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Wayne E. Sabbe Arkansas Soil Fertility Studies 2014

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Wayne E. Sabbe ARKANSAS SOIL FERTILITY STUDIES • 2014 •

Nathan A. Slaton, Editor

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Cover: Soybean is planted annually on more than 3 million acres in Arkansas, which typically ranks 10th in production among soybean-producing states in the USA. The cover photograph shows soybean leaves near the top of the plant exhibiting the onset of potassium deficiency symptoms during mid-reproductive growth. Potassium deficiency symptoms begin as a yellowing at the soybean leaf tip and progresses along the leaf margin and deeper into the leaf blade as the severity of deficiency increases. The picture was taken from plots located at the Pine Tree Research Station from research validating the accuracy of soil-test-based phosphorus and potassium fertilizer recommendations for irrigated soybean. (photograph by Matthew Fryer, Graduate Research Assistant, 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
– 2014 –

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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 2014 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 2013. 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.

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Soil-Test and Fertilizer Sales Data: Summary for the 2013 Growing Season

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

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Soil-test data from samples submitted to the University of Arkansas Division of Agriculture Soil Testing and Research Laboratory in Marianna between 1 January 2013 and 31 December 2013 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 2013 and 31 December 2013, 179,588 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 (14,982), the total number of client samples was 164,606. A total of 52,387 of the submitted soil samples were collected using the field average sampling technique, representing 1,289,936 acres for an average of 25 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 remaining 112,219 samples include grid samples (111,074) collected primarily from row-crop fields and research samples (1,145). 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 46% of the total field average samples and 73% of the total acreage (Table 1). The average number of acres represented by each field-average soil sample ranged from 1 to 93 acres/sample (Table 2). Counties that have a very low number of acres per sample are counties that have a substantial number of grid soil samples. Clients from Craighead (20,507, 93% from five clients); Crittenden (18,531, 93% from two clients); Clay (Corning and Piggott offices, 12,129, 75% from four clients); Lawrence (10,773, 88% from one client); and Mississippi (8,496, 78% 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, Lawrence, and Mississippi 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), 32 (Rilla-Hebert), and 45 (Crowley-Stuttgart). However, the soil associations representing the largest acreage were 44, 45, 22 (Foley-Jackport-Crowley), and 32 which represented 29%, 14%, 10%, and 8% 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 74% of the sampled acreage and 45% of submitted samples, ii) hay and pasture production accounted for 24% of the sampled acreage and 26% of submitted samples, and iii) home lawns and gardens accounted for 1% of sampled acreage and 21% of submitted samples (Table 4). In row-crop producing areas, 51% of the soil samples are collected following soybean in the crop rotation.

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 5.7 to 6.6 (Table 5). 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, irrigated grain sorghum, 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, Mississippi, 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.

The estimated cation exchange capacity (ECEC) approximates the soil's nutrient holding capacity, which is related to clay type, soil organic matter, and clay content. Tables 10, 11, and 12 show seven ranges and median ECEC values by county in 2011, 2012, and 2013, respectively. Crittenden and Baxter counties consistently had the highest median ECEC values among counties. The majority of soils with the lowest ECEC were in the Coastal Plain, Highlands, and Mountains. The predominant soils of Crittenden and Desha counties, and the eastern half of St. Francis County are alluvial with a higher clay content than the soils with a lower ECEC.

The number of soil samples submitted for field average and grid sampling methods in 2006 were 69,494 and 14,838, respectively. In 2013, the field average samples decreased to 52,387 and the grid samples increased to 111,074. In 2006 and 2013, the category of previous crops soybean, home lawn, and pasture had the greatest number of submitted samples with pasture samples supplanting the home lawn samples in 2013. The greatest number of soil samples submitted by county and previous crop in 2006 occurred in October and January through March and was lowest from May through September, and the distribution was similar for the subset of field average samples (Table 13) and all samples (field average and grid samples, Table 14). The previous crop category Turf was not included in 2006. In 2013, the county samples which included grid samples showed the months with the greatest number of samples submitted were October, November, December, and March indicating that the time of soil sample collection has shifted from late winter to fall immediately following harvest (Table 15). When the grid samples are removed from the database, the previous crop data illustrates that the greatest mean number of samples occurs in March, similar to 2006 (Table 16). With an almost 8X increase in grid samples from 2006 to 2013, the collection of grid soil samples by private companies appears to occur in greater numbers in the early fall with other growers predominantly submitting soil samples in the late winter and early spring. Cotton and wheat were sampled more often in the fall than the spring with the increase of corn sampling in 2013 occurring more frequently in the fall instead of the spring. Collection of home lawn samples also appears to be increasing during the fall months.

