc (Zn).

The research area consisted of 4 adjacent blocks that accommodated 3, 30-ft long strips of each soybean variety with each strip containing 20, 15-inch wide rows. Three glyphosate-resistant soybean varieties having different maturity were selected for this study and were randomized within each block. The varieties included Armor 39-R16 (Armor Seed LLC, Jonesboro, Ark.), Armor 48-R40, and Armor 53-R15 to represent varieties that can be described as an indeterminate late maturity group (MG) III, an indeterminate late MG IV, and a determinate early MG V, respectively. To ensure plant nutrition was not yield limiting, the trial was fertilized with 50 lb P_2O_5/acre as triple superphosphate; 60 lb K_2O/acre as muriate of potash; and 20 lb K_2O/acre, 19 lb S/acre, and 10 lb Mg/acre as $K_2SO_4 \cdot 2MgSO_4$ to the soil surface and incorporated with shallow (<2 inch) tillage before planting. After planting, 0.5 lb boron (B)/acre as solubor was also sprayed to the soil surface. The seeding rate, irrigation, and weed and pest management were done following the recommendation of the University of Arkansas System Division of Agriculture's Cooperative Extension Service.

After soybean emergence, eight, 4-ft long areas for collecting plant samples were selected within each plot and thinned to a uniform density of 15 plants/4 linear ft of row (equivalent to

130,000 plants/acre). Plant samples were collected eight times during the season beginning 28 days after emergence (DAE; or 178 day of year; Fig. 1). At each sample time, the 15 whole plants were collected by cutting at the soil surface. In addition, a fully expanded, trifoliolate leaf from one of the top three nodes of 12 plants surrounding each sample site was collected. Each plant was examined and the number of nodes, branches, and the presence (or absence) of flowers at each node were recorded to determine the average plant development stage as described by Fehr et al. (1971). After growth characterization, the 15 plants from each plot were divided into trifoliolate leaves, petioles, stems and branches, pods, and mature seed. Plant samples were dried at 60 °C, weighed for dry matter, ground to pass a 1-mm sieve, digested, and analyzed for K concentration by inductively coupled plasma atomic emission spectroscopy (ICP-AES). At maturity, for each variety, a 40- to 50-ft^2 area within each block was harvested with a small plot combine and seed yield was determined by adjusting the seed moisture to 13%.

The K content of each plant part was calculated as the product of K concentration and dry matter accumulation and expressed as lb K/acre. The percent distribution of total dry matter and K content of the individual plant structures was also calculated for each sample time. The actual K harvest index was calculated by the ratio of the seed K content at harvest to the maximum aboveground K accumulation during the growing season (Schapaugh and Wilcox, 1980). The apparent K harvest index was calculated as the ratio of mature seed K content to the total plant K content at harvest (maturity).

The experiment was a randomized complete block design with four blocks. The ANOVA and Fisher's protected LSD ($P = 0.05$) were used through the Fit Model of JMP Pro 11 (SAS Institute, Cary, N.C.) to determine the differences in seed yield and harvest index of the three soybean varieties. Further analyses were conducted by regressing dry matter, K accumulation, and trifoliolate K concentration against day of year (DOY) using a nonlinear Gaussian peak model. In the Gaussian equation, the coefficient 'a' is the peak value (lb/acre, lb K/acre, or % K), 'b' is the critical point with units of DOY (e.g., the DOY number at which dry matter, K content, and K concentration peaked), and 'c' is the value (with units of days) equal to one-half the width of the 'bell' shaped curve at 60% of the peak value (a). A linear model was used to predict the decline in trifoliolate leaf K concentration after K concentration peaked. The slopes of the model for each soybean variety were tested to compare among varieties. The studentized residuals and Cook's D influence for all dependent variables were also examined to identify potential outliers and influential data, respectively. When appropriate, the model was refit by omitting the outliers or influential data.

RESULTS AND DISCUSSION

Soybean plants accumulated dry matter rapidly from the vegetative stage to the onset of the seed-filling period (R5), dry matter accumulation peaked between the R6 and R7 stage for all three varieties, and then declined as the leaves senesced and seed matured (Fig. 1). The nonlinear regression showed that the pattern of dry matter accumulation for determinate and indeterminate varieties was significantly different in terms of the maximum dry matter produced (coefficient a) and the DOY that (coefficient b) maximum dry matter was reached (Fig. 1; Table 1). Armor 53-R15, the determinate variety, produced 12% to 15% more aboveground dry matter with the peak dry matter occurring 9 or 10 days later than that predicted for Armor 39-R16 and 48-R40 (Table 1). In Table 1, time is expressed as the DOY maximal dry matter was achieved and corresponds to 103, 102, and 112 DAE for the Armor 39-R16, 48-R40, and 53-R15, respectively.

Before blooming (R0), 66% of the aboveground dry weight of Armor 48-R40 consisted of leaves; but with the onset of reproductive growth, the proportion of the total plant weight from leaves declined to 17% by the R5 to R6 stage (Fig. 2). The percentage of the plant total weight from petioles and stems showed less fluctuation than the leaves, but gradually increased in dry weight until the seed started to form (R4 to R5). At the R4 to R5 stage, soybean plants started allocating most of their dry matter to the developing bean seed (pods and seeds) which increased in weight until maturity. At the R6 to R6.5 stage, which is the time of maximum dry weight accumulation, the bean seed, stems, leaves, and petioles accounted for an average of 49%, 24%, 14%, and 12%, respectively, of the total dry matter. Armor 39-R16 and 53-R15 showed similar trends in dry matter accumulation and dry matter distribution among plant structures (not shown).

Aboveground K uptake (lb K/acre) in soybean is more or less parallel to dry matter accumulation throughout the growing season and both parameters peak at nearly the same time (Table 1). Similar to dry matter accumulation, the K accumulation pattern for determinate and indeterminate growth habits was statistically different among the varieties with respect to the maximum amount of K (coefficient a) accumulated and the day of year (coefficient b) where peak accumulation occurred (Fig. 3; Table 1). The predicted K accumulation was greatest at the R6 stage amounting to 110, 125, and 147 lb K/acre for 39-R15, 48-R40, and 53-R15 varieties, respectively. The peak K accumulation time [101 days after emergence (DAE) for 39-R15, 97 DAE for 48-R40, and 111 DAE for 53-R15] coincided with the seed-filling period (R5 to R7) when the plant's demand for K reached a maximum.

The distribution of K content among the soybean plant structures was similar to that of dry matter distribution (Fig. 4). Leaves contained about 60% of total plant K before flowering and the proportion of K residing in the leaves gradually decreased with time. The K allocation pattern for petioles and stems was similar across the season. At the R2 stage, 30% to 35% of the total aboveground K content was located in the petioles and stems; but when the soybean pods began to develop (R3 to R4), the K content gradually declined for both structures. The depletion of K in the petioles, stems, and branches was attributed to the mobilization and subsequent translocation of K to the developing seeds. In Armor 48-R40, about 34% (39 lb/acre) of the total K was mobilized from the vegetative plant parts (e.g., leaves, petioles, stems, and pods) to the seed, which accounted for 61% of the total seed K content (Table 2).

Potassium translocation from the vegetative structures to the developing bean seed begins at the R5 stage; however, during the early seed-filling period (R5 to R5.5), the soybean plant started allocating most of its accumulated K to the developing beans and continued until maturity. At the R5 stage, the total plant K distribution among plant parts was 17% in the leaves, 7% in petioles, 14% in the stems and branches, and 62% in the seed (pods and seeds), respectively.

The seasonal change of trifoliolate leaf K concentration was similar for all three soybean varieties although the Armor 48-R40 variety had significantly greater K concentration (1.66% after 56 DAE) at the R2 stage than Armor 39-R16 (1.45% after 41 DAE) and Armor 53-R15 (1.53% after 48 DAE; Fig. 5; Table 1). Irrespective of soybean maturity group and growth habit, the trifoliolate leaf K concentration gradually increased from the vegetative stage to the early reproductive stage (R1 to R2) and peaked at the R2 stage. The linear models showed that after peak K concentrations were reached at R2, the trifoliolate leaf K concentration declined linearly with plant age at the same rate of 0.017% K/day (Fig. 5) until leaf senescence (R7 stage).

Soybean seed yield was statistically different among soybean varieties (Table 2). Armor 39-R16 and Armor 53-R15 varieties produced statistically similar yields (59 and 63 bu/acre, respectively) that were higher than Armor 48-R40 (54 bu/acre). The actual harvest index of soybean seed was statistically similar though the apparent harvest index was different among varieties (Table 2). Soybean seed comprised 53% to 59% of the total aboveground dry matter produced at harvest (apparent harvest index). There was no difference in actual and apparent K harvest index among varieties (Table 2). According to actual harvest index, the proportion of K removed by the harvested soybean seed accounted for 51% to 66% of the maximum amount of K accumulated during the growing season (e.g., R6 stage). However, the seed K content accounted for an average of 74% of the total aboveground K content at maturity (e.g., after leaf senescence, apparent harvest index).

PRACTICAL APPLICATIONS

Knowledge of the dry matter and K accumulation pattern among soybean plant parts of both determinate and indeterminate varieties would be of value for developing diagnostic tissue sampling protocols to monitor the nutritional status of soybean. Improved diagnostics for interpreting the change of soybean trifoliolate leaf K concentration across a range of growth stages would enable farmers to better assess in-season plant K nutritional problems. The dry matter and K accumulation pattern suggests that K deficiency of soybean could possibly be corrected by timely fertilization during early reproductive growth

ACKNOWLEDGMENTS

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Table 1. Coefficient and estimated parameter values for the Gaussian† model predicting aboveground dry matter and K accumulation and trifoliolate leaf K concentration during the growing season.

Variety (‡; §)	A	b	c	r^2	*P-value*
Fig. 1. Total dry matter accumulation of three soybean varieties.					
39-R16 (MG III; ID)	9132B¶	253B	34.4	0.90	<0.0001
48-R40 (MG IV; ID)	9368B	252B	32.8	0.93	<0.0001
53-R15 (MG V; D)	10469A	262A	39.3	0.89	<0.0001
Fig. 3. Total K accumulation of three soybean varieties.					
39-R16 (MG III; ID)	110B	251B	39.4	0.73	<0.0001
48-R40 (MG IV; ID)	125B	247B	32.8	0.88	<0.0001
53-R15 (MG V; D)	147A	261A	41.7	0.84	<0.0001
Fig. 5. Trifoliolate K concentration of three soybean varieties.					
39-R16 (MG III; ID)	1.45B	191	43.2	0.83	<0.0001
48-R40 (MG IV; ID)	1.66A	206	45.8	0.88	<0.0001
53-R15 (MG V; D)	1.53B	198	41.6	0.86	<0.0001

† Gaussian peak: y = a*exp(-0.5*((x-b)/c)^2); a = Peak value (lb/acre or %), b = Critical point (DOY), c = is the value (with units of days) equal to one-half the width of the 'bell' shaped curve at 60% of the peak value (a).

‡ Maturity group (MG).

§ Growth habit; ID = Indeterminate, D = Determinate.

¶ Similar letters in a column under each figure head do not differ significantly at 5% level of probability.

Table 2. Potassium mobilization, seed yield and harvest index of three Armor soybean varieties during the 2012 growing season at the Pine Tree Research Station near Colt, Ark.

			Harvest index			
			Actual		Apparent	
Variety (†; ‡)	Total mobilized K	Seed yield	Seed	K	Seed	K
	(lb/acre; %§; %¶)	(bu/acre)				
39-R16 (MG III; ID)	21.3 (22; 33)	59	0.47	0.66	0.59	0.76
48-R40 (MG IV; ID)	39.3 (34; 61)	54	0.41	0.51	0.53	0.74
53-R15 (MG V; D)	65.5 (54; 77)	63	0.51	0.62	0.55	0.73
$LSD_{0.05}$	12 (11; 18)	5	NS#	NS	0.01	NS
P-value	0.0003 (0.001; 0.003)	0.0203	0.3329	0.1367	<0.0001	0.4641

† Maturity group (MG).

‡ Growth habit; ID = Indeterminate, D = Determinate.

§ Percent of K mobilized from plant structures to seeds.

¶ Percent of total seed's K from mobilization by other plant structures.

NS = not significant ($P > 0.05$).

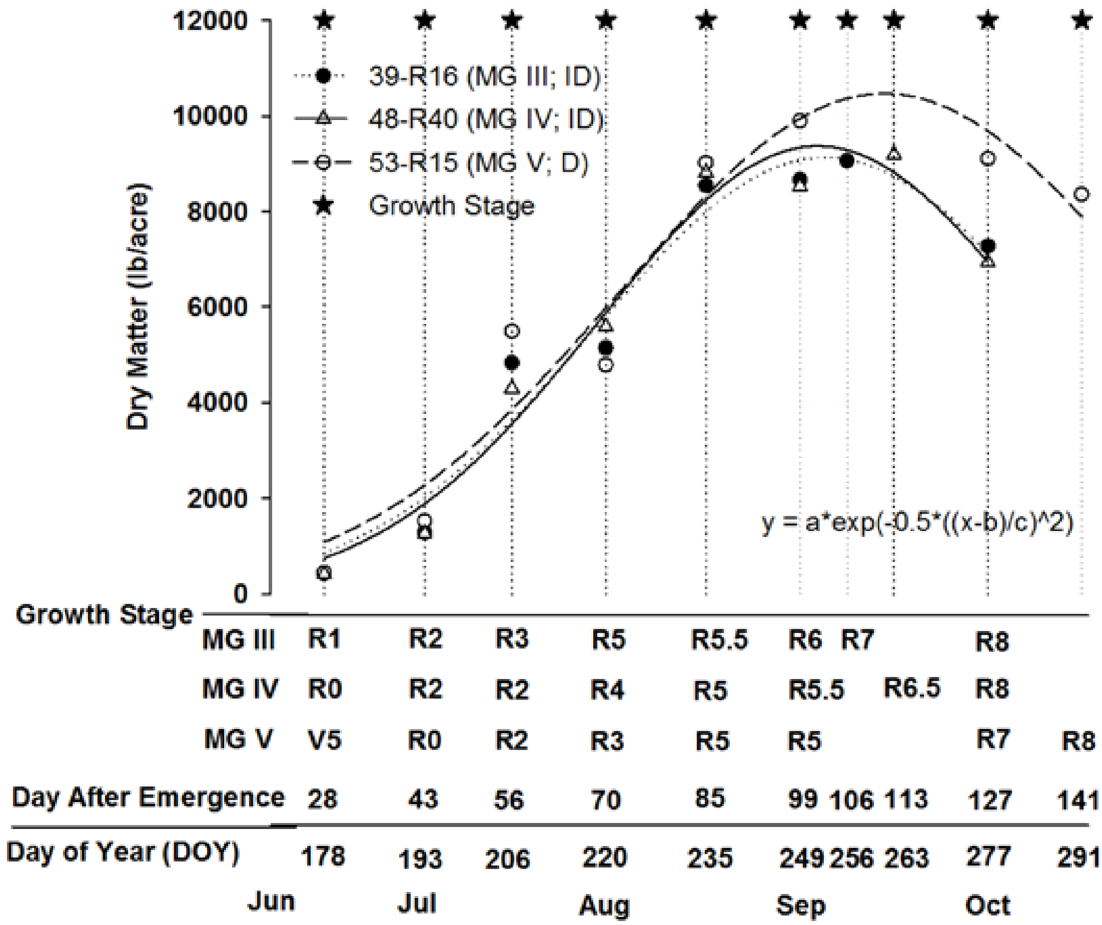

Fig. 1. Seasonal total dry matter accumulation of three different maturity groups (MG) having determinate (D) or indeterminate (ID) growth habit as predicted with a nonlinear model of Gaussian peak. Coefficient and estimated parameter values are listed in Table 1.

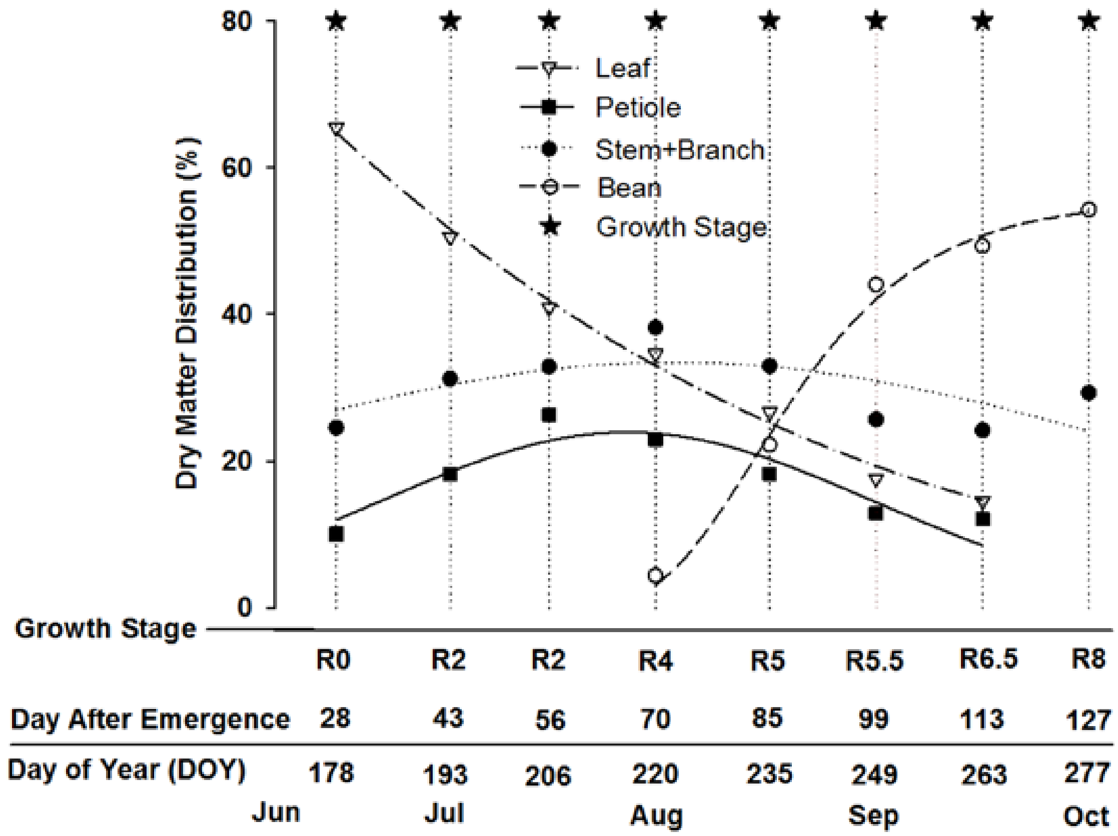

Fig. 2. Seasonal dry matter distribution of Armor 48-R40 (MG IV) soybean variety.