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. For the soil samples submitted in 2013, 79% of the samples and 99% of the represented acreage had commercial agricultural/farm crop codes. Likewise, 99% of the fertilizer and soil amendment tonnage sold was categorized for farm use. Four counties in eastern Arkansas (Arkansas, Craighead, Mississippi, and Poinsett) accounted for 18% of the total fertilizer sold.

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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 2013 through 31 December 2013.

Geographic area	Acres sampled	No. of samples	Acres/ sample
Ozark Highlands - Cherty Limestone and Dolomite	126,354	8,328	15
Ozark Highlands - Sandstone and Limestone	10,306	735	14
Boston Mountains	20,718	2,424	9
Arkansas Valley and Ridges	52,499	4,636	11
Ouachita Mountains	19,701	2,812	7
Bottom Lands and Terraces	300,266	10,923	28
Coastal Plain	36,899	3,876	10
Loessial Plains	439,964	9,394	47
Loessial Hills	10,368	950	11
Blackland Prairie	2,609	106	25
Sum or Average	1,019,684	44,184	23

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 2013 through 31 December 2013.

County	Acres sampled	No. of samples	Acres/ sample	County	Acres sampled	No. of samples	Acres/ sample
Arkansas, DeWitt	93,881	1,949	48	Lee	144,044	5,236	28
Arkansas, Stuttgart	10,937	346	32	Lincoln	6,579	230	29
Ashley	16,190	623	26	Little River	4,724	7,949	1
Baxter	2,715	428	6	Logan, Booneville	507	81	6
Benton	13,432	1,162	12	Logan, Paris	4,909	415	12
Boone	14,793	826	18	Lonoke	75,747	3,129	24
Bradley	392	66	6	Madison	6,861	447	15
Calhoun	507	75	7	Marion	1,483	164	9
Carroll	33,451	1,437	23	Miller	7,898	457	17
Chicot	18,822	339	56	Mississippi	16,721	10,937	2
Clark	2,979	373	8	Monroe	273,798	2,947	93
Clay, Corning	7,842	6,455	1	Montgomery	1,512	140	11
Clay, Piggott	7,864	9,744	1	Nevada	1,405	95	15
Cleburne	4,691	394	12	Newton	2,919	247	12
Cleveland	3,301	3,524	1	Ouachita	500	148	3
Columbia	2,360	238	10	Perry	1,428	130	11
Conway	22,541	751	30	Phillips	10,644	950	11
Craighead	13,367	24,282	1	Pike	3,979	212	19
Crawford	8,757	1,103	8	Poinsett	24,699	3,468	7
Crittenden	8,520	19,914	1	Polk	2,304	256	9
Cross	56,189	1,182	48	Pope	7,071	834	9
Dallas	444	78	6	Prairie, Des Arc	8,414	240	35
Desha	21,421	2,286	9	Prairie, De Valls Bluff	1,847	99	19
Drew	2,548	439	6	Pulaski	4,860	1,242	4
Faulkner	8,052	835	10	Randolph	16,712	1,183	14
Franklin, Charleston	789	132	6	Saline	2,029	854	2
Franklin, Ozark	5,461	378	15	Scott	2,530	150	17
Fulton	3,578	290	12	Searcy	2,228	127	18
Garland	2,675	1,572	2	Sebastian	3,958	622	6
Grant	713	136	5	Sevier	4,887	285	17
Greene	17,979	3,136	6	Sharp	5,113	392	13
Hempstead	8,141	634	13	St. Francis	3,834	2,483	2
Hot Spring	1,418	179	8	Stone	2,061	347	6
Howard	7,052	372	19	Union	1,099	194	6
Independence	7,202	464	16	Van Buren	3,569	326	11
Izard	5,504	360	15	Washington	38,750	3,049	13
Jackson	12,654	5,647	2	White	13,013	1,528	9
Jefferson	54,874	6,413	9	Woodruff	5,368	104	52
Johnson	6,157	419	15	Yell, Danville	6,040	338	18
Lafayette	2,598	76	34	Yell, Dardanelle	989	82	12
Lawrence	50,120	12,271	4	Sum or Average	1,289,944	163,445	8

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 2013 through 31 December 2013.