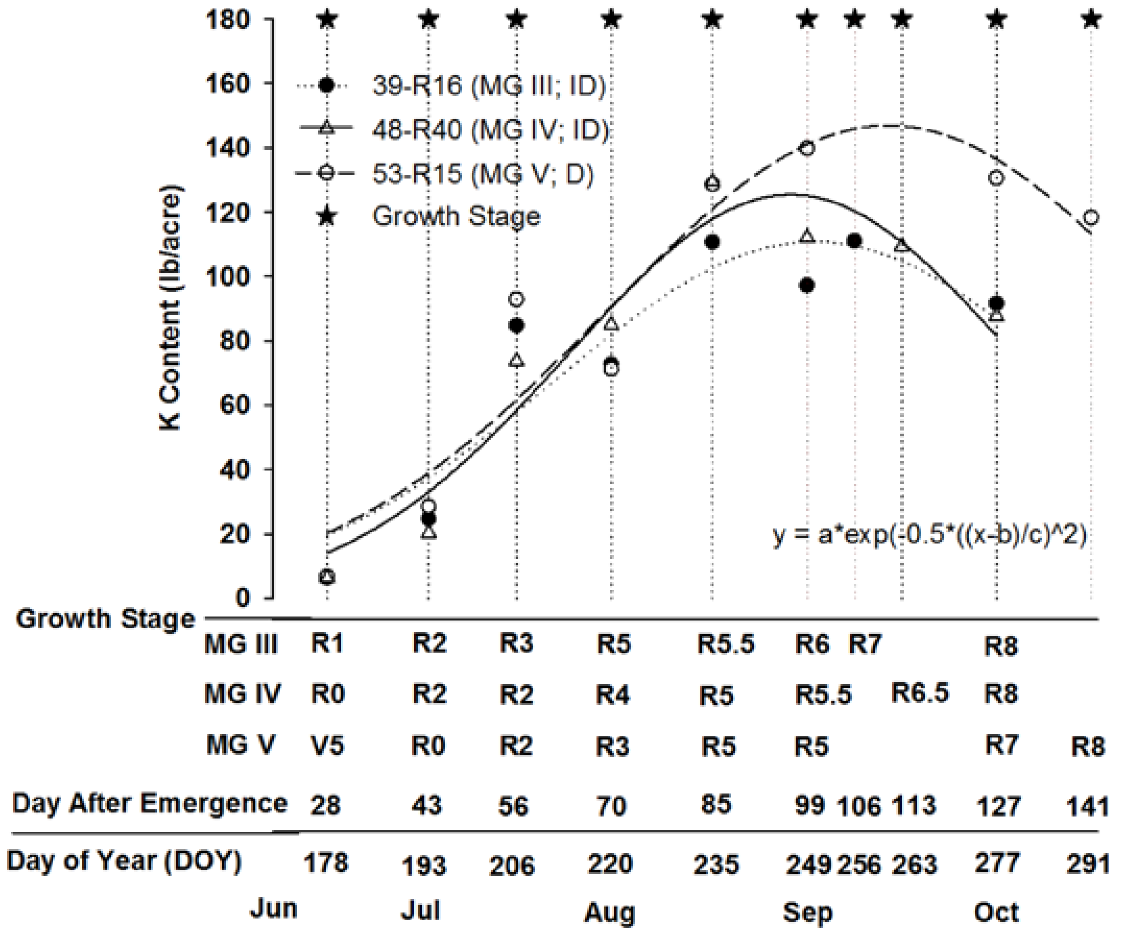

Fig. 3. Seasonal total K accumulation of three different maturity groups (MG) having determinate (D) or indeterminate (ID) growth habit as predicted with a nonlinear model of Gaussian peak. Coefficient and estimated parameter values are listed in Table 1.

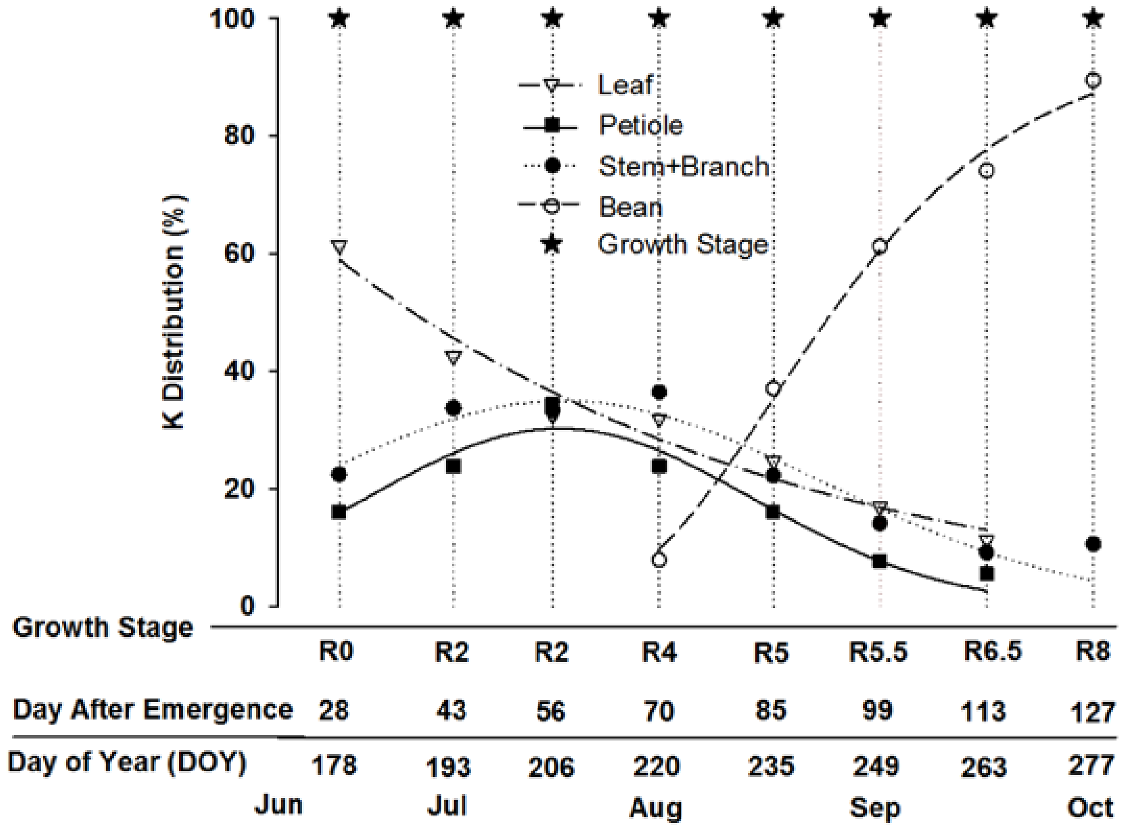

Fig. 4. Seasonal K distribution of Armor 48-R40 (MG IV) soybean variety.

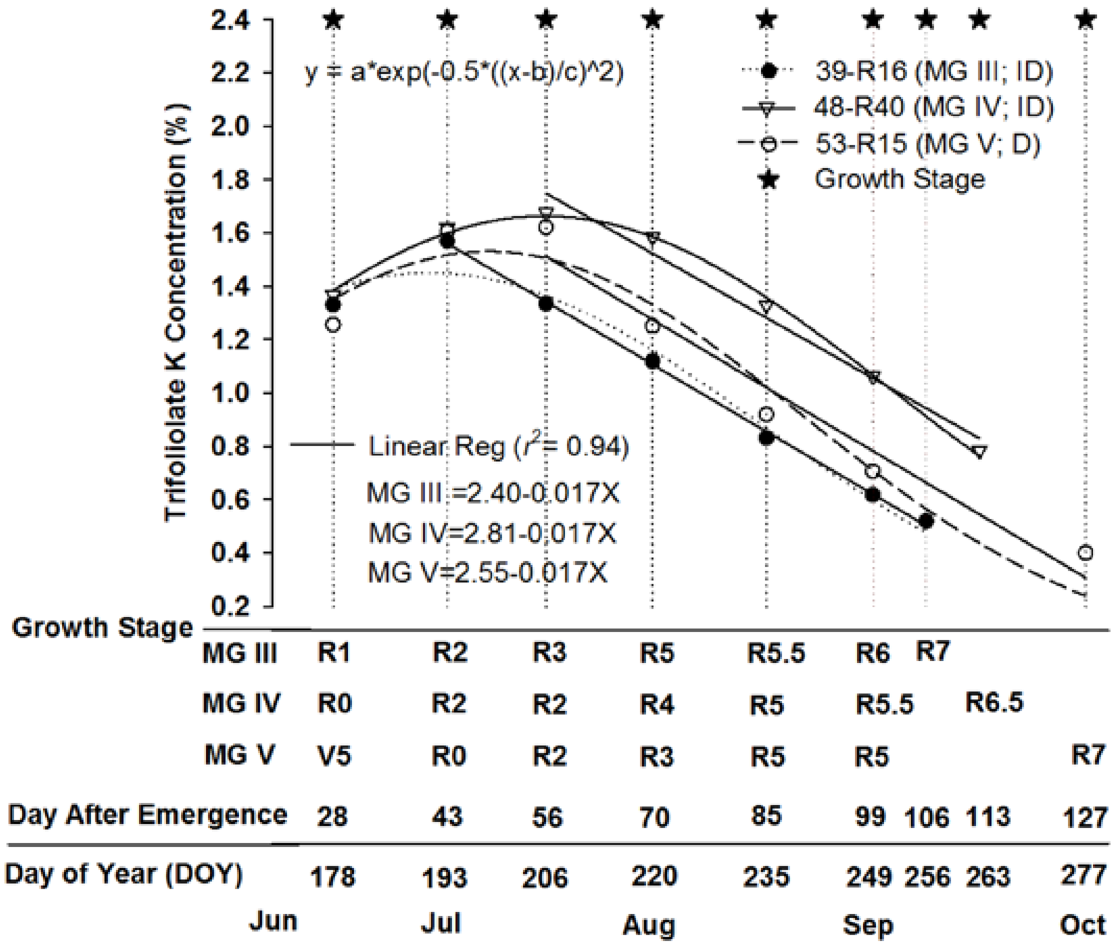

Fig. 5. Seasonal change of trifoliolate K concentration of three different maturity groups (MG) having determinate (D) or indeterminate (ID) growth habit as predicted with a nonlinear model of Gaussian peak. Coefficient and estimated parameter values are listed in Table 1. Linear models are to predict the diminishing of K concentration after it gets the peak.

Nodal Seed Yield and Potassium Concentration as Affected by Variety and Long-Term Potassium Fertilization

M.R. Parvej, N.A. Slaton, T.L. Roberts, R.E. DeLong, and C.G. Massey

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Soybean [*Glycine max* (L.) Merr.] seed yield and seed potassium (K) concentration are known to vary among the nodes of both determinate (Sojka et al., 1985; Sadler et al., 1991) and indeterminate (Hanway and Weber, 1971) varieties. Sadler et al. (1991) showed that the middle nodes (7th to 15th nodes of 20 total nodes) of a determinate soybean variety produced about 75% of the total reproductive (pod with seed) dry matter. Sojka et al. (1985) reported that the mean K concentration of mature beans (pod with seed) gradually decreased from the bottom to the top of a determinate soybean variety. The yield of soybean grown on low cation exchange capacity soils often responds positively to K fertilization. Coale and Grove (1990) reported that K fertilization increased soybean yield by increasing the number of branches and pods/plant and seeds/pod. We could find no research that has investigated how K deficiency influences soybean seed yield and K concentration among the nodes of soybean varieties having either a determinate or indeterminate growth habit.

Knowledge of the specific effects of K deficiency on soybean yield and seed composition across the nodes of soybean plants is needed to better understand the nutritional requirements needed for the production of high yields and to develop efficient K-fertilization methods. Our research objective was to evaluate soybean seed yield and K concentration among nodes of an indeterminate and determine soybean variety as affected by annual K-fertilization rate.

PROCEDURES

The experiment was conducted on a Calhoun silt loam (fine-silty, mixed, active, thermic Typic Glossaqualfs) in 2012 at the Pine Tree Research Station (PTRS) near Colt, Ark., in a long-term K-fertilization trial that was established in 2002 and has been cropped with a 1:1 rice (*Oryza sativa* L.): soybean rotation. Before the application of K-fertilizer treatments, one composite soil sample composed of 5, 2-cm diameter soil cores was collected from the 0- to 10-cm soil depth of each main plot. The soil samples were oven-dried at 55 °C and crushed to pass a 2-mm sieve, extracted with Mehlich-3 solution, and the extract was analyzed for nutrient concentrations by inductively coupled plasma atomic emission spectroscopy (ICP-AES). The mean Mehlich-3, soil-test K values in 2012 were 64 ppm [5 ppm standard deviation (SD)], 73 ppm (6 ppm SD), 78 ppm (8 ppm), 82 ppm (10 ppm), and 91 ppm (11 ppm SD) for soil collected from the 0, 40, 80, 120, and 160 lb K_2O/acre/year treatments, respectively. Other Mehlich-3, nutrient-availability indices averaged 27 ppm phosphorus (P), 2342 ppm calcium (Ca), 392 ppm magnesium (Mg), 22 ppm sulfur (S), 10 ppm zinc (Zn), and 0.7 ppm boron (B). Soil pH averaged 7.7 and was determined in a 1:2 v:v soil:water mixture. Soil organic matter content averaged 3.0% (by weight loss-on-ignition) for soil samples collected from the 0 lb K_2O/acre/year treatment.

The field experiment was a strip-plot with nine blocks where annual-K rate was the main plot and soybean variety was the subplot. The main plots were 25-ft wide by 16-ft long and were divided into subplots by splitting the width into two equal halves (12.5 ft × 16 ft). Two glyphosate-resistant soybean varieties, Armor 48-R40 [Indeterminate growth habit and 4.8 maturity group (MG); Armor Seed LLC, Jonesboro, Ark.] and Armor 53-R15 (determinate growth habit and 5.3 MG) were selected for this study. Both varieties contain the Roundup Ready 2 yield gene and were rated as chloride excluders. Each strip-plot contained 10, 38-cm wide rows of each variety. Soybean was planted into an untilled seedbed on 26 April 2012 and emerged on 4 May 2012.

Five annual rates of 0, 40, 80, 120, and 160 lb K_2O/acre/year as muriate of potash were broadcast by hand to each main plot of each block on 24 April 2012. These or similar K rates have been applied to the same plots each year since 2002 and provide a soil environment with a range of K availability to which significant yield differences are routinely measured (Slaton et al., 2011, 2012). To ensure that P and B were not yield limiting, 60 lb P_2O_5/acre as triple superphosphate and 1 lb B/acre as granubor were applied to each main plot on the same day. The seeding rate, irrigation, and weed and pest management closely followed recommendations provided by the University of Arkansas System Division of Agriculture's Cooperative Extension Service.

Four representative whole plants of each variety were collected at maturity from plots that received 0, 80, and 160 lb K_2O/acre from five of the nine blocks (2, 3, 4, 6, and 7) to evaluate seed yield and seed nutrient concentration as affected by main stem node location. The nodes of the sampled plants were numbered from the topmost node (node 1) to the bottom node. Each of the four plants was dissected from the top of the plant to the bottom and tissues from the four plants were composited into a single sample. The plant was dissected by cutting immediately above nodes (from top to bottom) 3, 5, 7, 9, 11, 13, 15, 17, 19, and 21 so that each sample consisted of two nodes and two internodes. Sojka et al. (1983) used a similar plant dissection strategy where each node segment was made up of a single node (noden) plus the internodal tissue immediately below the node and above the next node ($node_{n-1}$). Tissues from each dissected node segment were separated into i) stems plus pods and ii) seed. The seeds from each node segment were counted and weighed after discarding the aborted and/or malformed seed.

Armor 48-R40 plants had an upright growth habit, no lateral branches, and up to 22 nodes/plant at maturity. Armor 53-R15 was a bushy plant, had up to 16 nodes at maturity and contained multiple branches that also contained pods. Nodes on the lower one-half of many of the 53-R15 plants contained one primary branch that had up to eight nodes. Branches were initially dissected by node; nodes were counted from the top of the branch towards the stem, and separated into the same plant components as described previously. For evaluating seed K composition at different main stem node segments, a subsample of three whole soybean seeds was weighed, digested, and analyzed by ICP-AES. Seed weight in bu/acre at each node segment was calculated assuming 130,000 plants/acre and 60 lb seed/bu.

Analysis of variance (ANOVA) was performed on seed yield and K concentration data for each variety separately using SAS v. 9.4 (SAS Institute, Cary, N.C.). Field yield data were analyzed as split-plot design where annual K rate was the main plot and variety was the subplot. Data from the four-plant/plot composite samples were also analyzed as a split-plot where annual K rate was the main plot and node segment was the subplot. When a significant F-test was obtained, the means were separated by Fisher's Protected Least Significant Difference Method ($P = 0.05$).

RESULTS AND DISCUSSION

The seed K concentration of Armor 48-R40 was affected by the interaction between node segment and annual-K rate (Table 1). Seed K concentration results for Armor 53-R15 are not included in this report. Within each K rate there was a significant change in seed K concentration from the top to bottom nodes with the lowest concentration occurring on the uppermost node segment and the greatest K concentration on the lowest node segment. The range of values was greatest on soybean that received 0 lb K_2O/acre/year (0.66% K) and least on soybean that received 160 lb K_2O/acre/year (0.29% K). In general, seed K concentrations increased as annual-K rate increased with the greatest seed K concentration of soybean fertilized with 0 lb K_2O/acre/year being approximately equal to the lowest seed K concentration produced by soybean fertilized with 80 lb K_2O/acre/year. A similar trend occurred for the 80 and 160 lb K_2O/acre/year rates. When comparing the same node segment across K rates, the seed K concentration increased numerically and usually significantly as annual-K rate increased. The numerical differences for the same node segment were greater between the 0 and 80 lb K_2O/acre/year rates (0.20% to 63% K) than between the 80 and 160 lb K_2O/acre/year rates (0.09% to 0.29% K). These results suggest that K availability may limit soybean yield on the upper plant nodes.

The interaction between annual-K rate and nodal position significantly influenced the seed yield produced at each node segment for both the indeterminate ($P = 0.0001$, Table 2) and determinate ($P = 0.0062$, Table 3) varieties. For Armor 48-R40, the indeterminate variety, there was no seed yield difference among annual-K rates from the bottom node segment (19+20) to node segments near the middle of the plant (09+10). Starting with node segment 07+08 to the top of the plant (01+02), soybeans fertilized with 80 and 160 lb K_2O/acre/year produced near equal yields that were 51% to 69% greater than the yield of soybean receiving no K. The theoretical, calculated per acre yield of Armor 48-R40 soybean was estimated to be 84, 97, and 102 bu/acre for the 0, 80, and 160 lb K_2O/acre annual-K rates, respectively. The calculated yields were 18 to 30 bu/acre greater than the field yield of Armor 48-R40 measured by harvest with a plot combine (Table 4). Regardless of the annual-K rate, the largest proportion (~60%) of the yield per plant was produced by on the nodes (node segments 07+08 to 13+14) near the middle of the plant.

For Armor 53-R15, the determinate variety, the significant interaction showed that seed yield was different among annual-K rates at two upper node segments (03+04 and 05+06) and the bottom node segment (13+14, Table 3). At the three node segments that showed yield differences, seed yield was decreased by 46% to 56% for soybean fertilized with 0 lb K_2O/acre/year compared to the 80 and 160 lb K_2O/acre/year. Nodal seed yield between soybean fertilized with 80 and 160 lb K_2O/acre/year was similar for node segments 03+04 and 05+06; but, at node segment 13+14, the yield of soybean fertilized with 80 lb K_2O/acre/year was intermediate. The seed yield from the bottom node segments was affected by the branching habit of the determinate variety where the number of nodes on each branch was numerically, but not statistically affected by annual-K rate. Plants that received no K fertilizer produced branches with approximately 5 nodes/branch compared to 6 and 7 nodes/branch produced by soybean fertilized with 80 and 160 lb K_2O/acre, respectively.

PRACTICAL APPLICATIONS

Our preliminary research shows that the yield loss from K deficiency occurred on the top one-half of nodes of a non-branching indeterminate soybean variety and that seeds produced on the lower nodes receive K preferentially due to their position in relation to the location of K uptake (e.g., roots). The bushy, determinate variety exhibited a different pattern of yield loss among nodes in which yield loss occurred on the top and bottom nodal segments, which was attributed to the position of the upper nodes and the determinate variety's extensive branching on the lower nodes. Although it is not clear from our research, it is likely that the number of nodes with decreased yield would increase as the severity and duration of K deficiency increases. Preliminary results suggest that it may be possible to diagnose K deficiency at maturity by examining seed K concentrations on specific or among individual nodes, but additional research is needed to develop a critical seed K concentration and to validate this hypothesis. Other important aspects from the preliminary results are that collecting a representative subsample of seed is critical for determining crop K removal rates (and perhaps other nutrients) and that seed may accumulate K luxuriously when K availability is high. If soybean seeds accumulate K luxuriously, fertilizer recommendations that aim to maintain soil-test K at optimal levels may need to be reconsidered.

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Table 1. Seed K concentration of Armor 48-R40 soybean as affected by annual-K fertilizer rate and node segment in the long-term, K-fertilization trial conducted at the Pine Tree Research Station in 2012.

Node segment	Seed K concentration at different annual-K fertilization rates		
	0 lb K_2O/acre	80 lb K_2O/acre	160 lb K_2O/acre
	(% K)		
01+02 (top of the plant)	1.29	1.84	2.13
03+04	1.33	1.96	2.19
05+06	1.54	2.05	2.23
07+08	1.65	2.02	2.24
09+10	1.74	2.05	2.22
11+12	1.74	2.08	2.19
13+14	1.79	2.10	2.19
15+16	1.75	2.17	2.33
17+18	1.84	2.14	2.42
19+20 (bottom of the plant)	1.95	2.15	2.36
P-value (annual-K rate × node segment)			<0.0001
$LSD_{(0.05)}$ (compare among node segments within an annual-K rate)			0.10
$LSD_{(0.05)}$ (compare among annual-K rates within a node segment)			0.20
$LSD_{(0.05)}$ (compare among node segments for different annual-K rates)			0.20

Table 2. Calculated seed yield of Armor 48-R40 soybean as affected by annual-K fertilizer rate and node segment in the long-term K-fertilization trial conducted at the Pine Tree Research Station in 2012.