		Acres	No. of	Acres/	Median			
SAN	Soil association	sampled	samples	sample	pH	P	K	Zn
1.	Clarksville-Nixa-Noark	15,303	1,011	15	6.1	72	140	5.2
2.	Gepp-Doniphan-Gassville-Agnos	7,401	826	9	6.5	58	135	6.1
3.	Arkana-Moko	45,014	2,126	21	6.0	112	171	10.0
4.	Captina-Nixa-Tonti	55,902	4,234	13	6.2	116	156	9.6
5.	Captina-Doniphan-Gepp	1,377	51	27	5.8	29	74	1.6
6.	Eden-Newnata-Moko	1,357	80	17	5.6	57	117	3.6
7.	Estate-Portia-Moko	946	61	16	5.7	59	91	4.1
8.	Brockwell-Boden-Portia	9,360	674	14	6.2	38	110	4.4
9.	Linker-Mountainburg-Sidon	3,915	339	12	5.8	51	96	3.8
10.	Enders-Nella-Mountainburg-Steprock	16,803	2,085	8	5.9	81	117	6.2
11.	Falkner-Wrightsville	246	6	41	6.0	35	115	4.4
12.	Leadvale-Taft	18,553	2,227	8	5.8	57	116	6.1
13.	Enders-Mountainburg-Nella-Steprock	6,850	379	18	5.8	51	105	3.4
14.	Spadra-Guthrie-Pickwick	5,380	246	22	5.6	73	122	6.8
15.	Linker-Mountainburg	21,470	1,778	12	5.7	53	112	4.8
16.	Carnasaw-Pirum-Clebit	4,839	514	9	5.6	72	104	5.8
17.	Kenn-Ceda-Avilla	3,368	344	10	5.7	92	115	6.9
18.	Carnasaw-Sherwood-Bismarck	6,437	1,755	4	5.7	72	106	5.4
19.	Carnasaw-Bismarck	1,361	40	34	6.1	38	76	2.3
20.	Leadvale-Taft	1,034	46	23	5.5	47	93	4.3
21.	Spadra-Pickwick	2,662	113	24	5.6	33	118	4.2
22.	Foley-Jackport-Crowley	101,016	2,190	46	6.4	27	106	3.0
23.	Kobel	7,353	636	12	6.3	46	142	3.0
24.	Sharkey-Alligator-Tunica	18,000	620	29	6.6	39	201	3.4
25.	Dundee-Bosket-Dubbs	14,535	1,066	14	6.3	57	205	3.4
26.	Amagon-Dundee	19,233	910	21	6.4	62	162	4.0
27.	Sharkey-Steele	953	62	15	6.3	49	327	5.0
28.	Commerce-Sharkey-Crevasse-Robinsonville	2,068	64	32	6.1	62	168	4.0
29.	Perry-Portland	19,686	1,023	19	6.7	33	237	2.8
30.	Crevasse-Bruno-Oklared	2,534	92	28	6.4	26	193	2.6
31.	Roxana-Dardanelle-Bruno-Roellen	13,117	376	35	6.3	36	123	4.1
32.	Rilla-Hebert	86,029	3,414	25	6.5	39	133	2.9
33.	Billyhaw-Perry	6,238	214	29	6.8	24	121	3.2
34.	Severn-Oklared	5,842	102	57	6.0	54	144	5.1
35.	Adaton	508	19	27	5.0	56	119	6.5
36.	Wrightsville-Louin-Acadia	2,967	126	24	5.9	35	121	4.1
37.	Muskogee-Wrightsville-McKamie	187	9	21	5.9	75	162	6.8
38.	Amy-Smithton-Pheba	1,522	166	9	5.5	46	70	4.5
39.	Darco-Briley-Smithdale	31	12	3	5.5	30	80	3.5
40.	Pheba-Amy-Savannah	1,628	226	7	5.5	41	87	3.4
41.	Smithdale-Sacul-Savannah-Saffell	14,800	1,640	9	5.7	82	114	5.2
42.	Sacul-Smithdale-Sawyer	13,553	1,507	9	5.9	42	93	4.0
43.	Guyton-Ouachita-Sardis	5,365	325	17	5.5	108	143	9.2
44.	Calloway-Henry-Grenada-Calhoun	295,511	6,021	49	6.7	28	103	2.8
45.	Crowley-Stuttgart	144,453	3,373	43	6.5	27	104	3.1
46.	Loring	2,741	145	19	6.0	44	101	3.7
47.	Loring-Memphis	6,853	762	9	6.1	44	138	4.0
48.	Brandon	774	43	18	6.2	16	96	1.8
49.	Oktibbeha-Sumter	2,609	106	25	5.8	31	108	3.2
	Sum or Average	1,019,684	44,184	23	6.0	52	128	4.5