Node segment	Seed yield at different annual-K rates		
	0 lb K_2O/acre	80 lb K_2O/acre	160 lb K_2O/acre
	(bu/acre)		
01+02 (top of the plant)	5.7	9.1	9.9
03+04	5.8	8.9	9.8
05+06	7.5	11.2	13.0
07+08	10.1	15.1	16.6
09+10	14.1	17.1	17.0
11+12	14.9	14.6	15.2
13+14	13.1	10.4	10.7
15+16	7.6	5.9	6.3
17+18	3.1	3.3	2.1
19+20 (bottom of the plant)	2.4	1.7	1.7
P-value (annual-K rate × node segment)			0.0001
$LSD_{(0.05)}$ (comparison among node segments within an annual-K rate)			2.9
$LSD_{(0.05)}$ (comparison among annual-K rates within a node segment)			3.0
$LSD_{(0.05)}$ (comparison among node segments for different annual-K rates)			3.2

Table 3. Calculated seed yield of Armor 53-R15 soybean as affected by annual-K fertilizer rate and node segment in the long-term, K-fertilization trial conducted at the Pine Tree Research Station in 2012.

Node segment	Seed yield at different annual-K rates		
	0 lb K_2O/acre	80 lb K_2O/acre	160 lb K_2O/acre
	(bu/acre)		
01+02 (top of the plant)	9.7	9.0	5.3
03+04	13.7	20.9	23.3
05+06	6.5	13.8	16.3
07+08	3.1	8.1	9.4
09+10	14.7	12.7	11.4
11+12	10.2	9.3	12.3
13+14 (bottom of the plant)	9.0	19.4	26.3
P-value (annual-K rate × node segment)			0.0062
$LSD_{(0.05)}$ (comparison among node segments within an annual-K rate)			7.4
$LSD_{(0.05)}$ (comparison among annual-K rates within a node segment)			6.8
$LSD_{(0.05)}$ (comparison among node segments for different annual-K rates)			7.4

Table 4. Soybean yield as affected by variety and annual-K fertilizer rate in the long-term K-fertilization trial conducted at the Pine Tree Research Station in 2012.

Annual-K rate	Variety		Variety average
	Armor-48-R40	Armor 53-R15	
(lb K_2O/acre/year)	(bu/acre)		
0	66	55	60
40	75	56	65
80	72	56	64
120	74	57	66
160	72	57	65
P-value (annual-K rate)	0.0665		
$LSD_{(0.10)}$ (annual-K rate)	3		

Corn Yield Response to Nitrogen Source and Time of Application

N.A. Slaton, T.L. Roberts, R.E. DeLong, C.G. Massey, M.R. Parvej, R.J. Dempsey, M.S. Fryer and S. Hayes

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Nitrification inhibitors like dicyandiamide (DCD) and nitrapyrin (sold as Instinct® or N-Serve®, Dow AgroSciences, Indianapolis, Ind.) have been thoroughly researched and used in specific corn (*Zea mays* L.) fertilization situations in the Corn Belt for several decades. Established nitrification inhibitors like DCD and N-Serve are seldom if ever used as crop nitrogen (N) management tools in the mid-South United States because their efficacy under warmer temperatures is usually regarded as low. Research has established that nitrification inhibitors behave differently among soils (Touchton et al., 1979). We have observed this variation in efficacy among Arkansas soils with DCD (Golden et al., 2009) and nitrapyrin (unpublished data). Walters and Malzer (1990) showed that a nitrification inhibitor could help reduce N loss and loss of corn grain yield from N deficiency when applied preplant to irrigated corn.

In Arkansas, N management on sandy soils and clayey soils can be challenging due to leaching, runoff, and/or denitrification. Government conservation programs sometimes offer incentives for growers to use urease and nitrification inhibitors that may help reduce N losses and hence theoretically improve air, soil, and water quality. Nitrogen management guidelines from universities in the mid-South generally lack information advocating for or warning against the use of nitrification inhibitors. Thus, mid-South corn growers are largely unable to take advantage of such incentives pertaining to the use of nitrification inhibitors since they are not university recommended N management tools. Our primary research objective was to determine whether corn grain yield benefits from the use of Instinct with UAN or urea applied preplant or sidedressed at the V4 stage. A secondary question that was addressed by the research treatments included examining whether preplant N is required to produce near maximum yields on a N-deficient soil.

PROCEDURES

Three research trials were established at the Rohwer Research Station on soils mapped as Sharkey and Desha clays or a Hebert silt loam. Composite soil samples were collected from the 0- to 6-inch soil depth at each site to characterize soil chemical properties (Table 1). Soil particle size analysis showed that the Sharkey/Desha clay soil contained 42% clay, 48% silt, and 10% sand and the Hebert series contained 9% clay, 58% silt, and 33% sand. Inorganic-N in the 0- to 6-inch soil depth was 10 ppm NH_4-N and 12 ppm NO_3-N for the Hebert silt loam and 4 ppm NH_4-N and 12 ppm NO_3-N for the Sharkey/Desha clay. The Hebert silt loam trial received 150 lb of muriate of potash after planting to ensure K was not yield limiting. All corn trials were established in plots that were 30-ft long and 4 rows wide and corn was planted on beds that were 38 inches apart. Corn was furrow-irrigated as needed during the growing season. Mycogen® hybrid 2V707 (Mycogen Seeds, Indianapolis, Ind.)was planted on 25 April in each trial with an intended population of 35,000 seed/acre. Details of the treatments used in each trial are given below.

The urea trial was conducted only on the clay soil and contained eight treatments including a 1) no-N control, 2 & 3) urea applied preplant at 220 and 260 lb N/acre, 4 & 5) Instinct-treated urea appled preplant at 220 and 260 lb N/acre, 6) urea applied preplant followed by urea applied at V4 at 260 lb N/acre, 7) urea applied preplant followed by Instinct-treated urea applied at V4 at 260 lb N/acre, and 8) Instinct-treated urea applied preplant followed by urea applied at V4 at 260 lb N/acre. All of the urea was also amended with the equivalent of 3 qt Agrotain® Ultra/acre (Koch Fertilizer LLC, Wichita, Kansas) to reduce NH_3 volatilization. Instinct was applied to urea at a rate equivalent to 35 oz/acre. When both Agrotain Ultra and Instinct were applied to the urea, the products were mixed and applied to the urea at the same time within 3 to 4 days before the fertilizer was applied. The preplant N was applied to established beds on 24 April and was shallowly incorporated by a second pass of the bedding implement before planting. The V4 sidedress applications were made on 25 May.

A total of 6.3 inches of rain were recorded between planting and the sidedress N application with an average daily temperature of 67 °F. Monthly rainfall was <2 inches in June (2.0 inches), July (1.9 inches), and August (1.7 inches). Rainfall occurred 4 days (1.2 inches) after the preplant N and 6 (0.6 inches) days after the V4 sidedress N applications were made.

The number of corn plants with harvestable ears from the two middle rows was counted after black layer formation and the harvested portion of each row was measured (e.g., stalks without ears were not included) before harvest with a plot combine. The weight and moisture of grain harvested from each plot was recorded and yields were adjusted to a uniform moisture of 15.5% for statistical analysis.

The urea experiment was a randomized complete block (RCB) design with each treatment represented in each of four blocks. The ANOVA was conducted by site with the GLM procedure in SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.). When appropriate, mean separations were performed using Fisher's Protected Least Significant Difference (LSD) method at a significance level of 0.10.

Trials with UAN (28%) were conducted on both the silt loam and clay soils. The clay soil trial contained nine treatments including a no-N control plus eight additional treatments that included all combinations of two N rates (220 or 260 lb N/acre), two application times (preplant or V4), and two N sources (UAN or Instinct-treated UAN). The UAN was applied with a CO_2 backpack sprayer equipped with stream nozzles that allowed the UAN to be applied to each side (shoulder) of the bed. The volume of UAN needed for each plot equivalent to the desired N rate was measured into 3-L bottles and amended with Agrotain Ultra (1.5 qt/ton UAN) to reduce NH_3 volatilization, and/or Instinct at a rate equivalent to 35 oz/acre on the same day as the N was applied. The preplant and V4 application dates were the same as previously listed for the urea trial.

The UAN trial established on the silt loam soil contained five treatments including the no-N control and two rates of preplant-applied UAN-N with or without Instinct. The preplant N rates were applied at 158 and 134 lb N/acre. Nitrogen management and Agrotain Ultra and Instinct were added and applied as described for the clay soil trial.

Chlorophyll meter (SPAD) readings were taken from each UAN trial on 11 and 25 June, which approximated the V9 and VT stages. For the V9 readings, measurements were taken near the middle of the uppermost leaf with a collar on six plants in the middle two rows of each plot and averaged for a single reading from each plot. At the VT stage, eight measurements were taken on the middle of the topmost ear leaf from eight plants in the two middle rows. The SPAD readings were then converted to relative SPAD readings by replicate by dividing each plot's average SPAD reading by the highest SPAD meter reading from that replicate (and multiplied by 100).

Data from the clay soil UAN trial were analyzed as a RCB having four blocks with a 2 × 2 × 2 factorial treatment structure. The silt loam trial data included only four preplant treatments, which were subjected to ANOVA as a RCB. The ANOVA was performed using the GLM procedure in SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.). In each trial the no-N control was excluded from the ANOVA. When appropriate, mean separations were performed using Fisher's Protected Least Significant Difference (LSD) method at a significance level of 0.10.

RESULTS AND DISCUSSION

Corn stand density averaged 32,908 plants/acre and was not affected by the main effects or the interaction among N-fertilizer treatments (Table 2). The N source by N rate by application time interaction had a significant effect on the relative SPAD meter reading at the V9 stage, but there was no consistent trend among the treatments and the main effects were not significant. In contrast, the main effect of N application time was significant (P = 0.0113) at the VT stage and showed that corn fertilized at the V4 stage (97%, $LSD_{0.10}$ = 2) had a greater relative SPAD than corn fertilized preplant (94%). None of the other model terms or interactions had significant effects on corn relative SPAD readings at VT (not shown). Corn grain yield was affected by the N source by rate interaction (P = 0.0747) and the main effect of N application time (P < 0.0001). Averaged across, N sources and rates, corn fertilized at V4 produced greater yields (228 bu/acre) than corn fertilized preplant (153 bu/acre). The 2-way N source by rate interaction showed that corn fertilized with 260 lb N/acre produced similar yields regardless of whether Instinct (203 bu/acre, $LSD_{0.10}$ = 12 bu/acre) was added to the UAN (201 bu/acre), but yields were always greater than corn fertilized with 220 lb N/acre. Corn receiving 220 lb N/acre as Instinct-treated UAN (188 bu/acre) produced a greater yield than corn receiving the same rate of UAN (172 bu/acre). Yield results suggest that corn grain yield was likely maximized by slightly less than 260 lb N/acre as yields were not different among 260 lb N/acre treatments. However, the 220 lb N/acre was likely below the optimal N rate and the yield difference suggests that the Instinct may have prevented some N loss. On the silt loam soil, the preplant N treatments had no significant effect on corn stand, relative SPAD reading, or grain yield (Table 3).

Among the most interesting results from the UAN trial conducted on the clay soil involved the corn yield produced when N was applied only at the V4 stage. The clay soil was very low in available N and produced corn plants that were very N deficient. Corn that received no N preplant was very N deficient by the V4 stage and the vegetative growth differences were large. Even after N was applied at the V4 stage, the biomass of corn fertilized only at V4 was visibly behind that of corn receiving N preplant for several weeks. Based on these observations, we doubted that corn receiving N only at V4 would produce equal yields as that receiving the same amount of N preplant. Despite the poor early season growth, corn receiving N only at V4 produced greater yields than corn receiving the same amount of N preplant. Although the preplant N obviously helped early season corn vigor, the preplant N is clearly taken up less efficiently than N that is applied at the V4 stage. These results suggest that the farmers could perhaps reduce the total N applied by limiting the amount of immediately available N applied preplant and applying a greater proportion of the total N following corn emergence. The early-season vigor imparted by preplant N is an important crop management consideration for increasing corn competitiveness with weeds, ensuring an adequate early season root system and hastening maturity for early harvest

On the clayey soil, urea-N treatments had no significant influence on corn stand, but did influence corn grain yield (Table 4). The highest yields were produced when 260 lb N/acre was applied in split applications. However, for reasons that are not clear, grain yields were not maximized when Instinct-treated urea applied preplant was followed by urea at the V4 stage. The total N rate (260 lb N/acre) applied preplant as urea or Instinct-treated urea produced lower yields than the two top-yielding split applications. The addition of Instinct to the preplant-applied urea rates had no significant benefit on corn yield. The benefit of preplant-applied urea-N was not visibly apparent in this trial until the late vegetative growth (V9 to V10) stage as the soil apparently had a significant amount of plant-available N.

PRACTICAL APPLICATION

Results of these trials do not provide clear evidence that the nitrification inhibitor marketed as Instinct consistently reduces N losses and increases N uptake by corn. However, the results did show some promise for Instinct to reduce N loss of UAN applied preplant on a clay soil. The consistency of these results can be verified only by establishing additional field trials and examining whether nitrification in this soil is inhibited by Instinct in laboratory trials. The UAN trial clearly showed that corn recovery of preplant-applied N is less efficient than that of N applied postemergence and that early-season, N deficiency of corn has minimal effect on corn yield provided N is applied on a timely basis following emergence. Additional research is required to develop a database regarding the benefits of Instinct and other legitimate nitrification inhibitors in corn N fertilization programs in the mid-South.

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Table 1. Selected soil chemical property means from 0- to 6-inch soil samples for N-fertilization trials conducted at the Rohwer Research Station during 2013.

Site	Soil OM[a]	Soil pH	Mehlich-3 soil nutrients								
			P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
	(%)		(ppm)								
Hebert	1.5	6.7	49	122	936	133	8	225	117	3.2	0.7
Sharkey/Desha	3.0	7.6	56	235	3276	749	7	324	99	2.4	2.4

[a] OM = organic matter.

Table 2. Stand density, relative SPAD (R-SPAD) meter readings at the V9 and VT corn growth stages, and corn yield means of each UAN-N fertilizer treatment involving Instinct applied preplant or the V4 stage to a clay soil at the Rohwer Research Station during 2013.

N source	N application time	N rate	Population	R-SPAD V9[a]	R-SPAD VT[a]	Grain yield
		(lb N/acre)	(plants/acre)	----(% of maximum	SPAD)---	(bu/acre)
No-N control[b]	None	0	31,339	53	73	45
UAN	Preplant	220	34,266	92	94	135
Instinct-treated UAN	Preplant	220	32,442	95	94	152
UAN	Preplant	260	33,154	94	95	163
Instinct-treated UAN	Preplant	260	32,535	97	95	160
UAN	V4 stage	220	31,088	97	97	210
Instinct-treated UAN	V4 stage	220	32,502	93	97	223
UAN	V4 stage	260	34,037	91	96	239
Instinct-treated UAN	V4 stage	260	32,790	97	97	235
		$LSD_{0.10}$	NS[c]	5	NS	NS
	Interaction *P*-value		0.2388	0.0960	0.9804	0.8052

[a] V9 and VT represent corn growth stages.
[b] The No-N control means are shown for reference only. The ANOVA compares only the treatments that received N.
[c] NS = not significant ($P > 0.10$).

Table 3. Stand density, relative SPAD (R-SPAD) meter readings at the V9 and VT corn growth stages, and corn yield as affected by UAN-N fertilizer treatments applied to a Hebert silt loam soil at the Rohwer Research Station during 2013.

N source	N appliication time	N rate	Population	R-SPAD V9[a]	R-SPAD VT[a]	Grain yield
			(Plants/acre)	-----(% of maximum	SPAD)----	(bu/acre)
No-N control[b]	None	0	33,435	76	73	125
UAN	Preplant	134	33,924	96	93	216
Instinct-treated UAN	Preplant	134	34,582	97	93	207
UAN	Preplant	158	33,623	99	94	216
Instinct-treated UAN	Preplant	158	35,065	98	94	231
		$LSD_{0.10}$	NS[c]	NS	NS	NS
		P-value	0.5754	0.3493	0.9402	0.3284

[a] V9 and VT represent corn growth stages.
[b] Values for the No-N control are listed for reference only as they were not included in the ANOVA. The ANOVA compares only the treatments that received N.
[c] NS = not significant ($P > 0.10$).

Table 4. Corn yield as affected by urea-N fertilizer treated with two rates of a nitrification inhibitor (Instinct-nitrapyrin) treatments applied to a clay soil at the Rohwer Research Station during 2013.

N source[a]	Total N rate	Preplant N rate	V4[b] N rate	Population	Grain yield
	-----------------------	(lb urea-N/acre)	---------------------	(plants/acre)	(bu/acre)
No-N control	0	0	0	32,290	45
Urea preplant	220	220	0	33,186	188
Instinct-treated urea preplant	220	220	0	33,322	186
Urea preplant	260	260	0	35,172	195
Instinct-treated urea preplant	260	260	0	33,255	207
Urea fb urea	260	130	130	34,807	243
Instinct-treated urea fb urea	260	130	130	33,959	212
Urea fb Instinct-treated urea	260	130	130	34,019	240
			$LSD_{0.10}$	NS	12
			P-value	0.3092	<0.0001

[a] Nitrogen treatments that were applied in split applications included the abbreviation ‘fb’ which stands for followed by.
[b] V4 represents corn growth stage.

Corn Yield Response to Nitrogen Source, Time of Application, and/or Placement

N.A. Slaton, T.L. Roberts, R.E. DeLong, C.G. Massey, M.R. Parvej, R.J. Dempsey, M.S. Fryer, J. Hedge, and S. Hayes

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Arkansas corn (*Zea mays* L.) growers typically apply nitrogen (N) fertilizer, as either urea ammonium nitrate (UAN) or urea in two or three split applications that include preplant and sidedressed N applications during early vegetative growth and near tasseling. Among these N application times, N applied preplant is taken up by corn with the lowest efficiency because it is applied weeks in advance of the time when corn needs N for rapid growth which allows more time for plant-available N to be lost via immobilization, leaching, denitrification, or runoff. Each year questions are asked whether preplant N and other fertilizer can be broadcast shortly before or after planting and needs to be incorporated or pulled in the bed. Blaylock and Cruse (1992) reported no difference in N recovery efficiency by corn of N that was broadcast, injected in the row, or injected between the rows in a ridge tillage system in Iowa. Mengel et al. (1982) showed that surface application of urea and UAN generally resulted in lower corn yields than subsurface injected UAN or NH_3 in no-tillage systems, which was attributed to NH_3 volatilization losses.

The relative efficiency of N in the different locations (e.g., bed or furrow) of a ridge tillage system is probably affected by rainfall or irrigation amount and frequency and soil N availability among other factors. Logic suggests that N fertilizer that remains in the furrow would be taken up later in the season and be subject to potentially greater losses via runoff and denitrification than N fertilizer that is pulled into the bed (removed from the furrow after broadcast application) or located on the top and shoulders of the bed. Likewise, N from a slow-release N fertilizer like ESN® (Environmentally Smart N, Agrium Advanced Technologies, Loveland, Colo.) would likely be more efficient than UAN or urea when located in the furrow. Our research objectives were to evaluate corn yield response to 1) a suboptimal N rate applied as either urea or ESN placed in the bed or furrow and 2) an N-fertilization strategy using suboptimal to near optimal rates of urea-N, ESN-N, or both.

PROCEDURES

Four research trials, two at each of two sites, were established at the Pine Tree Research Station (PTRS, Calloway silt loam) and the Rohwer Research Station (RRS, Sharkey and Desha clays). General agronomic information for each of the two sites is listed in Table 1. Both soils are classified as poorly drained. At least four composite soil samples were collected from the 0- to 6-inch soil depth at each site to characterize soil chemical properties (Table 2). At the RRS, soil particle size analysis was also determined and showed that the soil contained 42% clay, 48% silt, and 10% sand. At the PTRS, the trials received 150 lb of muriate of potash (preplant incorporated) and 150 lb triple superphosphate per acre (broadcast after planting). All corn trials were established in plots that were 30-ft long and 4 rows wide and corn was planted on beds. The row width was 30 inches at the PTRS and 38 inches at the RRS. Corn was furrow-irrigated as needed during the growing season.