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 2013 through 31 December 2013.

Crop	Acres sampled	No. of samples	Acres/ sample
Corn	173,039	3,318	52
Cotton	22,171	2,118	11
Grain sorghum, non-irrigated	1,141	61	19
Grain sorghum, irrigated	7,667	167	46
Rice	120,142	2,923	41
Soybean	356,247	9,711	37
Wheat	14,651	493	30
Cool-season grass hay	9,752	494	20
Native warm-season grass hay	6,311	308	21
Warm-season grass hay	36,027	1,915	19
Pasture, all categories	173,860	8,341	21
Home garden	5,477	4,612	1
Turf	8,704	1,445	6
Home lawn	5,328	4,320	1
Small fruit	1,025	618	2
Ornamental	1,688	1,384	1
Sum or Average	943,230	42,228	22

Table 5. The percentage of sampled acres as distributed within five soil-test levels and median (Md) soil chemical property values by geographic area for soil samples submitted to the Soil Testing and Research Laboratory in Marianna from 1 January 2013 through 31 December 2013.

	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)
Ozark Highlands - Cherty Limestone and Dolomite	12	17	26	25	20	6.1	3	7	7	10	73	100	8	14	19	18	41	153	4	13	8	24	51	8.6
Ozark Highlands - Sandstone and Limestone	13	18	24	28	17	6.2	16	17	14	11	42	40	14	22	26	16	22	110	12	23	12	26	27	4.4
Boston Mountains	23	21	24	21	11	5.9	6	8	8	11	67	77	14	21	23	16	26	115	8	16	9	29	38	5.9
Arkansas Valley and Ridges	28	21	21	18	12	5.8	13	11	9	13	54	56	14	21	24	17	24	114	8	21	11	25	35	5.3
Ouachita Mountains	28	23	22	19	8	5.7	6	9	10	12	63	71	15	23	26	17	19	107	7	18	13	27	35	5.5
Bottom Lands and Terraces	11	11	20	36	22	6.4	11	17	18	21	33	38	6	16	23	19	36	141	11	36	19	24	10	3.2
Coastal Plain	33	19	18	19	11	5.7	14	10	8	11	57	62	24	19	21	15	21	103	10	24	11	19	36	4.8
Loessial Plains	8	9	17	30	36	6.6	18	27	21	18	16	27	9	28	36	17	10	103	16	37	15	23	9	2.9
Loessial Hills	19	18	20	26	17	6.1	18	16	10	14	42	42	12	15	22	21	30	131	9	28	14	23	26	3.9
Blackland Prairie	26	24	13	13	24	5.8	25	18	19	10	28	31	20	24	18	9	29	109	11	37	12	21	19	3.2
Average	20	18	21	24	17	6.0	13	14	12	13	48	55	14	20	24	17	25	119	10	35	12	24	19	4.8

[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. The percentage of sampled acres as distributed within five soil-test levels and median (Md) soil chemical property values by county for soil samples submitted to the Soil Testing and Research Laboratory in Marianna from 1 January 2013 through 31 December 2013.