Nitrogen Placement Trial

To compare corn grain yield as affected by N source and preplant N placement, urea (46% N) and ESN (44%) were hand applied immediately before or after planting at a rate of 100 lb N/acre. Each fertilizer source was hand applied so that the fertilizer was applied either into the furrow or distributed across the top of the bed. All urea was treated with Agrotain® Ultra (26% NBPT; Koch Fertilizer LLC, Wichita, Kansas) at a rate of 3 qt/ton urea to reduce NH_3 volatilization loss. At each site, the trial contained a total of seven treatments including the four treatments described previously plus a no-N control, 100 lb Agrotain-treated urea-N/acre broadcast applied at the V4 stage, and a high-yield standard treatment. The high-yield standard included ESN applied preplant at 100 (PTRS) or 140 (RRS) lb N/acre, 65 (PTRS) or 85 (RRS) lb Agrotain-treated urea/acre applied at V4 stage, and 45 lb Agrotain-treated urea/acre applied as a pretassel so that the total N rate was 210 lb N/acre for the PTRS and 270 lb N/acre for RRS. All preplant N fertilizer treatments, except the in-furrow applied ESN and urea, were applied and incorporated by a final pass with the bedding implement. Nitrogen fertilizer placed in the furrow was applied after the final pass with the bedding implement. Preplant N was applied and corn was planted on 23 April at the PTRS and 25 April at the RRS, V4 N-treatments were applied on 24 (PTRS) or 25 (RRS) May and pretassel N was applied 24 (PTRS) or 25 June (RRS). The number of corn plants with harvestable ears from the two middle rows was counted after black layer (e.g., stalks without ears were not included). At the PTRS, corn was hand harvested soon after black layer formation and allowed to dry before shelling. At the RRS, corn was harvested by combine. The weight and moisture of grain harvested from each plot was recorded and yields were adjusted to a uniform moisture of 15.5% for statistical analysis.

The experiment was a randomized complete block design with a factorial arrangement of N sources (ESN and urea) and fertilizer placement (furrow or bed) within each of four blocks. The no-N control, 100 lb urea-N/acre applied at V4, and the high N standard treatments were not included in the statistical analysis. The ANOVA was conducted by site with the MIXED procedure in SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.) with N source and placement treated as fixed variables. When appropriate, mean separations were performed using Fisher's Protected Least Significant Difference (LSD) method at a significance level of 0.10.

Nitrogen Fertilization Strategy

Each N fertilization strategy trial contained seven treatments including a no-N control and six treatments involving three total N rates of ESN applied preplant followed by (fb) urea sidedressed at the V4 stage (ESN fb urea) or urea applied preplant followed by urea sidedressed at the V4 stage (urea fb urea). The N rates were 90, 150, and 210 lb N/acre at the PTRS and 140, 210, and 255 or 280 lb N/acre at the RRS. The N rate and source applied at each time are outlined in Table 3. A calculation error resulted in unequal N rates for the greatest N rate at RRS. The strategies used differed slightly between the two sites. For the silt loam soil at the PTRS, the preplant urea-N rate was held constant at 45 lb N/acre and the rates applied at V4 or pretassel were varied; but for ESN, the preplant N rate applied varied, the V4 stage N rate was held constant at 70 lb N/acre, and the highest N rate also received 45 lb N/acre pretassel. At the RRS, on the clay soil, the preplant N rate was held constant at 140 lb ESN-N or 70 lb urea-N/acre and the rates applied at V4 or pretassel timings varied. The number of stalks with harvestable ears and harvest were performed as described previously.

The experiment was a randomized complete block design with a factorial arrangement of N sources and N rate within each of four blocks. The ANOVA was conducted by site with the MIXED procedure in SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.) where N source and rate were treated as fixed variables. When appropriate, mean separations were performed using Fisher's Protected Least Significant Difference (LSD) method at a significance level of 0.10.

RESULTS AND DISCUSSION

A total of 6.3 inches of rain were recorded at the RRS between planting and the sidedress N application in late May with an average daily temperature of 67 °F. Less than 2 inches of rainfall were recorded at the RRS in each of the months of June (2.0 inches), July (1.9 inches), and August (1.7 inches). At the PTRS, 7.5 inches of rainfall were received between planting and the V4 sidedress application with another 5.7 inches in June, 5.4 inches in July, and 2.3 inches in August. Rainfall occurred within 1 (PTRS, 0.3 inches) or 4 days (RRS, 1.2 inches) after the preplant N applications were made at each site. Likewise, 6 (RRS, 0.6 inches) or 8 days (PTRS, 1.3 inches) passed before rainfall occurred following the V4 sidedress N applications. Based on the rainfall data, soil conditions at both sites were moist and conducive for nitrification and potential denitrification on these poorly drained soils.

Nitrogen Placement

Application of 100 lb urea-N/acre at both sites produced yields that were numerically less than the yield produced by the high N standard 210 lb N/acre indicating that differences in N-fertilizer uptake efficiency by corn could potentially be identified (Table 4). Nitrogen fertilization had no significant effect on the number of ear-bearing stalks at the PTRS. The interaction between N placement (bed or furrow) and source (ESN or urea) did not significantly influence corn yield at PTRS or RRS, but one or both of the main effects were significant at each site. At the PTRS, only N placement, averaged across N sources, was significant with corn receiving preplant-applied N (100 lb N/acre) placed in the bed yielding 156 bu/acre ($LSD_{0.10}$ = 10) compared to 143 bu/acre when preplant-applied N was placed in the furrow. Although not significant, ESN (153 bu/acre) produced numerically higher yields than urea (146 bu/acre), averaged across N placements.

At the RRS, the number of ear-bearing stalks at maturity was significantly affected by N-fertilizer source. Averaged across N placement treatments, corn fertilized with ESN (38,048 plants/acre, $LSD_{0.10}$ = 3,104) had more ear-bearing plants than corn that received urea (34,345 plants/acre). Both of the main effects significantly influenced corn yield. Corn fertilized with preplant-applied ESN (104 bu/acre, $LSD_{0.10}$ = 8) produced greater yields than preplant-applied urea (70 bu/acre), averaged across N placement, and corn that received N placed on the bed (104 bu/acre, $LSD_{0.10}$ = 8) yielded more than when fertilizer was placed in the furrow (70 bu/acre). Although the grain yield of corn fertilized with urea sidedressed at the V4 stage was not included in the statistical analysis, the numerical results from both locations hint that ESN pulled into the bed at planting was taken up as efficiently as urea sidedressed at V4.

Results from the N source and placement trial suggest that N fertilizer source and placement can both influence whether stalks produce harvestable ears and perhaps plant vigor during the season with the most pronounced effect occurring on the clayey soil. The results also show that N fertilizer applied preplant, regardless of the source, should not be left in the furrow, but be incorporated into the bed before planting.

Fertilization Strategy

Corn plants with harvestable ears were not affected by the interaction between N source and rate at either site (Table 5).

The main effects had no influence on ear-bearing stalks at the PTRS. At the RRS, the population of ear-bearing stalks receiving 210 lb N/acre was greater than that of corn fertilized with 140 or 280 lb N/acre which had similar populations. For grain yield, the interaction between N source and rate was not significant at either site, but each of the main effects was either significant or nearly significant at both sites (Table 5). At PTRS, corn yields were equal between fertilization programs that used urea or ESN, which were greater than the yield of corn receiving no N. Averaged across N rates, corn fertilized with ESN (preplant) followed by urea (V4 sidedress) produced slightly greater yields (179 bu/acre) compared to the program that used urea for both the preplant andV4 sidedress applications (168 bu/acre). At the RRS, the urea program (210 bu/acre) produced numerically, but not statistically higher yields than the ESN program (204 bu/acre). It should be noted that due to a calculation error, the total N rate for the highest N rate for the ESN-urea treatment was 35 lb N/acre less than that of the the urea N source (Table 3), but the grain yields were very close (Table 5). At each location, corn was highly responsive to N as corn grain yields increased with each incremental increase in N rate. The amount of urea applied preplant was limited to a maximum of 45 lb urea-N/acre; whereas a much larger proportion of the season total N rate was applied preplant in the programs that used ESN. We expected there to be little or no yield difference between the N sources and splits used in this trial.

PRACTICAL APPLICATIONS

The results of this study show that preplant N, regardless of the urea-N source, should be pulled into the bed (or removed from the furrow) to enhance its availability and uptake by corn. Determining the reason why corn fertilized with urea-N placed directly in the furrow produced lower yields than urea-N placed in the bed was beyond the scope of this study. However, we rationalize that N left in the furrow will require a much greater time before root interception and is more likely to runoff or be subject to denitrification since the furrow (e.g., following rainfall or irrigation) will have greater moisture content and remain wet longer than the soil in the bed. Thus, farmers should either inject the preplant N into the shoulder of the bed or reform the beds following preplant N application. Applying a urease inhibitor such as NBPT (i.e., rather than incorporating the urea) to urea and leaving the urea on the surface of the furrow does not appear to be a good management practice as N loss mechanisms other than NH_3 volatilization cause N loss. Also, the polymer-coated urea marketed as ESN shows promise to produce equal yields as urea when applied preplant. Sufficient research with positive findings has been performed in Arkansas and other surrounding mid-South states to make a recommendation for farmers to incorporate ESN into their N-fertilization programs, especially in areas where farmers want to apply more than 20% to 25% of the season total N requirement preplant.

ACKNOWLEDGMENTS

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Table 1. Selected soil and agronomic management information for N fertilization trials conducted in 2013 at the Pine Tree Research Station (PTRS) and Rohwer Research Station (RRS).

Site	Soil series	Hybrid[a]	Previous crop	Row width	Plant date
				(inches)	(day/month)
PTRS	Calloway	My-2V707	Soybean	30	23 April
RRS-1[b]	Sharkey/Desha	P-1319HR	Soybean	38	25 April
RRS-2[b]	Sharkey/Desha	P-2088YHR	Soybean	38	25 April

[a] Hybrid abbreviations: My = Mycogen and P = Pioneer. At the RRS, Pioneer 1319HR was planted in the N Strategy trial and P2088YHR was planted in the N location trial.

[b] RRS-1 represents the N fertilization strategy trial and RRS-2 represents the N location trial.

Table 2. Selected soil chemical property means from a 0- to 6-inch soil sample of the soils present in the N fertilization trial located at the Pine Tree (PTRS) and Rohwer (RRS) Research Stations in 2013.

Site	Soil OM[a]	Soil pH	Mehlich-3 soil nutrients P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
	(%)		---(ppm)								
PTRS	2.5	6.9	15	116	1406	267	9	202	339	0.9	0.9
Rohwer	3.0	7.6	56	235	3276	749	7	324	99	2.4	2.4

[a] OM = organic matter.

Table 3. The N source, rate, and application date for the N fertilization trials conducted at the Pine Tree (PTRS) and Rohwer (RRS) Research Stations in 2013.

	Pine Tree Research Station				Rohwer Research Station			
N source	N rate	Preplant[a]	V4[b]	Pretassel[c]	N rate	Preplant[a]	V4[b]	Pretassel[c]
	--- (lb N/acre) ---							
ESN fb urea	90	90	--	--	140	140	--	--
ESN fb urea	150	150	--	--	210	140	70	--
ESN fb urea	210	165	0	45	255	140	70	45
Urea fb urea	90	45	45	--	140	70	70	--
Urea fb urea	150	45	105	--	210	70	140	--
Urea fb urea	210	45	120	45	280	70	165	45

[a] Preplant N applications were made on 23 April at the PTRS or 24 April at the RRS.
[b] V4 sidedress N applications were made on 24 May at the PTRS or 25 May at the RRS.
[c] Pretassel N applications were made on 25 June at both sites.

Table 4. Corn grain yield and ear-bearing stalk population means for each combination of urea source and preplant N placement treatments at the Pine Tree (PTRS) and Rohwer (RRS) Research Stations in 2013.

		Pine Tree Station		Rohwer Research Station	
N source	N placement	Plant population	Grain yield	Plant population	Grain yield
		(plants/acre)	(bu/acre)	(plants/acre)	(bu/acre)
None[a]	--	23,522	58	32,391	24
Urea-V4[a]	Broadcast	31,363	164	39,092	131
High standard[a]	Broadcast	31,363	222	39,316	244
Urea-PP[b]	Bed	29,621	151	36,153	85
Urea-PP	Furrow	30,056	141	32,537	56
ESN-PP	Bed	28,641	160	38,796	123
ESN-PP	Furrow	28,967	145	37,299	85
	$LSD_{(0.10)}$	NS[c]	NS	NS	NS
P-value	N source	0.5165	0.2718	0.0541	<0.0001
	N location	0.8091	0.0565	0.1607	<0.0001
	Interaction	0.9724	0.7065	0.5422	0.3512

[a] Yield and plant population values are shown for numerical comparison as these treatments were not included in the ANOVA.
[b] PP = preplant.
[c] NS = not significant (> 0.10).

Table 5. Corn grain yield and ear-bearing stalk population means for each combination of N rate and N source treatments for two trials evaluating N-fertilization strategy at the Pine Tree (PTRS) and Rohwer (RRS) Research Stations in 2013.

	Pine Tree Research Station			Rowher Research Station		
N source	N Rate	Plant population	Grain yield	N Rate	Plant population	Grain yield
	(lb N/acre)	(plants/acre)	(bu/acre)	(lb N/acre)	(plants/acre)	(bu/acre)
None[a]	0	25,918	60	0	43,897	30
Urea fb urea[b]	90	27,987	126	140	42,644	158
ESN fb urea	90	30,383	134	140	41,145	155
Urea fb urea	150	29,512	171	210	45,088	231
ESN fb urea	150	30,819	190	210	43,895	221
Urea fb urea	210	31,363	208	280	41,113	240
ESN fb urea	210	30,601	210	255	40,952	235
	$LSD_{(0.10)}$	NS[c]	NS		NS	NS
P-value	N source	0.5311	0.0633	--	0.2362	0.1341
	N rate	0.6387	<0.0001	--	0.0244	<0.0001
	Interaction	0.6987	0.5918	--	0.9605	0.7759

[a] The no N control was not included in the ANOVA and results are shown only as a reference value.
[b] The N sources applied were either preplant urea followed by V4-applied urea (Urea fb urea) or preplant-applied ESN followed by V4-applied urea (ESN fb urea) as detailed in Table 3.
[c] NS = not significant (> 0.10).

Corn Yield Response to Nitrogen Fertilization Strategies With and Without a Pretassel Nitrogen Application

N.A. Slaton, T.L. Roberts, R.E. DeLong, C.G. Massey, M.R. Parvej, R.J. Dempsey, M.S. Fryer, and S. Hayes

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Application of nitrogen (N) fertilizer in multiple splits is typically more efficient than a large, single rate of N applied preplant because it takes advantage of the existing plant root system and minimizes the time between N application and plant uptake. Multiple split applications also spread the risk associated with N loss created by adverse environmental conditions that can result in rapid N losses. Many Arkansas and other mid-South corn (*Zea mays* L.) growers have adopted the practice of applying a small portion of their season-total N rate near (e.g., before) the time that the corn plant reaches the VT stage which is known as the pretassel N application. Based on the typical N rate recommended for silt loam and clayey soils recommended by the University of Arkansas System Division of Agriculture's Cooperative Extension Service, the pretassel N application represents 15% to 25% of the total N applied to corn. The remainder of the N is split between preplant and early vegetative growth stages. Research results supporting the use of this practice in Arkansas have not been published.

Sripada et al. (2005) showed that corn receiving insufficient early-season N rates responded positively to N applied at VT. They also showed that corn yield could not be maximized on a N-deficient soil from N applied only at VT. In other words, corn yields were consistently greater when the same N rate was applied at planting compared to VT. Their results also showed that corn yields were not enhanced by the combination of N applied at planting and at VT. Maintaining a supply of adequate N through the reproductive growth phase to ensure that the yield components of corn are maximized and ears fill out completely is one reason that is often cited in support of a midseason N application made shortly before tasseling or silking. Bender et al. (2013) showed that by the VT stage, corn has taken up about two-thirds of its total N suggesting that the midseason N application may have potential for increasing corn yield in some situations. The objective of this research was to evaluate the potential benefit of applying a portion of the season-total N rate in the weeks before tasseling.

PROCEDURES

Two separate research trials were established adjacent to each other at the Rohwer Research Station on soils mapped as Sharkey and Desha clays. The treatments in each trial were identical and differed only in the hybrid that was seeded. Pioneer hybrids 1319HR and 2088YHR were seeded at rates targeted at 35,000 plants/acre on 25 April. Four composite soil samples were collected from the 0- to 6-inch soil depth from the entire field to characterize soil chemical properties. The soil contained 42% clay, 48% silt, and 10% sand. No phosphorus (P) or potassium (K) were applied to this soil as it contained Optimal or Above Optimal levels of P (56 ppm) and K (235 ppm) and a pH of 7.6. All corn trials were established in plots that were 30-ft long and 4 rows wide and corn was planted on 38-inch wide beds. Corn was furrow-irrigated and pest control was performed as needed during the growing season.

Nitrogen was applied at two rates, 230 and 300 lb N/acre, with the total N rate being divided between preplant, V4 stage, and pretassel N application times. Nitrogen fertilizer was applied preplant on 24 April, V4 sidedress on 25 May, and the pretassel N applications were made on 11 June [14 days before silking (DBS)] or 25 June (2 DBS). The dates of the pretassel N applications were estimated by Pioneer based on geographic location and the number of accumulated growing degree units required for each variety to reach silking (1400 to 1450).

After black layer (22 August), five ears from each of the two middle rows were collected and placed in a labeled bag. The weight of all ten ears was recorded and the number of corn rows and rings on five randomly selected ears was counted. Five of the ten ears were selected and the number of kernel rows and rings was counted and averaged to obtain a single value for each plot. The two center rows of each hybrid were harvested either by hand (P1319HR) or by combine (P2088YHR). The number of stalks with harvestable ears was determined after black layer.

The experiment was a randomized complete block design with a factorial arrangement of pretassel N application time and total N rate within each of four blocks. The ANOVA was conducted by site with the GLM procedure in SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.). When appropriate, mean separations were performed using Fisher's Protected Least Significant Difference (LSD) method at a significance level of 0.10.

RESULTS AND DISCUSSION

The harvested plant population was not significantly affected by N management treatments (Table 1). Only N rate influenced grain moisture content of Pioneer 1319HR and grain yield of both hybrids. For hybrid 1319HR, the moisture content of corn fertilized with 230 lb N/acre, averaged across pretassel treatments, was 20.8% compared to 21.4% for corn fertilized with 300 lb N/acre. Note that the moisture content of hybrid 1319HR was measured following hand harvest and the ear corn was placed in a greenhouse to dry for 6 days before it was shelled. Averaged across the three pretassel N application strategies, application of 300 lb N/acre increased the yield of corn hybrid 1319HR by 25 bu/acre and 2088YHR by 30 bu/acre above the yield produced by corn fertilized with 230 lb N/acre.

Examination of the 10-ear weight and the numbers of rings and rows from five ears showed there were no significant differences for hybrid1319HR; but for hybrid 2088YHR, N rate significantly affected all three parameters and the N rate by pretassel N strategy interaction had a significant effect on the number of kernel rings (Table 2). Application of 300 lb N/acre increased the 10-ear weight from 4.6 to 5.2 pounds and the number of kernel rows from 13.5 to 14.0 rows compared to the 230 lb N/acre rate, averaged across pretassel N strategies. The interaction showed no general trend among pretassel N strategies; but, on average, corn receiving the greater N rate averaged 41.5 rings compared to 40 rings for the lower N rate.

PRACTICAL APPLICATIONS

The pretassel-N application has been incorporated into N-fertilization programs by growers in Arkansas. The origin and reasons why this general N application time is routinely used and how the N application is timed are not well documented. Some growers are likely applying the 40 to 50 lb N/acre as an 'insurance' application of N, which is not included in their season-total N rate plan, especially when they feel that some of the early applied N has been lost from unfavorable environmental conditions. Other growers may be including the pretassel N application in their N-management plan and season-total N rate. The results of research conducted at a single clay-soil site in 2013 with two Pioneer hybrids showed that corn grain yield was the same among three different pretassel N-fertilization strategies, of which two included a pretassel N application, so long as the total amount of applied N was the same among fertilization strategies.

Based on this research, inclusion of a pretassel N application is a valid approach to N management on a clay soil so long as it is included in the season-total N rate. Other research has shown that plant uptake of N that is applied pretassel is taken up very efficiently by corn (Roberts, unpublished data, 2013). To our knowledge, there is no published research that shows a consistent yield advantage to a pretassel applied N program compared to other well-managed, N-application strategies that use the same total N rate. Additional research is needed to verify that the overall conclusion made from these trials with two different hybrids is consistent across sites, soils, and hybrids.

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Table 1. The effect of season-total N rate and pretassel N application strategy on corn grain yield and harvest population (ear-bearing stalks) for trials conducted with two Pioneer corn hybrids at the Rohwer Research Station on a Sharkey/Desha clay soil in 2013.

	N rate at each application time			Pretassel	P1319HR			P2088YHR		
N rate	Preplant	V4[a] stage	Pretassel	time[b]	Population	Moisture	Yield	Population	Moisture	Yield
	---------(lb urea-N/acre)-----------				(#/acre)	(%)	(bu/acre)	(#/acre)	(%)	(bu/acre)
230	90	90	50	14 DBS	33,005	21.3	222	35,594	16.0	242
230	90	90	50	2 DBS	33,302	20.5	239	33,212	13.1	244
230	90	140	0	None	34,239	20.8	236	33,863	15.5	252
300	90	160	50	14 DBS	34,430	21.3	253	33,117	13.8	265
300	90	160	50	2 DBS	34,303	21.5	253	33,919	13.6	288
300	90	210	0	None	34,391	21.4	266	35,089	16.2	276
				$LSD_{0.10}$	NS[c]	NS	NS	NS	NS	NS
				N rate	0.4412	0.0585	0.0007	0.8205	0.7955	0.0024
				N time	0.8855	0.6772	0.1588	0.6009	0.3574	0.4278
				Interaction	0.8817	0.3547	0.4226	0.1493	0.6541	0.4940

[a] V4 represents corn growth stage.
[b] DBS = days before silking as predicted by Pioneer Hybrid Growing Degree Day Calculator.
[c] NS = not significant.

Table 2. The effect of season-total N rate and pretassel N application strategy on the weight of 10 randomly selected corn ears and the number of kernel rows and rings for trials conducted with two Pioneer corn hybrids at the Rohwer Research Station on a Sharkey/Desha clay soil in 2013.

	N rate at each application time			Pretassel	P1319HR			P2088YHR		
N rate	Preplant	V4[a] stage	Pretassel	time[b]	10-ear wt.	Rings	Rows	10-ear wt.	Rings	Rows
	---------(lb urea-N/acre)-----------				(grams)	------- (#)---------		(grams)	-------- (#)---------	
230	90	90	50	14 DBS	1,895	38.8	14.0	2,026	39.5	14.0
230	90	90	50	2 DBS	2,038	39.0	14.3	2,034	38.8	14.0
230	90	140	0	None	2,045	41.5	13.8	2,221	41.8	14.3
300	90	160	50	14 DBS	2,043	38.5	14.0	2,277	40.5	13.8
300	90	160	50	2 DBS	2,182	40.0	14.3	2,435	43.5	13.5
300	90	210	0	None	2,043	38.5	13.8	2,349	40.5	13.5
				$LSD_{0.10}$	NS[c]	NS	NS	NS	1.9	NS
				N rate	0.2262	0.7318	1.000	0.0002	0.0276	0.0825
				N time	0.3413	0.2610	0.4893	0.1476	0.2576	0.9089
				Interaction	0.6403	0.5151	1.000	0.1397	0.0041	0.7535

[a] V4 represents corn growth stage.
[b] DBS = days before silking as predicted by Pioneer Hybrid Growing Degree Day Calculator.
[c] NS = not significant.

Nitrogen Rate Recommendations for Corn Grown on Clayey and Loamy Soils

N.A. Slaton, M. Mozaffari, L. Espinoza, T.L. Roberts, R.J. Norman, and J.R. Kelley

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Corn (*Zea mays* L.) receives the largest nitrogen (N) rate recommendation of any crop grown in Arkansas, with N rates ranging from 255 to 330 lb N/acre for high-yielding corn depending on soil texture. Prior to 2006, the N-fertilizer rate recommendations were based on Arkansas specific research that was summarized by Muir et al. (1992). Muir et al. (1992) showed the N requirement for corn was 250 to 300 lb N/acre on silty clay soils, 175 to 225 lb N/acre on alluvial silt loams, and 125 to 175 lb N/acre for loessial silt loams and reflected that approximately 2.0, 1.0, and 1.0 lb of fertilizer N were needed to produce one bushel of corn grain, respectively. Corn N rate recommendations were adjusted in 2006 using nine site-years of research conducted on silt loams between 1997 and 2004 and six site-years of research on clayey soils performed between 1990 and 2004 with N rate recommendations based on estimates of the amount of fertilizer N needed to produce one bushel of corn.

Since 2006, increased funding available for corn research has allowed a significant number of N rate calibration trials to be conducted to verify or refine N rate recommendations. Results from these trials have been published in the University of Arkansas System Division of Agriculture Agricultural Experiment Station reports (Mozaffari et al., 2005, 2006, 2007), made available from brief research reports in annual summaries made to the Arkansas Corn and Grain Sorghum Research and Promotion Board, or shared informally among university personnel. The objectives of this report are to summarize the available N-rate calibration research conducted with corn and document the process that was undertaken to update N rate recommendations for irrigated corn production in Arkansas. The overall goal of this effort was to provide Arkansas corn growers the most up-to-date N management guidelines for corn.

PROCEDURES

Information used to develop updated N rate recommendations for irrigated corn was published by Mozaffari et al. (2005, 2006, 2007) or provided by the individual researchers (Mozaffari, unpublished data, 2007-2008; Espinoza, unpublished data, 2007-2012). To be included in the summary, the research had to include a no-N control, four or more N rates, and the greatest N rate had to be at least 250 lb N/acre. The full database of research included a total of 72 site-years of research performed since 2004 of which 43 were on loamy-textured soils (silt and sandy loams) and 29 were on clayey-textured soils. Research trials were conducted in commercial production fields and agricultural experiment station research fields. The full database was not used in the process described in this report. Site-years were included or excluded based on their maximum yields and the yield response. Only site-years that had maximum corn yields ≥150 bu/acre were included in the loamy-soil summary since maximum yields <150 bu/acre suggest that factors besides N were likely limiting corn yield. For the clayey soils, analysis was performed with and without sites that had maximum yields <150 bu/acre. Second, all site-years were categorized by their responsiveness to N fertilization as indicated by the relative yield of corn receiving no N. The yield responsiveness to N of each site-year was categorized using the percent relative yield of corn receiving no N as high response (1% to 25%), moderate response (26% to 50%), low response (51% to 75%), and no response (76% to 100%). Relative yield was calculated for each site-year by dividing the mean grain yield of each N rate by the greatest overall mean yield produced in the trial multiplied by 100. Site-years that were categorized as having high, moderate, or low responses to N (≤75% of maximum yield) were used in the regression analyses. The final datasets included 20 loamy-soil, site-years with a total of 133 yield means with low and medium relative yields; 13 site-years having a total of 79 yield means from loamy-soil, site-years that produced high relative yields; and 28 site-years having 219 yield means from clayey-textured soils.

Selected details of the loamy and clayey soil trials are summarized in Tables 1 thru 4. Soil chemical properties that included inorganic soil N and organic matter content were not available for all trials and are not presented in this summary. The assumptions of this analysis include 1) all nutrients besides N were provided in sufficient amounts and were not yield limiting, 2) the most common soils on which corn is grown in Arkansas are represented by the sites, 3) the methods, times, and sources of N application were managed appropriately, 4) that agronomic management practices including pest control, stand density, irrigation, etc., were near optimal, performed using recommended practices, and were not yield limiting, and 5) that corn grown on loamy- and clayey-textured soils responds differently to N-fertilizer rate requiring that recommendations be developed for each soil-texture group.

The grain yield means and total applied N rates were assembled into a database and used to calculate relative grain yield for each site-year of research. For each soil textural class, the site-year mean relative yields were regressed against N rate allowing for both the linear and quadratic functions of N rate. Regression analysis was performed by soil textural classification (loamy or clayey soils) and, when of interest, by yield responsiveness to N fertilization. Potential outlying relative yield means were identified as having studentized residual values ≥±3.0 and were subsequently omitted from the analysis and the model was rerun until the final model was achieved. Three means were omitted from the loamy-soil analysis and one mean was omitted from the clayey-soil analysis.

The recommended N rate for high-yielding, irrigated corn was based on the maximum predicted relative yield minus 2.5% and will be referred to as the N rate needed to produce near maximal relative yield (NMRY). A second N recommendation for a lower yield potential was established as the N rate predicted to produce maximum relative yield minus 10%. The amount of N needed to produce one bushel of corn for the N rate that produced maximum (100%) relative grain yield was also evaluated by dividing the total N rate by the corn yield in bu/acre.

RESULTS AND DISCUSSION

Loamy Soils

The range of actual yields of corn receiving no N and the maximum yields produced from each of the loamy-soil, site-years are summarized in Table 1. Only 16% of all the loamy-soil, site-years produced maximum yields <150 bu/acre and were excluded from the loamy-soil analysis (data not shown). The average yield of corn receiving no N on loamy soils classified as having high, moderate, or low yield responses to N fertilization averaged 36, 76, and 119 bu/acre, respectively. Despite the differences in yield potential in the absence of N fertilization, the average maximum yields produced by corn responding to N fertilization were 203 (standard deviation = 38) bu/acre for highly responsive soils, 204 (standard deviation = 32) bu/acre for moderately responsive soils, and 195 (standard deviation = 26) bu/acre for low responsive soils suggesting that maximum yield potential is not necessarily associated with native soil N availability.

Regression analysis within each N response classification for loamy-textured soils showed that the amount of N required to produce NMRY declined as the relative yield potential of the soil in the absence of N fertilization increased (Table 5, Fig. 1). Soils that had a low yield response to N produced high relative yields (51% to 75% relative yield, average 119 bu/acre) when no N was applied and required, on average, 178 lb N/ acre to produce NMRY compared to 242 lb N/acre on soils that were highly responsive to N (≤25% relative yield, average 36 bu/acre). When the N response categories were combined, the NMRY N rate was 204 or 214 lb N/acre depending on whether site-years with low, moderate, and high responses to N or only sites with high and moderate responses to N, respectively, were included.

The N rate that produced the maximum, actual corn grain yield (100% RY) was divided by the maximum yield (bu/acre) to estimate the pounds N needed to produce each bushel of corn. For the loamy-textured soils, the 33 site-years ranged from 0.81 to 1.99 lb N/ bushel corn and averaged 1.36 lb N/bu corn (standard deviation = 0.32). Regressing maximum actual corn yield against the pounds of N required to produce 100% relative yield showed a negative linear relationship indicating that as maximum yield declined, more N was needed to produce maximum yield (Fig. 2). This relationship suggests sites that produced low to moderate corn grain yields require more actual N than sites that produced high grain yield presumably because of poor N uptake efficiency.

Clayey Soils

Of the 29 total clayey-soil site-years, in the full dataset, one site (not shown) was eliminated because it failed to respond to N applied directly to the corn (Mozaffari et al., 2006). Among the remaining 28 sites, the response of corn to N was high (≤25% of max yield by the no-N control, 24 site-years) or moderate (26% to 50% of max yield by the no-N control, 4 site-years) and the overall mean yield of corn receiving no N averaged only 26 (standard deviation = 14) bu/acre indicating low N availability on clayey soils. However, the overall yield potential of corn grown on the clayey soils was excellent, and comparable to corn grown on the loamy soils, with only 13.8% (4 site-years) of the site-years having maximum yields <150 bu/acre, 27.9% producing between 150 and 200 bu/acre, and 48.3% producing maximum yields >200 bu/acre. The overall, average maximum yield of corn grown on the clayey soils was 197 (standard deviation = 41) bu/acre. Regression analyses were conducted with and without the four low-yielding sites to determine whether they had a significant influence on the resultant N recommendations.

The N rate required to produce NMRY was not greatly affected by the inclusion or exclusion of the four low-yield potential site-years (Table 5, Fig. 1). The predicted N rate needed to produce NMRY ranged from 289 to 292 lb N/acre. Similar to the loamy-textured soils, the relationship between yield and the pounds of N needed to produce each bushel of corn was linear and negative (Fig. 2). The clayey-textured, site-years required from 1.21 to 2.26 lb N/bushel of corn grain with an average of 1.64 lb N/bushel of corn (standard deviation = 0.35).

PRACTICAL APPLICATION

The new recommended N rates for irrigated, high-yielding corn were set at 220 lb N/acre for loamy soils and 290 lb N/acre for clayey soils (Table 6). New N rate recommendations were also established for corn having lower yield potential with N rates of 160 lb N/acre for loamy soils and 230 lb N/acre for clayey soils. The N rates for lower yielding corn were established using the same regression equations listed in Table 5, but at maximum relative yield minus 10.0% rather than minus 2.5% for the NMRY. The previous recommendations included four corn yield goals of which two were eliminated because the results examining the pounds of N required to produce one bushel of corn at maximum yield indicated that other factors in addition to N rate influence corn yield. The results indicated the factors that influence N-fertilizer uptake efficiency contribute significantly to the magnitude of corn yield response to N. Therefore, the emphasis of N management should be on the use of efficient methods of applying the proper N rate. In some years, the weather or environmental conditions will dictate how N is managed and corn responds to N. The new recommendations described above were delineated in the spring of 2013 and included in corn N management guidelines provided on soil test reports. Nitrogen management of the 2013 corn crop was likely performed with the previous recommendations and the new N recommendations described in this report will be implemented or considered by farmers for the 2014 crop.

Regression analysis of the loamy-soil, site-years showed that the N rate maximizing corn grain yield declined as the relative yield of corn receiving no N increased (or yield responsiveness to N decreased). These results clearly indicate the need for an accurate method to estimate soil N availability for corn. Research investigating the potential of a soil N test to accurately predict the N needs for corn and efficient methods and sources of N fertilization should be the focus of corn N research in Arkansas.

ACKNOWLEDGMENTS

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Table 1. Characterization of corn grain yield ranges from 43 site-years of N rate research with corn conducted on loamy soils since 2004.

	Relative yield response of corn fertilized with no-N[a]				
Maximum yield	High (≤25%)	Moderate (26%-50%)	Low (51%-75%)	None (≥76%)[b]	Summary
(bu/acre)	[% of total loamy-soil, site-years (43)]				
<150[b]	9.1	2.3	4.5	0.0	16
150-200	4.5	13.6	18.2	4.5	41
≤201	6.8	22.7	9.1	4.5	43
Summary	20.0	39.0	32.0	9.0	--

[a] Underneath each yield response to N category name is the percent relative yield range that corn receiving no N produced compared to the maximum yield in each trial.

[b] Only site-years that produced ≥150 bu/acre and responded to N fertilizer were used to develop N rate recommendations for corn grown on loamy soils.

Table 2. Selected information for N-fertilization trials that had a loamy-soil texture classification, relative yields of corn receiving no N that were ≤50% of the maximum yield, and maximum actual yields that were ≥150 bu/acre.

				Classification[a]		Relative grain yield as affected by N rate (lb N/acre)[b]						
No	Year	County	Soil series	Max yield	No N	0	50	100	150	200	250	300
				------ (bu/acre)----		-------------------- (% of maximum yield produced)----------------------						
1[c]	2004	Desha	Desha	250	54	22	45	68	76	81	100	NA
2[c]	2004	Lee	Loring	160	72	45	76	88	97	100	94	NA
3[d]	2005	Jackson	Bosket	170	81	48	71	89	100	94	96	95
4[e]	2005	Jefferson	Roxana	181	49	27	72	83	93	95	94	100
5[e]	2005	Lee	Loring	180	41	23	55	70	88	88	89	100
6[f]	2006	Lee	Loring	184	59	32	45	78	80	95	100	99
7[f]	2006	Lee	Calhoun	218	68	31	51	74	83	90	98	100
8[f]	2006	Lee	Calhoun	151	9	6	26	55	69	89	95	100
9[f]	2006	Lee	Calloway	204	71	35	60	72	89	94	100	95
10[e]	2007	Lee	Loring	168	59	35	65[g]	77	--	88	92	100
11[e]	2007	Lee	Loring	203	71	35	57	81	92	91	100	86
12[e]	2008	Clay	Falaya	254	91	36	65[g]	80	--	92	100	99
13[e]	2008	Cross	Arkabutla	228	100	44	75[g]	89	--	86	100	92
14[e]	2008	Lee	Loring	218	39	18	46[g]	78	--	95	97	100
15[e]	2008	St Francis	Dundee	220	79	36	65[g]	80	--	85	100	99
16[e]	2008	Clay	Falaya	271	127	47	67[g]	80	--	92	92	100
17[e]	2008	Cross	Arkabutla	205	89	43	71[g]	80	--	91	97	100
18[e]	2008	Desha	Hebert	173	62	36	-- [g]	75	--	81	92	100
19[e]	2008	Lee	Loring	216	39	18	48[g]	74	--	90	93	100
20[e]	2008	St Francis	Dundee	214	58	27	48[g]	68	--	80	90	100

[a] Classification: Maximum yield is the actual maximum yield (bu/acre) that was produced by corn fertilized with N in the trial and corresponds to the N rate that produced 100% relative yield. No N, is the actual yield of corn receiving no N fertilizer and corresponds to the relative yield listed under the 0 lb N/acre rate.
[b] Relative grain yield, the N rate that produced the greatest yield has a relative yield of 100% and all other N rate yields are expressed as a percentage of the maximum. NA = not applicable, the N rate was not included in the trial.
[c] Mozaffari et al. (2005).
[d] Mozaffari et al. (2006).
[e] Unpublished data, Mozaffari.
[f] Mozaffari et al. (2007).
[g] Site-years had N rates in 60 unit increments including 60, 120, 180, 240, and 300 lb N/acre rather than the N rates listed in the column headings of 50, 100, 150, 200, and 250 lb N/acre.

Table 3. Selected information for N-fertilization trials that had a loamy-soil texture classification, relative yields of corn receiving no N that were 51% to 75% of the maximum yield, and maximum actual yields that were ≥150 bu/acre.

				Classification[a]		Relative grain yield as affected by N rate (lb N/acre)[b]						
No	Year	County	Soil series	Max yield	No N	0	50	100	150	200	250	300
				------ (bu/acre)----		-------------------- (% of maximum yield produced)----------------------						
1[c]	2005	Desha	Desha	169	94	56	67	91	98	100	95	83
2[c]	2005	St Francis	Henry	192	118	61	83	87	99	100	99	90
3[d]	2006	Clay	Falaya	185	111	60	72	87	99	95	97	100
4[d]	2006	Desha	Desha	187	112	60	84	92	98	97	98	100
5[d]	2006	Jackson	Amagon	184	136	74	79	91	92	91	93	100
6[d]	2006	Jackson	Dundee	153	102	67	75	80	86	94	92	100
7[d]	2006	Lee	Loring	232	133	57	66	81	88	100	96	96
8[e]	2007	Clay	Falaya	242	174	72[f]	84	93	--	95	98	100
9[c]	2007	Desha	Hebert	178	115	65[f]	85	84	--	88	96	100
10[c]	2007	Jackson	Bosket	222	131	59[f]	91	85	--	100	96	99
11[e]	2007	Jackson	Bosket	210	107	51[f]	89	94	--	90	100	96
12[c]	2007	Lee	Loring	178	105	59p	71	89	--	99	79	100
13[c]	2008	Desha	Hebert	200	107	54[f]	66	89	--	91	99	100

[a] Classification: Maximum yield is the actual maximum yield (bu/acre) that was produced by corn fertilized with N in the trial and corresponds to the N rate that produced 100% relative yield. No N, is the actual yield of corn receiving no N fertilizer and corresponds to the relative yield listed under the 0 lb N/acre rate.
[b] Relative grain yield, the N rate that produced the greatest yield has a relative yield of 100% and all other N rate yields are expressed as a percentage of the maximum.
[c] Unpublished data, Mozaffari.
[d] Mozaffari et al. (2007).
[e] Mozaffari et al. (2008).
[f] N rates for sites with the footnote had N rates in 60 units increments including 60, 120, 180, 240, and 300 lb N/acre rather than the N rates listed in the column headings of 50, 100, 150, 200, and 250 lb N/acre.

Table 4. Selected information for N-fertilization trials having a clayey-soil texture from N rate trials conducted in either Desha or Mississippi (Miss) county, Arkansas.

No	Year	County	Soil series	Classification[a]		Relative grain yield as affected by N rate (lb N/acre)[b]							
				Max yield	No N	0	50	100	150	200	250	300	350
				---------(bu/acre) -------		(% of maximum yield produced)							
1[c]	2005	Miss	Steele	145	31	21	46	85	69	100	93	97	--
2[d]	2006	Miss	Steele	133	23	17	41	65	79	96	98	100	--
3[d]	2006	Miss	Sharkey	170	10	6	36	56	88	91	95	100	--
4[e]	2007	Miss	Steele	162	15	9	46[f]	--	65	86	88	100	--
5[g]	2007	Miss	Sharkey	225	23	10	42	64	74	83	92	92	100
6[g]	2007	Miss	Sharkey	239	24	10	33	51	69	79	86	100	85
7[g]	2007	Desha	Sharkey	148	9	6	14	52	66	77	93	100	98
8[g]	2007	Desha	Sharkey	148	15	10	19	55	73	90	97	100	96
9[g]	2008	Miss	Sharkey	207	30	15	30	50	78	83	81	100	87
10[g]	2008	Miss	Sharkey	198	29	15	30	52	71	87	92	95	100
11[g]	2008	Desha	Sharkey	226	18	8	23	38	61	75	86	93	100
12[g]	2008	Desha	Sharkey	227	11	5	22	38	63	64	85	100	93
13[g]	2009	Miss	Sharkey	168	15	9	28	56	81	85	97	100	99
14[g]	2009	Miss	Sharkey	230	21	9	24	65	79	88	100	94	97
15[g]	2009	Desha	Sharkey	153	15	10	15	37	56	85	94	93	100
16[g]	2009	Desha	Sharkey	183	9	5	11	28	56	66	84	98	100
17[g]	2010	Miss	Sharkey	227	21	9	27	39	60	76	85	94	100
18[g]	2010	Miss	Sharkey	231	17	7	23	34	63	83	93	94	100
19[g]	2010	Desha	Sharkey	165	46	28	44	63	87	100	98	93	95
20[g]	2010	Desha	Sharkey	166	47	28	51	70	89	92	98	98	100
21[g]	2011	Miss	Sharkey	156	53	34	56	81	93	98	99	96	100
22[g]	2011	Miss	Sharkey	160	44	28	44	77	90	100	99	97	99
23[g]	2011	Desha	Sharkey	199	35	18	31	47	63	75	86	93	100
24[g]	2011	Desha	Sharkey	201	51	25	37	54	79	93	98	100	98
25[g]	2012	Miss	Sharkey	276	13	5	14	31	58	69	83	89	100
26[g]	2012	Miss	Sharkey	254	22	9	19	40	69	80	94	90	100
27[g]	2012	Desha	Sharkey	245	34	14	31	47	64	78	91	98	100
28[g]	2012	Desha	Sharkey	261	56	22	38	51	62	79	90	96	100

[a] Classification: Maximum yield is the actual maximum yield (bu/acre) that was produced by corn fertilized with N in the trial and corresponds to the N rate that produced 100% relative yield. No N, is the actual yield of corn receiving no N fertilizer and corresponds to the relative yield listed under the 0 lb N/acre rate.
[b] Relative grain yield, the N rate that produced the greatest yield has a relative yield of 100% and all other N rate yields are expressed as a percentage of the maximum.
[c] Unpublished data, Mozaffari .
[d] Mozaffari et al. (2007).
[e] Mozaffari et al. (2008).
[f] Site-year had N rates in 60 unit increments including 60, 120, 180, 240, and 300 lb N/acre rather than the N rates listed in the column headings of 50, 100, 150, 200, and 250 lb N/acre.
[g] Espinoza, unpublished data.

Table 5. Summary of regression analysis including soil texture and yield grouping, observation number, regression coefficients and standard errors, maximum relative yield predictions, and the predicted N rate recommendations.

Classification[a]			Regression coefficient				Prediction[b]	
Texture	Level	n	Intercept	Linear	Quadratic	r^2	Max yield	Recommendation
			----------[Coefficient (SE)]----------				(%)	(lb N/acre)
Clayey soil-1	≤50%	218	11.2 (1.5)	0.501 (0.020)	-0.00072 (0.000056)	0.91	98.35	289
Clayey soil-2	≤50%	189	11.5 (1.7)	0.492 (0.022)	-0.00070 (0.000061)	0.91	97.95	292
Loamy soil	≤25%	30	21.5 (2.4)	0.520 (0.036)	-0.00088 (0.000012)	0.96	98.31	242
Loamy soil	≤50%	125	35.2 (1.5)	0.465 (0.024)	-0.00087 (0.000077)	0.90	97.33	214
Loamy soil	≤75%	208	46.1 (1.5)	0.397 (0.023)	-0.00076 (0.000076)	0.79	97.95	204
Loamy soil	26%-50%	95	38.9 (1.5)	0.457 (0.024)	-0.00089 (0.000076)	0.91	97.57	204
Loamy soil	51%-75%	83	61.9 (1.4)	0.300 (0.021)	-0.00062 (0.000068)	0.85	98.19	178

[a] Clayey soil-1 included all site-years regardless of maximum yield potential (4 site-years had max yields <150 bu/acre) and clayey soil-2 included only sites that had maximum yields ≥150 bu/acre. Classification level is the percent relative yield (or percent of maximum yield) produced by the no-N control and indicates the responsiveness to N of the site-years.

[b] Prediction: Maximum yield is the maximum percent relative yield that can be calculated from the listed coefficients. Recommendation is defined as the N rate that produces near maximum relative yield which is the maximum yield prediction minus 2.5%.

Table 6. Revised University of Arkansas System Division of Agriculture Cooperative Extension Service N rate recommendations for irrigated corn in Arkansas based on yield goal and soil texture.

		Soil texture	
Relative yield	Yield goal	Loamy soils	Clayey soils
(% of maximum)	(bu/acre)	------------------(lb N/acre)-----------------	
Maximum -2.5%	>175	220	290
Maximum - 10%	<175	160	230

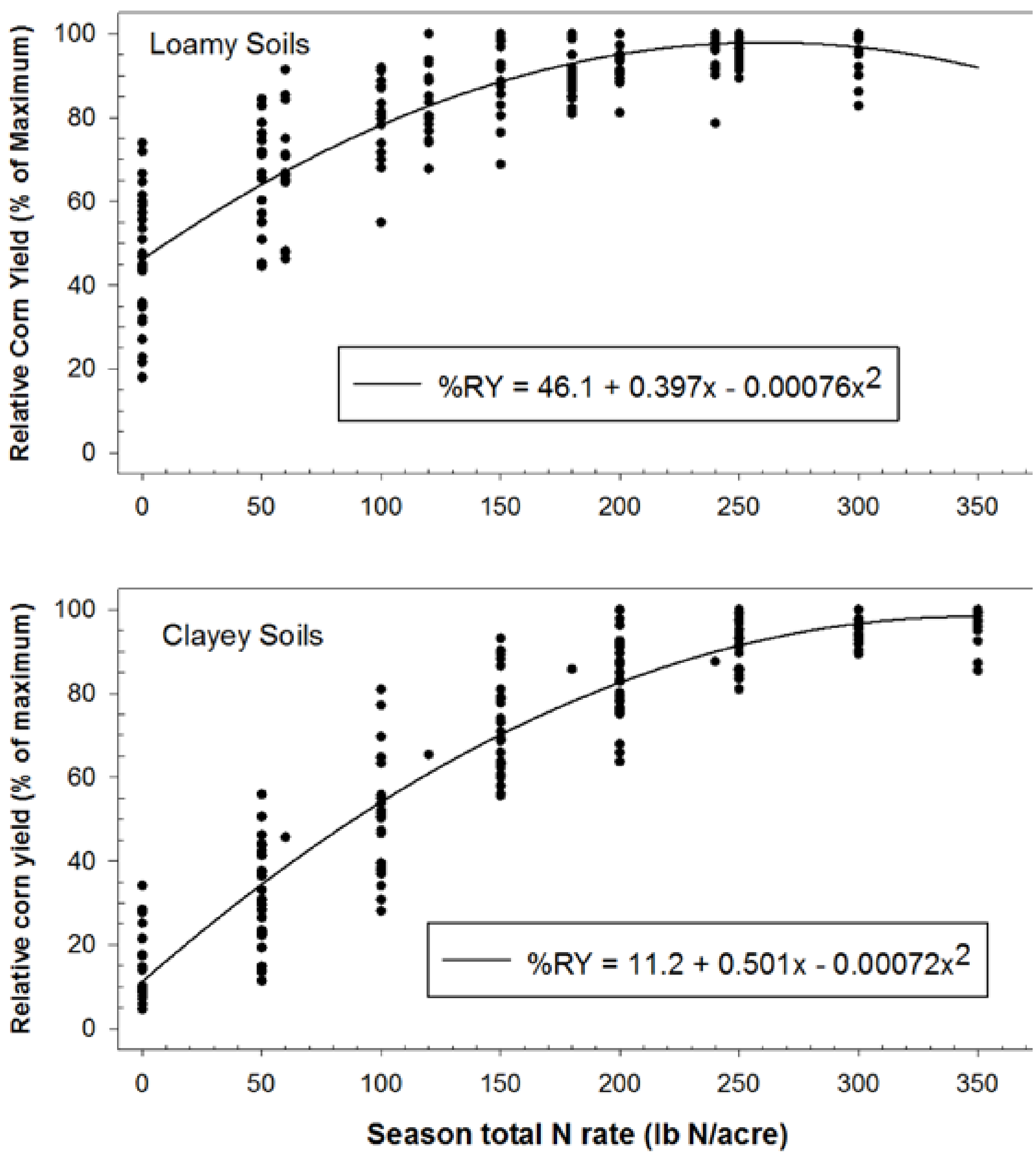

Fig. 1. Relationship between relative corn yield and N-fertilizer rate for loamy- and clayey-textured soils. Additional details on regression coefficients are listed in Table 5.

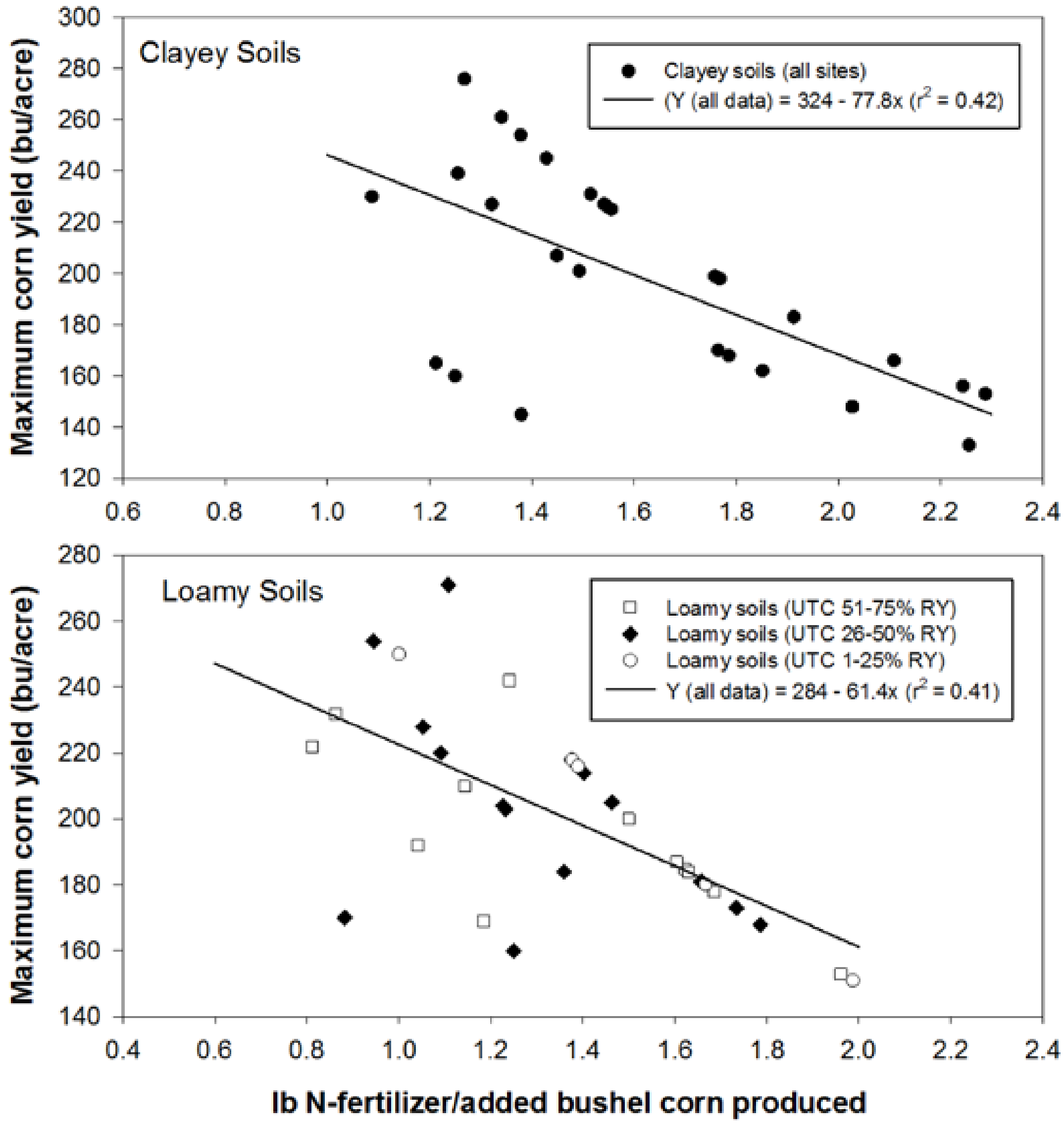

Fig. 2. Relationship between actual grain yields regressed against the pounds of N to produce one bushel of corn for loamy- and clayey-textured soils.

Validation of Soil-Test-Based Fertilizer Recommendations for Irrigated Soybean

N.A. Slaton, M.S. Fryer, T.L. Roberts, R.E. DeLong,
R.J. Dempsey, M.R. Parvej, J. Hedge, and C.G. Massey

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Routine soil testing is the accepted and best science available for determining whether phosphorus (P) and potassium (K) fertilizers are needed to maximize crop yield. Soil testing as an aid for making crop fertilization decisions has been a developing science since the early 1900s, but the demand for soil testing has recently increased substantially from the regulation of nutrient management and precision agriculture. Advocates of precision agriculture technologies like grid soil sampling and variable rate fertilization have capitalized on the well-developed infrastructure of soil-test laboratories and the availability of routine soil analysis. DeLong et al. (2013) reported that the number of grid soil samples submitted to the University of Arkansas Soil Test Lab had increased by 18,424 samples per year since 2006 while the number of field average soil samples had declined by 4,204 samples per year. Although precision agriculture technologies are clearly valuable tools for crop and nutrient management, it is imperative that we understand the difference between precise and accurate nutrient management. The ability to distribute different fertilizers and rates in different locations within a field is only as good as the accuracy of the information on which the fertilizer source and rate decisions were based upon (Slaton et al., 2010).

The objective of our research was to develop an independent database of irrigated-soybean [*Glycine max* (L.) Merr.] response to P and K fertilization to validate the accuracy of existing soil-test based fertilization guidelines. The overall research goal is to define the accuracy of soil-test based recommendations for identifying whether the soybean yield response would agree with the interpretation of the soil-test level definition. A secondary goal was to evaluate the accuracy of the fertilizer rate calibration.

PROCEDURES

Nine P and K-fertilization trials were established in experiment station fields across eastern Arkansas in 2013. Specific soil and agronomic information for each site is presented in Table 1. Each location will be referred to by the site name listed in Table 1. Management with respect to seeding rate, irrigation, and pest control at all sites closely followed recommendations from the University of Arkansas System Division of Agriculture's Cooperative Extension Service. In each trial, soybean was flood- or furrow-irrigated as needed.

As soon as the research field was identified, composite soil samples (0- to 4-inch depth) were collected from most sites in the early spring of 2013 to use as a guide for defining the recommended P and K fertilizer practices. More specific soil samples were eventually collected from each no-fertilizer control plot, along with a second set of soil samples collected from the 0- to 12-inch or 0- to 18-inch soil depth. At each site, individual plots were 20- to 26-ft long by 10- to 13-ft wide. Before fertilizer was applied to the research tests, a composite soil sample was collected from the 0- to 4-inch depth from each replicate (n = 3 to 6). Soil samples were oven-dried at 130 °F, crushed, and passed through a 2-mm sieve. Soil water pH was determined in a 1:2 soil weight:water volume mixture, plant-available nutrients were extracted using the Mehlich-3 method, and elemental concentrations in the extracts were determined using inductively coupled plasma spectroscopy (ICPS). Selected soil chemical property means are listed in Table 2.

Each trial contained a total of six treatments that involved four K_2O rates and two P_2O_5 (0 and 60 lb P_2O_5/acre) rates including 1) the recommended P rate plus 0 lb K_2O/acre, 2) the recommended P rate plus 60 lb K_2O/acre, 3) the recommended P rate plus 120 lb K_2O/acre, 4) the recommended P rate plus 160 lb K_2O/acre, 5) the recommended K rate plus the second P_2O_5 rate, and 6) no P and K fertilizer (control). Only two P rates were used because research in Arkansas has shown the relationship between crop yield and soil-test P is weak ($r^2 <$ 0.40). Triple superphosphate (46% P_2O_5) and muriate of potash (60% K_2O) were used as the nutrient sources. Lime (1000 lb pelleted lime/acre) was also applied at the Marianna site (following soil sample collection). Boron (B) was also applied to selected sites based on geographic proximity to areas where B deficiency is common to soybean.

At the R1 to R2 stage, trifoliate leaves were collected from the interior rows of every plot at each site. The leaf samples were dried to a constant moisture, ground to pass a 1-mm sieve, digested, and analyzed for elemental concentrations by ICPS. Seed were also saved from each plot to examine the effect of fertilization on seed nutrient concentration. Leaf and seed nutrient composition will not be included in this report. A 16- to 22-ft long section of the middle of each plot was harvested with a plot combine. Soybean moisture was adjusted to 13% for final yield calculations.

Each trial contained six treatments arranged as a randomized complete block design. Each treatment was blocked six times at each site except Newport, which had only three blocks. For each trial, ANOVA was conducted by site with the MIXED procedure in SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.). Single-degree-of-freedom contrast statements were used to make specific comparisons among treatments. The three yield comparisons that will be reported include 1) P fertilizer alone compared to no fertilizer, 2) K fertilizer alone compared to no fertilizer, and 3) P and K fertilization compared to no fertilizer. For this report, significant yield differences were identified for comparisons at three levels of significance, 0.05, 0.10, and 0.25. Responses to fertilization were designated as Correct, Type A Error, or Type B Error. Our hypothesis for testing was that soils with Very Low or Low soil-test nutrient levels should respond positively to fertilization, and soils with Optimum or Above Optimum soil-test levels would not respond positively or negatively to fertilization. For soils having a Medium soil-test nutrient level, either no response or a small positive response would be expected and therefore either was considered as a correct outcome.

RESULTS AND DISCUSSION

Soil-test results indicated that soybean yield increases from fertilization were expected at seven of the nine research sites. Six sites had soil-test P levels that were Very Low (1), Low (4) or Medium (1) and five sites had Low (2) or Medium (3) soil-test K levels. Table 3 summarizes the soybean yield response to P fertilization, K fertilization, and the combination of P and K fertilization. A positive yield increase to P fertilization was measured only at the PTRS-D20 site, which had a Very Low soil-test P. The interpretation of soybean yield response to P fertilization was not affected by the level of significance at which the comparisons were made (Table 4). Overall soil-test P based recommendations accurately predicted soybean response to P fertilization at five of the nine sites. This first year of results suggest that soil-test P values that are currently interpreted as Very Low, Optimum, and Above Optimum are accurate. Although fertilization is recommended on soils that have Low and Medium soil-test P levels, yield responses were not measured and the interpretation of soil-test P values defined by these levels may need to be revised. Overall, the current interpretation of soil-test P accurately defined the response at five of the nine sites or at 56% of the sites (Table 5) with prediction errors being Type B which suggests that soil-test P based recommendations should be revised so that P is recommended only for soils that are currently interpreted as having Very Low soil-test P.

Soil-test K accurately predicted that soybean yield at sites with Above Optimum soil-test K levels would not increase or decrease significantly from K fertilization, regardless of the level of significance (Table 3 and 4). The interpretation of soybean yield response was also consistent across the three levels of significance for soils that had a Medium soil-test K level. Of the three sites (PTRS-D2, PTRS-D20, and RREC) with Medium soil-test K two (PTRS-D2 and PTRS-D20) responded positively (avg of 5.7 bu/acre) to K fertilization. The Medium soil-test level is considered as the level of relative uncertainty and the prediction is considered correct if no yield increase occurs or a yield increase occurs. The interpretation of the results for soils having Low or Optimum soil-test K levels differed depending on the level of statistical significance used to make the comparison (Table 4). For the Low soil-test level, soybean yields were increased by K fertilization only at the 0.25 significance level. Likewise, for the Optimum soil-test level, soybean yield was increased nominally at one of the two sites (Rohwer-sl) for interpretations made at 0.10 and 0.25 (Tables 3 and 4). Current guidelines for soil-test K interpretations were accurate at 78% to 89% of the sites in this first year of research (Table 5). The type of error made with current soil-test K guidelines differed depending on which level of significance the yield results were interpreted. The inconsistency makes the revision of current recommendations more difficult as Type A error occurred at $P \leq 0.25$ and Type B error occurred at $P \leq 0.05$.

PRACTICAL APPLICATIONS

The current soil-test-based recommendations for P and K fertilization of irrigated soybean were reasonably accurate at the nine sites that were established in 2013. For soil-test P, the results confirmed what we anticipated and were very consistent in that current guidelines recommended P fertilization on soils where no response occurred. For K, the overall accuracy of predictions (78% to 89%) were slightly better than what was found for P (56%), but the type of error changed as the level of statistical significance changed. Other aspects of this research not summarized in this report may explain why certain errors occurred and include temporal and spatial variability (horizontal and vertical variability) of soil-test properties within the research area and the short-term history of cropping and fertilization.

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Table 1. Selected soil and agronomic information for P and K-fertilization trials conducted in 2013.

Site[a]	Soil series	Cultivar	Previous crop	Tillage	Row width	Plant date
Marianna	Convent	Armor 55-R22	Soybean	CT	38	4 June
Newport	Foley-Calhoun	Armor X1307	Rice	NT	15	13 Apr
NEREC	Sharkey-Steele	Armor X1307	Soybean	CT	38	21 June
PTRS-C4	Calloway	Armor 48-R40	Soybean	CT	15	13 June
PTRS-D2	Calloway	Armor X1307	Rice	CT	15	13 June
PTRS-D20	Calloway	Armor X1316	Soybean	CT	15	13 June
RREC	Dewitt	Armor 55-R22	Soybean	CT	30	23 May
RRS-Clay	Sharkey-Desha	Armor 55-R22	Soybean	CT	38	9 May
RRS-Loam	Desha	Armor 55-R22	Soybean	CT	38	9 May

[a] NEREC, Northeast Research and Extension Center; PTRS, Pine Tree Research Station; RREC, Rice Research and Extension Center; and RRS, Rohwer Research Station.

Table 2. Selected soil chemical property means (n = 3 to 6) of P or K of soil from the unfertilized control in P and K-fertilization trials conducted at multiple sites during 2013.

	4-inch sample							12- or 18-inch sample		
Site[a]	pH	P[b]	K[b]	Ca	Mg	Mn	Zn	pH	P	K
		---------- (ppm) ----------							------(ppm) ----	
Marianna	5.6	23 (4)	83 (6)	758	143	196	1.5	5.5	15 (4)	66 (12)
Newport[12]	5.5	118 (19)	131 (28)	973	102	15	4.3	5.6	71 (23)	100 (24)
NEREC[12]	6.4	25 (3)	330 (16)	4315	898	70	4.1	6.5	19 (2)	334 (19)
PTRS-C4	6.9	18 (3)	88 (5)	1487	224	445	2.3	5.0	6 (1)	76 (8)
PTRS-D2	7.2	43 (9)	96 (10)	1988	293	228	5.4	5.7	18 (6)	66 (10)
PTRS-D20	7.0	8 (2)	94 (12)	1542	326	445	2.4	5.7	3 (1)	81 (5)
RREC	6.4	21 (1)	102 (5)	981	152	295	0.6	6.0	8 (2)	73 (8)
RRS-Clay	7.5	64 (2)	353 (17)	4527	847	172	3.7	7.1	52 (2)	397 (14)
RRS-Loam	7.2	29 (12)	157 (10)	2110	544	165	2.1	6.5	20 (12)	193 (18)

[a] NEREC, Northeast Research and Extension Center; PTRS, Pine Tree Research Station; RREC, Rice Research and Extension Center; and RRS, Rohwer Research Station. The superscripted number '12' for Newport and NEREC indicates the alternate depth of the soil sampling for the values in the last three columns. The alternate soil sample depth at all other sites was 18 inches.
[b] The values in parentheses are the standard deviation of the mean soil-test P or K for the research area.

Table 3. Expected soybean yield response to P, K, or P and K fertilization compared to a no P and K control at nine research sites established during 2013.

	Expected response[b]		Check	Yield response to[d]					
Site[a]	P	K	yield[c]	P fert.	K fert.	P & K fert.	P fert.	K fert.	P & K fert.
			(bu/acre)	------(*P*-value)------			-----[yield difference (bu/acre)]----		
Marianna	Yes	Yes	58.2	0.7716	0.1513	0.0685	+1.5	+7.3	+7.7
Newport	No	No	75.3	--	0.2762	0.3165	--	-4.2	-5.2
NEREC	Yes	No	75.2	0.3853	--	0.3658	-2.4	--	+0.3
PTRS-C4	Yes	Yes	49.8	0.6400	0.2250	0.0073	-0.9	+2.2	+4.3
PTRS-D2	No	Maybe	78.0	0.4364	0.0044	--	-1.4	+4.6	--
PTRS-D20	Yes	Maybe	43.7	0.0220	0.0109	0.0011	+5.9	+6.7	+7.3
RREC	Yes	Maybe	61.6	0.8546	0.9925	0.7649	0.7	0.0	0.9
RRS-Clay	No	No	75.4	0.6950	0.4257	--	-0.4	+0.7	--
RRS-Loam	Maybe	No	80.0	0.0750	0.0729	0.0913	+2.2	+2.2	+1.7

[a] NEREC, Northeast Research and Extension Center; PTRS, Pine Tree Research Station; RREC, Rice Research and Extension Center; and RRS, Rohwer Research Station.
[b] Expected Response: Yes, soil-test level is Very Low or Low; Maybe, soil-test level is Medium; and No, soil-test level is Optimum or Above Optimum.
[c] Check yield, the mean yield of soybean that received no P or K.
[d] Yield response: P Fert., single-degree-of-freedom contrast comparing the yield with no P or K to P fertilizer; K Fert., single-degree-of-freedom contrast comparing the yield with no P or K to K fertilizer; and P & K Fert., single-degree-of-freedom contrast comparing the yield with no P or K to that of soybean fertilized with both P & K fertilizer. Cells with '--' indicate that the treatment was not represented in the trial. The P & K comparison was used when the comparison involving only one nutrient was absent.

Table 4. Summary of soybean yield response to P and K fertilization at three levels of significance (0.05, 0.10, and 0.25) as categorized by soil-test P and K level.

	Soil-test concentration		Phosphorus			Potassium		
Soil-test level	P	K	0.05	0.10	0.25	0.05	0.10	0.25
	------- (ppm) -------		--------------------(sites with yield differences / total number of sites)---------------------					
Very Low	≤15	≤60	1/1	1/1	1/1	--	--	--
Low	16-25	61-90	0/4	0/4	0/4	0/2	0/2	2/2
Medium	26-35	91-130	0/1	0/1	0/1	2/3	2/3	2/3
Optimum	36-50	131-175	0/1	0/1	0/1	0/2	1/2	1/2
Above Optimum	≥51	≥176	0/2	0/2	0/2	0/2	0/2	0/2

Table 5. The accuracy of soil-test prediction of soybean yield response to fertilization at nine research sites in 2013 as defined by soil-test P and K level and the level of significance at which statistical comparisons were made.

			Interpreted at *P*-value ≤0.05[b]			Interpreted at *P*-value ≤0.25		
Nutrient	Soil-test range[a]	Total trials	Test success	Type A error	Type B error	Test success	Type A error	Type B error
			---------------------------------------(% of sites)---					
P	≤25	5	20	0	80	20	0	80
P	26-35	1	100	0	0	100	0	0
P	≥36	3	100	0	0	100	0	0
P Summary	9	56	0	44	56	0	44	
K	≤90	2	0	0	100	100	0	0
K	91-130	3	100	0	0	100	0	0
K	≥131	4	100	0	0	75	25	0
K Summary	9	78	0	22	89	11	0	

[a] Ranges are grouped as Suboptimal (≤25 ppm P and ≤90 ppm K, including the Very Low and Low levels in which a positive yield response is expected); Medium (26 to 35 ppm P and 91 to 130 ppm K, response is unpredictable meaning no yield increase or a slight increase is expected); and Optimal (≥36 ppm P and ≥131 ppm K including the Optimum and Above Optimum levels in which no yield increase or decrease is expected).

[b] Type A Error occurs when the soil test predicts that soil nutrient (P or K) availability is Optimal but subsequent yields are reduced by nutrient (P or K) deficiency (False Positive). Type B Error occurs when the soil test predicts that soil nutrient (P or K) availability is suboptimal but subsequent yields do not respond to fertilization with that nutrient (False Negative).

Soybean Response to Short- and Long-Term Fertilization and/or Foliar Amendment

N.A. Slaton, T.L. Roberts, R.E. DeLong, C.G. Massey, and J.B. Shafer

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Soil testing is used to identify soils that are nutrient deficient and to recommend how much of each deficient nutrient should be applied to optimize crop yield, maintain soil fertility, or both. The University of Arkansas uses the Mehlich-3 soil test method to assess soil phosphorus (P) and potassium (K) availability. Our research efforts have demonstrated that the Mehlich-3 method does an adequate job of estimating soil K availability (Slaton et al., 2010); but the accuracy of recommendations based on soil-test P is less than desired. Specifically, Mehlich-3 soil-test P appears to accurately predict soils that have sufficient P availability (e.g., >25 to 30 ppm), but is not accurate on soils with <25 to 30 ppm P. Other land grant universities provide fertilizer recommendations based on the Mehlich-3 soil test method and, in general, their interpretation of soil-test P is in close agreement with those used by the University of Arkansas.

One long-term goal of our soybean (*Glycine max* (L.) Merr.) research program is to build a database to refine soil-test based P- and K-fertilization recommendations for irrigated soybean. Our short-term research objective is to evaluate soybean responses to P and K fertilizer rates on soils with a range of soil P availability index values. To achieve this objective we collected soybean data from one-year trials (rate trials in new fields) and from ongoing trials that receive the same fertilizer rates annually.

PROCEDURES

Phosphorus and K-fertilization trials with soybean were established at the Pine Tree Branch Station (PTRS) and Rice Research and Extension Center (RREC) during 2013. Specific soil and agronomic information for each site is listed in Table 1. Each location will be referred to by the site name listed in Table 1. Management with respect to seeding rate, irrigation, and pest control at all sites closely followed recommendations from the University of Arkansas System Division of Agriculture's Cooperative Extension Service. In each trial, soybean was flood- or furrow-irrigated as needed.

At each site, individual plots were 16- to 25-ft long by 6.5- to 15-ft wide. Before fertilizer was applied to the research tests, a composite soil sample was collected from the 0- to 4-inch depth from each replicate (n = 6-8). Soil samples were oven-dried at 130 °F, crushed, and passed through a 2-mm sieve. Soil water pH was determined in a 1:2 soil volume:water volume mixture, plant-available nutrients were extracted using the Mehlich-3 method, and elemental concentrations in the extracts were determined using inductively coupled plasma spectroscopy (ICPS). Selected soil chemical property means are listed in Table 2. More specific details of each trial are provided in the following sections.

RREC Long-Term Phosphorus and Potassium Trials

Annual soil samples were collected from each plot (0- to 4-inch depth) in March 2013, processed as previously described, and analyzed for soil pH and Mehlich-3 extractable nutrients. Armor 48-R40 soybeans were drill-seeded into the previous year's soybean stubble on 17 April 2013. Annual P (as triple superphosphate, TSP, 0-46-0) and K (as muriate of potash, MoP, 0-0-60) rates of 0, 40, 80, 120 and 160 lb P_2O_5 and K_2O/acre were applied to the soil surface on 17 April. A maintenance application of P fertilizer as TSP (60 lb P_2O_5/acre) was applied to the K trial and K fertilizer as MoP (60 lb K_2O/acre) was applied to the P trial. Additional agronomic details of the experiment are given in Tables 1 and 2. Trifoliate leaf samples were collected on 24 June at the R2 growth stage. Grain yield was measured at maturity. Each trial was a randomized complete block (RCB) design with six replications of each annual P or K rate.

Phosphorus Rate Trial

A trial was established at the PTRS to evaluate the influence of P fertilizer source and rate on soybean yield. The PTRS-PSR (P source and rate) trial was on a Calloway silt loam that followed soybean in the rotation. Selected agronomic information and soil chemical property means are shown in Tables 1 and 2. The trial consisted of two P fertilizer sources including TSP and MicroEssentials (MESZ, 12-40-0-10S-1Zn) applied at rates of 0, 40, 80, 120, and 160 lb P_2O_5/acre. The 0 lb P_2O_5/acre rate was treated as both a rate and a source (No P) in the analysis of variance (ANOVA). The P fertilizer was applied to the soil surface the same day as the soybeans were seeded. The treatments were arranged as a 2 (Source) × 4 (rate) factorial plus a no P control with five blocks.

Foliar Amendment Trials

An experiment evaluating the benefits of soil-applied P and K fertilizer and various foliar-applied products was established adjacent to the P source trial at the PTRS and contained the same treatments as trials conducted in 2012 (Slaton et al., 2013). Selected soil properties and management information are listed in Tables 1 and 2. The experiment consisted of two soil-applied fertilizer treatments of no fertilizer (0 lb P_2O_5 and 0 lb K_2O/acre) and 60 lb P_2O_5 plus 80 lb K_2O/acre applied as triple superphosphate and muriate of potash. Each site also contained five foliar-applied treatments which will be referred to as the control (foliar-applied B only), Foliar Blend (Agri-Gro Marketing, Inc., Doniphan, Mo.), Stoller products (Stoller USA, Houston, Texas), Perc Plus (3% N, 17% P_2O_5, 0.25% Cu, and 0.50% Zn; McRight Services, LLC, DeltAg Formulations, Greenville, Miss.), and ProTea products (Protea Botan UA, Inc., Collierville, Tenn.). The control treatment consisted of a single application of 0.25 lb B/acre applied as Borosol-10 (10% B, Loveland products, Inc., Greeley, Colo.) at the V3 stage on the same day the other treatments were applied. The Stoller products treatment included 8 oz BioForge/acre (N,N'-diformyl urea) applied at the V3 to V4 stage followed by 32 oz Sugar Mover/acre (8% B and 0.004% Mo) at the R2 stage. Foliar Blend was applied at 32 oz/acre/application with applications made at the V3 to V4 and R2 growth stages. Perc Plus was applied at 16 oz/acre/application at the V3 to V4 and R2 stages. The ProTea products consisted of applying the product sold as SoyAstim-27 (5%N, 16% P_2O_5, 6% K_2O, 0.10% Fe, and ≤0.05% B, Cu, Mn, Mo, and Zn) at 32 oz/acre/application at the V3 and R2 growth stages. Additional information on each of these products can be obtained by visiting the manufacturer's web site. All applications were made with a CO_2 backpack sprayer calibrated to deliver 10 gal/acre at 3 mph. The V3 to V4 and R2 applications were made on 24 June (V3 to V4) and 1 August (R2). Trifoliolate leaf samples were collected before the second foliar application was applied to evaluate the effect of the V3 to V4 application on leaf nutrient concentration. The trial was a RCB with a 2 × 5 factorial treatment arrangement and five blocks.

In all trials, 12 to 15 of the most recently matured trifoliate leaves on one of the upper four nodes were collected at the R2 growth stage, dried to a constant moisture, ground to pass a 1-mm sieve, digested, and analyzed for elemental concentrations by inductively coupled plasma spectroscopy (ICPS). A 12- to 20-ft long section of the middle of each plot was harvested with a plot combine. Soybean moisture was adjusted to 13% for final yield calculations. For all studies, ANOVA was conducted by site with the MIXED procedure in SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.). When appropriate, mean separations were performed using Fisher's Protected Least Significant Difference (LSD) method at a significance level of 0.10. In some trials, single-degree-of-freedom contrasts were used to compare selected treatments with significant differences identified when $P < 0.10$.

RESULTS AND DISCUSSION

RREC Long-Term Phosphorus and Potassium Trials

Six years of P and K fertilization and cropping have changed soil-test P and K availability (Table 3). Linear regression of the soil-test P and K means indicate that the soil-test P and K have increased by 1 ppm for every 22.2 lb P_2O_5/acre and 9.4 K_2O/acre, respectively. Six years ago the mean soil-test P and K values of these two research areas were 19 ppm P and 148 ppm K suggesting that soil-test P in the no P control has not changed greatly but soil-test K availability has decreased substantially. Soil-test K in soil that has received no K fertilizer has ranged from 80 to 148 ppm and has decreased linearly across time at a rate of -11.5 ppm K/year ($r^2 = 0.81$). We expected soil-test K to decline across time when no K was applied because it was initially Optimum. In contrast, we expected that soil-test P would likely remain nearly constant in the absence of fertilization since it was initially Low and has fluctuated from 16 to 22 ppm showing no trend to increase or decrease.

Despite the suboptimal soil-test P and K values in the unfertilized control treatments, soybean yields were not affected by P fertilization in 2013 (Table 4), but yield differences were measured in the K trial. Soybean yields increased numerically as annual K rate increased, but there were no significant differences among soybean fertilized with 40 to 160 lb K_2O/acre, which yielded 13% to 25% more than soybean in the no K control. Trifoliolate leaf P and K concentrations were affected in each of the trials showing that leaf concentrations generally increased as annual fertilizer rate increased. Soybean that received no K showed very subtle symptoms of K deficiency during the season and had deficient leaf K concentrations. The mean leaf K concentration of soybeans fertilized with 40 lb K_2O/acre/year was marginally sufficient. These results indicate that yield differences among K rates will likely be measured in future years, but despite a Low soil-test P level, consistent growth and yield differences have yet to be measured in the P trial.

Phosphorus Rate Trials

Trifoliolate leaf P concentrations at PTRS-PSR were marginally influenced by P fertilizer rate, averaged across sources (Table 5), but there were no differences among P fertilizer sources, averaged across rates, ($P = 0.6508$), or the interaction ($P = 0.6605$). Leaf P concentrations were considered sufficient for all P rates at PTRS-PSR, being well above the critical P level of 0.30% P suggested by Sabbe et al. (2000). Soybean yields were not affected by P fertilizer ($P = 0.2071$), P rate ($P = 0.7533$), or their interaction ($P = 0.3649$).

Foliar Amendment Trials

The main effect of foliar-applied product ($P = 0.6598$), averaged across fertilizer rates, did not significantly influence soybean yield, but the main effect of fertilizer rate ($P = 0.0059$) and the 2-way interaction ($P = 0.0364$) significantly influenced soybean yield (Table 6). Averaged across all foliar products, soybean receiving 60 lb P_2O_5 plus 80 lb K_2O/acre (59 bu/acre) produced a greater yield than soybean that received no P and K (55 bu/acre). The interaction shows that fertilization with P and K increased yields only when Perc Plus or the Stoller products (Bio-forge® and Sugar Mover) were applied. However, the mean yield of soybean was always numerically greater when 60 lb P_2O_5 plus 80 lb K_2O/acre was applied with each foliar product. For soybean that received no P and K fertilizer, yields were similar among all five foliar-applied product treatments. Within the foliar product treatments that received P and K, the greatest yields were produced when Stoller products and Perc Plus were also applied. The results suggest that either fertilization had no benefit on soybean that received B only, SoyAstim-27 and Foliar Blend due perhaps to spatial variability within the plot area. Alternatively, the application of B only, SoyAstim-27 and Foliar Blend suppressed the yield increase from fertilization.

The concentrations of K, Mg, B, and Zn in the trifoliate leaves collected at the R1 to R2 stage (before the second foliar application was made) were significantly affected by the main effect of foliar-applied product. Application of 60 lb P_2O_5 plus 80 lb K_2O/acre increased leaf K and Zn, but decreased Mg and B concentrations (Table 7). Trifoliate leaf B concentration also differed among foliar-applied product treatments with soybean from the control treatment having greater leaf B concentration (39.6 ppm) than soybean that received any of the four foliar-applied products (28.8 to 29.6 ppm) (not shown). The results show no evidence suggesting the foliar-applied products stimulated the uptake of nutrients from the soil. The amount of nutrients contained in the applied solutions was likely too small to influence leaf nutrient concentrations. For example, Perc Plus contains 17% P_2O_5, which when applied at 16 oz/acre supplies 0.092 lb P or 0.21 lb P_2O_5/acre.

PRACTICAL APPLICATIONS

Phosphorus fertilization rate trials with soybean have been conducted on over 50 site-years since 2004. To date, the correlation between Mehlich-3 soil-test P and the relative yield of soybean receiving no P fertilizer is significant ($P < 0.05$) when examined with a linear-plateau model, but the relationship is not very strong ($r^2 = 0.30$). The relationship suggests that the critical soil-test P is about 23 ppm, but the 95% confidence interval ranges from 15 to 31 ppm. Trial results continue to show that when soil-test P is >20 to 25 ppm, a significant yield response to P fertilization is unlikely. Trials conducted in 2012 and 2013 showed that yields were not affected by P source.

A trial examining soybean response to P- and K-fertilization rate with and without foliar-applied fertilizers or biostimulant products showed no benefit from the foliar-applied biostimulants/fertilizers, but significant yield increases from preplant P and K fertilization were measured in some treatments. Results suggest that supplying adequate P and K to maintain or build soil fertility is likely to be a better investment than foliar-applied nutrient or biostimulant solutions. The benefits of foliar-applied solutions to soybean yield should be approached like fertilizer rate trials in that numerous site-years of research are needed to determine the probability that a yield increase will occur from their application to answer the questions of how frequently significant, positive/negative responses are observed, what is the magnitude of positive/negative responses, and under what conditions do positive responses occur. Our research has failed to document benefits from the selected foliar-applied stimulants in three trials conducted during the last two years.

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Table 1. Selected soil and agronomic management information for soybean P- and K-fertilization trials conducted in 2013 in Arkansas.

Site (nutrient)†	Soil series	Cultivar	Previous crop	Tillage	Row width	Plant date
RREC-LTP	Dewitt	Armor 48-R40	Soybean	No-till	7.5	17 April
RREC-LTK	Dewitt	Armor 48-R40	Soybean	No-till	7.5	17 April
PTRS-PSR	Calloway	Armor 48-R40	Soybean	Conventional	15.0	13 June
PTRS-PK	Calloway	Armor 53-R15	Soybean	Conventional	15.0	13 June

† P = phosphorus; K = potassium; PSR = P source and rate; LT = long-term; RREC = Rice Research and Extension Center; and PTRS = Pine Tree Research Station.

Table 2. Selected soil chemical property means (n = 4-6) of soil from the unfertilized control in soybean P- and K-fertilization trials conducted at multiple sites during 2013 in Arkansas.

Site (nutrient)†	Soil OM	Soil pH	Mehlich-3 soil nutrients P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
	(%)		(ppm)								
RREC-LTP	2.4	5.8	–‡	120	1144	155	8	426	118	8.2	1.2
RREC-LTK	2.3	6.1	31	–‡	1172	177	8	438	100	6.5	1.1
PTRS-PSR	2.4	7.2	22§	91	1610	245	9	264	428	1.8	1.3
PTRS-PK	2.4	7.0	27§	101¶	1514	228	11	271	417	2.2	1.1

† P = phosphorus; K = potassium; PSR = P source and rate; LT = long-term; RREC = Rice Research and Extension Center; and PTRS = Pine Tree Research Station.
‡ Soil test P and/or K means for each annual P or K rate from the RREC trials are listed in Table 3.
§ The standard deviations of the mean soil-test P were 1.6 ppm for PTRS-PSR and 1.7 ppm for PTRS-PK.
¶ The standard deviation of soil-test K mean is 4.7 ppm for PTRS-PK.

Table 3. Mehlich-3 extractable soil P or K means as affected by annual P- or K-fertilization rate for two multi-year trials from samples collected in March 2013 at the Rice Research and Extension Center (RREC) in 2013.

Annual nutrient rate	P rate trial	K rate trial
(lb K_2O or P_2O_5/acre)	(ppm P)	(ppm K)
0	19	80
40	27	98
80	39	118
120	49	140
160	62	186
$LSD_{0.10}$	5	13
P-value	<0.0001	<0.0001
Linear slope†	0.045	0.106

† Slope values represent the soil-test P and K values (shown above) regressed against the cumulative amount of each fertilizer applied since 2007 (multiply annual rates by six) and has units of ppm soil-test P or K/lb P_2O_5 or K_2O applied over the six-year period.

Table 4. Trifoliate leaf P or K concentration and seed yield of soybean as affected by annual P- or K-fertilization rate for multi-year trials conducted at the Rice Research and Extension Center (RREC) in 2013.

Annual nutrient	RREC-P trial		RREC-K trial	
rate	Leaf P	Seed yield	Leaf K	Seed yield
(lb K_2O or P_2O_5/acre)	(% P)	(bu/acre)	(% K)	(bu/acre)
0	0.31	38	1.35	29
40	0.35	43	1.71	32
80	0.36	44	1.96	34
120	0.35	39	2.15	35
160	0.37	44	3.33	36
$LSD_{0.10}$	0.013	NS†	0.15	3
P-value	<0.0001	0.1751	0.0192	<0.0001
SDF‡	<0.0001	0.0946	<0.0001	0.0038

† NS = not significant ($P > 0.10$).
‡ SDF = single-degree-of-freedom contrast comparing the yield of soybean receiving no P or K fertilizer against the mean yield of soybean fertilized with 80, 120, and 160 lb P_2O_5 or K_2O/acre.

Table 5. Trifoliate leaf P concentration and seed yield of soybean as affected by P-fertilization rate at the Pine Tree Research Station (PTRS-PSR) during 2013.

P Fertilizer Rate†	Leaf P	Seed yield
(lb P_2O_5/acre)	(% P)	(bu/acre)
0	0.44	57
40	0.44	57
80	0.46	57
120	0.46	58
160	0.46	58
$LSD_{0.10}$	0.01	NS‡
P-value	0.0962	0.7533

† Average of two P sources: TSP = triple superphosphate (46% P_2O_5) and MESZ = MicroEssentials fertilizer (40% P_2O_5). PSR = P source and rate.
‡ NS = not significant ($P > 0.10$).

Table 6. Soybean seed yield as affected by P- and K-fertilization rate and foliar-applied treatments at the Pine Tree Research Station (PTRS-PK) during 2013.

	Fertilizer treatment‡	
Foliar treatment†	0-0-0	0-60-80
	------------------(bu/acre)-------------------	
Control	56	60
Perc Plus	53	62
SoyAstim-27	57	56
Stoller products	54	62
Foliar Blend	57	55
$LSD_{0.10}$	5	
P-value	0.0364	

† Foliar treatments: Control, boron only; Perc Plus, 16 oz/acre/application at the V3 and R1 stages; Stoller products, 8 oz Bio-forge/acre applied at V3 stage followed by 32 oz Sugar Mover/acre at R1 stage; Foliar Blend, 32 oz/acre/application with applications made at the V3 and R1 stages; SoyAstim-27, 32 oz/acre/application at the V3 and R1 stages.
‡ Fertilizer treatments consisted of 0-0 (0 lb P_2O_5 and 0 lb K_2O/acre) or 60-80 (60 lb P_2O_5 and 80 lb K_2O/acre).

Table 7. Soybean leaf nutrient concentrations at the R1 to R2 stage as affected by preplant P- and K-fertilization rate, averaged across foliar-applied product treatments, at Pine Tree Research Station (PTRS-PK) during 2013.

	Preplant fertilizer rate	
Leaf nutrient	0-0[†]	60-80
	---------------- (bu/acre)[‡] -----------------	
P	0.424 a	0.431 a
K	1.61 b	1.79 a
Ca	1.01 a	0.99 a
Mg	0.434 a	0.406 b
S	0.298 a	0.295 a
Fe	125 a	124 a
Mn	118 a	123 a
Zn	35.6 b	39.0 a
Cu	9.3 a	9.3 a
B	32.5 a	29.9 b

† Fertilizer treatments consisted of 0-0 (0 lb P_2O_5 and 0 lb K_2O/acre) or 60-80 (60 lb P_2O_5 and 80 lb K_2O/acre).

‡ Nutrient concentration means between P and K fertilizer rates within the same row followed by different letters indicates that values were significantly different at the 0.10 level.

Wheat Yield Response to Phosphorus Fertilization on Soils with Optimal Phosphorus Levels

N.A. Slaton, R.E. DeLong, T.L. Roberts, M.R. Parvej, R.J. Dempsey, J.A. Hedge, and J.B. Shafer

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Soft red winter wheat (*Triticum aestivum* L.) is generally regarded as a phosphorus (P) responsive crop because it is grown in cool, wet soils which limit P availability and uptake. Farmers and consultants are increasingly collecting multiple soil samples from grids or zones within a field to apply fertilizer at variable rates based on the soil-test based fertilizer recommendations. Precision agriculture (grid samples and variable rate fertilizer application) is perceived as being an improvement in nutrient management compared to collecting soil samples using the field average method and applying a uniform fertilizer rate. However, precision placement of fertilizer is only as good as the accuracy of the fertilizer recommendations and the soil-test methods on which the prescription field maps are developed. Our research objectives were to evaluate wheat response to P fertilization and continue to build our database describing wheat response to soil-test P and P fertilization rate.

PROCEDURES

Three trials were established to examine wheat response to P fertilizer rate and included a Captina silt loam at the Arkansas Agricultural Research and Extension Center in Fayetteville (AAREC) and Calloway silt loams at the Pine Tree Research Station (PTRS). The two trials at the PTRS evaluated three P application rates and five fertilizer sources, and the trial on the Captina silt loam included only a single P source applied at four rates.

A composite soil sample was collected from the 0- to 4-inch depth from each replicate of each trial following emergence (Table 1). Soil was oven-dried at 130 °F, crushed, and passed through a 2-mm sieve for measurement of Mehlich-3 extractable nutrients, organic matter by weight loss on ignition, and soil water pH. Mean values of selected soil chemical properties are listed in Table 1. Armor 'Ricochet' wheat, rated resistant to lodging, was drill-seeded (120 lb seed/acre) into conventionally tilled seedbeds on 25 October at the PTRS and 22 October at the AAREC. Individual plots were 20-ft long and 6.5-ft wide at the PTRS and 20-ft long by 9.0-ft wide at the AAREC with rows spaced 7.5- and 7.0-inches apart, respectively.

For the P source by rate trials, the fertilizer treatments consisted of five P fertilizer sources including granular monoammonium phosphate (MAP, 11-52-0), liquid P obtained from Stratton Fertilizer (Stuttgart, Ark.) which uses MAP as its P source, MicroEssentials (MESZ, 12-40-0-10S-1Zn), triple superphosphate (TSP, 0-46-0), and 'No P' with ammonium sulfate (21-0-0-24) rates to match the three N amounts applied with each MESZ rate. Each P source was applied at rates of 35, 70, and 105 lb P_2O_5/acre. At the AAREC, the same rates plus 0 lb P_2O_5/acre were applied as triple superphosphate as outlined for the PTRS trials. All P fertilizers were applied to the soil surface on 16 November at the PTRS or 29 November at the AAREC following wheat emergence. Muriate of potash (0-0-60) was applied to supply 70 lb K_2O/acre at all three sites. For the two PTRS trials, a total of 150 lb urea-N/acre was applied as urea in splits of 90 and 60 lb urea-N/acre made on 6 and 20 March, respectively. A total of 60 lb urea-N/acre was applied at the AAREC on 8 March. At maturity, grain yields were measured by harvesting all eight rows of each plot at the PTRS and the middle eight of twelve rows of each plot at the AAREC with a small-plot combine. Grain yields were adjusted to a uniform moisture content of 13%. Lodging notes were also recorded immediately before harvest at each site.

The P rate trial at the AAREC was a randomized complete block (RCB) design with six blocks. The P rate by fertilizer source trials were a RCB design with a 5 (P sources) by 2 or 3 (P rates) factorial treatment structure with four blocks. The 35 lb MESZ-P_2O_5/acre rate at PTRS-2 was omitted from analysis due to harvest error on three of the four plots. Thus, all other 35 lb P_2O_5/acre rates were also omitted to maintain balance among treatments. For the two trials located at the PTRS, analysis of variance was also performed by P rate by omitting P source from the model, including the 35 lb P_2O_5/acre rate, and assigning the ammonium sulfate (No P) P source as the 0 lb P_2O_5/acre rate. Analysis of variance was performed using the MIXED procedure in SAS v. 9.2 (SAS Institute Inc., Cary, N.C.). When appropriate, mean separations were performed using Fisher's Protected Least Significant Difference method at a significance level of 0.10.

RESULTS AND DISCUSSION

The soil-test P level at each of the three sites was considered Optimum (36 to 50 ppm) and we did not expect to find a significant yield increase from P fertilization. At the AAREC, grain yield and lodging were both significantly affected by P application rate (Table 2). Wheat lodging was increased by application of 70 and 105 lb P_2O_5/acre compared to the two lower P rates. The increased lodging from the two highest P rates probably contributed to the measured yield reductions, most likely from reduced harvest efficiency. Phosphorus fertilization had no significant benefit or detriment to grain yield and lodging at the two PTRS sites (Table 2). Although not significant, the PTRS-2 site also showed a trend for yields to decline when moderate to high rates of P fertilizer were applied (Table 2). The analysis of variance for the P source by P rate factorial treatment structure at PTRS-2 (Table 3) also showed no significant benefit from P fertilization and wheat fertilized with MESZ and MAP, both N-containing P sources, tended to have greater lodging than wheat fertilized with no P or a P source that contained no N.

PRACTICAL APPLICATIONS

The three P rate trials conducted in 2012-13 provided sites having Optimal soil-test P levels to the database, which were needed to provide balance to the range of soil-test levels represented in our database on wheat response to P fertilization. As we anticipated, there was no benefit to P fertilization, but increasing the P rate tended to numerically or significantly increase wheat lodging. Lodging was great enough at one site to negatively influence wheat yield. This phenomenon of increased lodging when P fertilizer is applied to a soil on which P is not needed to optimize crop yield has previously been noted in flood-irrigated rice on lodging-prone varieties and/or slightly acidic soils. These findings highlight the need for growers to be cautious in using high P fertilizer rates simply to build and/or maintain soil-test P at an Optimum (36 to 50 ppm) or Above Optimum (>50 ppm) level.

Our database contains 39 site-years of P-fertilization trials since 2004 to model the relationship between relative wheat grain yield (% of maximum yield when no P fertilizer is applied) and soil-test P (Mehlich-3 P in ppm, Fig. 1). The linear-plateau relationship shows that the critical soil-test P is about 41 ppm, but has a 95% confidence interval that ranges from 22 to 59 ppm.

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Research was funded by Arkansas Wheat and Soybean Checkoff Program funds administered by the Arkansas Wheat and Soybean Research and Promotion Boards and the University of Arkansas System Division of Agriculture.

Table 1. Selected soil chemical property means (*n* = 4-6) from wheat P trials established at the Arkansas Agricultural Research and Extension Center (AAREC) and Pine Tree Research Station (PTRS) during the 2012-2013 growing season.

Site	Soil OM[a]	Soil pH	Mehlich-3 extractable soil nutrients P[b]	K	Ca	Mg	S	Na	Fe	Mn	Zn	Cu
	(%)		(ppm)									
AAREC	1.8	6.2	36	127	1163	48	10	4	73	164	2.5	2.7
PTRS-1	2.3	7.0	47	82	1397	264	11	27	366	65	1.8	1.0
PTRS-2	2.9	5.7	43	121	1167	202	16	14	214	231	2.7	1.5

[a] OM = organic matter.
[b] Standard deviation of soil-test P was 2.2 ppm for AAREC, 10.4 ppm for PTRS-1, and 9.4 ppm for PTRS-2.

Table 2. Wheat grain yield and lodging response to P rate at three sites having Optimum soil-test P levels at the Arkansas Agricultural Research and Extension Center (AAREC) and Pine Tree Research Station (PTRS) during the 2012-13 growing season.

P rate	AAREC Lodging	AAREC Grain yield	PTRS-1 Lodging	PTRS-1 Grain yield	PTRS-2 Lodging	PTRS-2 Grain yield
(lb P_2O_5/acre)	(%)	(bu/acre)	(%)	(bu/acre)	(%)	(bu/acre)
0	8	99	10	88	46	95
35	12	93	11	81	50	97
70	29	82	9	89	51	95
105	25	80	8	89	56	94
$LSD_{0.10}$	12	6	NS[a]	NS	NS	NS
P-value	0.0010	0.0228	0.9911	0.2567	0.7573	0.5732

[a] NS = not significant.

Table 3. The effect of P source, averaged across P rates, on wheat grain yield and lodging at two trials at the Pine Tree Research Station (PTRS) conducted during the 2012-13 growing season.

	PTRS-1		PTRS-2	
P source	Lodging	Grain yield	Lodging	Grain yield
(lb P_2O_5/acre)	(%)	(bu/acre)	(%)	(bu/acre)
No P	1	89	46	95
TSP	6	87	45	97
MESZ	10	91	67	93
MAP	7	88	54	94
Liquid MAP	11	89	42	98
$LSD_{0.10}$	NS	NS	15	NS
P-value	0.8909[a]	0.9307[a]	0.0641	0.1195

[a] Neither the main effect of P rate nor the 2-way interaction were significant ($P > 0.10$).

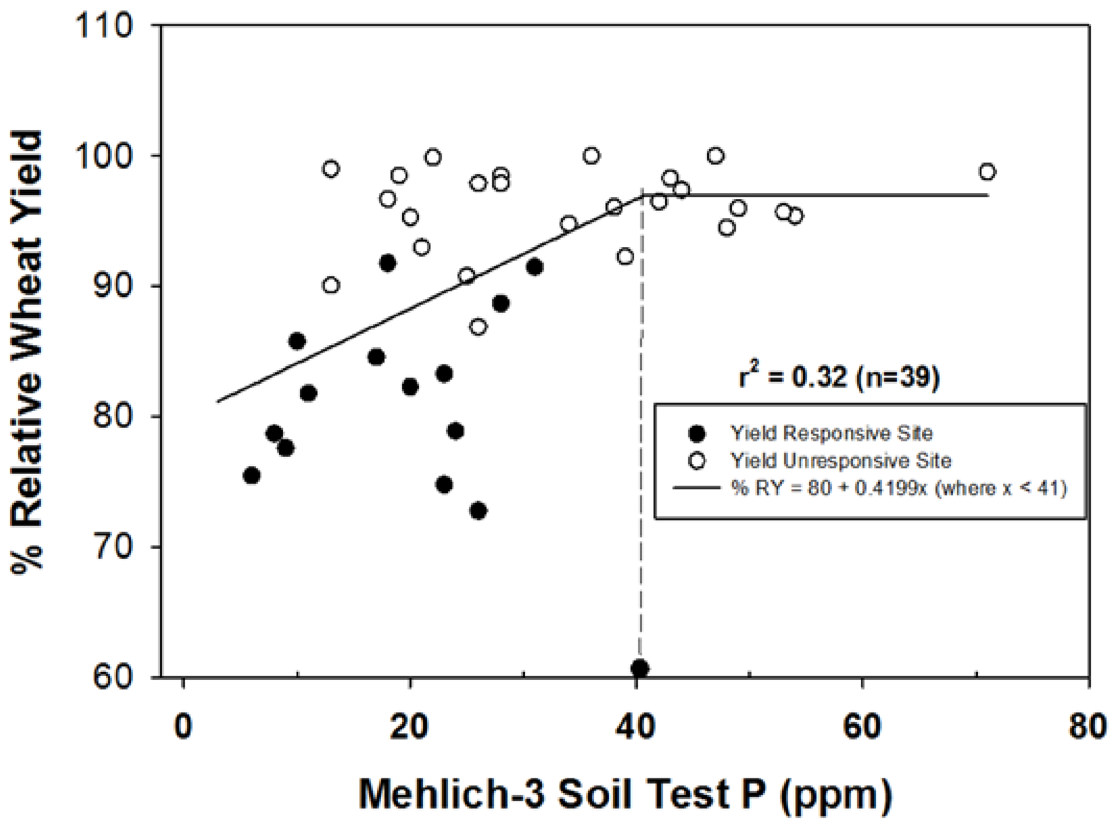

Fig. 1. Relationship between soil-test P and relative soft red winter wheat yield (% of maximum yield produced by wheat receiving P fertilizer) as defined by a linear plateau regression model.

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