	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)
Arkansas, DeWitt	4	6	11	23	56	7.1	11	29	28	22	10	29	4	26	43	18	9	107	6	25	23	38	8	3.9
Arkansas, Stuttgart	10	13	23	29	25	6.3	26	25	11	17	21	25	4	27	34	13	22	109	22	28	17	24	9	3.0
Ashley	14	19	23	31	13	6.1	10	14	13	20	43	45	14	18	22	16	30	120	21	32	13	19	15	2.9
Baxter	7	8	11	24	50	7.0	5	8	7	12	68	88	5	3	23	22	37	147	1	11	7	22	56	10.5
Benton	14	19	25	27	15	6.1	1	4	5	8	82	133	5	13	19	18	45	164	1	7	6	24	62	10.6
Boone	10	17	30	27	16	6.1	5	10	10	13	62	71	11	12	17	16	44	155	6	20	10	24	40	5.8
Bradley	23	15	24	23	15	6.1	9	3	2	8	78	144	14	15	23	17	31	122	15	12	5	23	45	7.3
Calhoun	44	27	15	11	3	5.4	19	8	15	16	42	44	45	27	13	9	6	64	12	27	7	24	30	4.5
Carroll	13	21	26	24	16	6.0	1	4	5	9	81	139	7	10	13	13	57	199	1	5	5	22	67	13.3
Chicot	7	10	19	43	21	6.6	15	26	11	9	39	34	7	16	12	13	52	196	6	24	18	29	23	4.2
Clark	31	22	20	19	8	5.7	12	13	9	12	36	64	20	17	21	17	25	118	10	24	11	26	29	4.6
Clay, Corning	2	7	20	45	26	6.6	11	25	24	23	17	31	7	29	36	18	10	104	12	24	13	30	21	4.2
Clay, Piggott	7	10	23	40	20	6.4	4	9	13	21	53	53	4	15	28	26	27	137	10	32	19	31	8	3.4
Cleburne	30	20	22	23	5	5.7	7	10	10	12	61	71	16	18	26	20	20	111	15	24	7	22	32	4.6
Cleveland	23	22	22	24	9	5.9	3	13	14	20	50	51	2	6	16	19	57	192	3	28	25	37	7	3.8
Columbia	41	22	16	11	10	5.5	14	11	11	11	53	57	35	23	21	9	12	78	17	27	13	14	29	3.4
Conway	33	16	16	16	19	5.8	21	15	14	10	40	36	21	23	23	16	17	102	15	24	11	25	25	4.1
Craighead	5	9	20	38	28	6.6	7	12	14	21	46	47	4	11	21	23	41	157	6	30	23	35	6	3.6
Crawford	16	14	15	14	41	6.4	13	18	14	17	38	40	7	15	22	22	34	143	3	16	14	43	24	5.3
Crittenden	7	9	18	40	26	6.6	9	19	23	26	23	35	3	7	14	17	59	201	6	27	25	39	3	3.7
Cross	5	4	11	29	51	7.0	15	23	21	19	22	31	13	29	26	12	20	100	9	37	17	2	9	3.2
Dallas	32	24	18	18	8	5.6	10	15	17	19	39	43	31	21	23	10	15	85	22	21	10	19	28	3.7
Desha	1	4	15	42	38	6.7	11	17	19	27	26	35	3	11	20	16	50	160	13	44	23	17	3	2.7
Drew	35	19	22	16	8	5.6	28	21	13	11	27	26	36	17	16	11	20	86	14	24	11	30	21	4.1
Faulkner	31	19	18	18	14	5.7	18	15	12	15	40	39	15	27	27	14	17	102	13	25	14	21	27	3.9
Franklin, Charleston	39	17	17	14	13	5.5	18	14	6	12	50	49	20	16	25	9	30	111	8	22	9	22	39	5.5
Franklin, Ozark	25	32	25	12	6	5.6	10	11	8	8	63	92	15	20	18	14	33	125	7	17	9	19	48	7.3
Fulton	12	18	22	27	21	6.2	7	10	14	20	49	50	10	16	23	21	30	133	11	20	17	25	27	4.1
Garland	27	22	24	20	7	5.8	4	7	12	14	63	69	11	25	30	17	17	105	5	17	15	30	33	5.3
Grant	37	24	13	11	15	5.5	18	19	11	9	43	37	29	26	15	7	23	82	15	29	13	21	22	3.2
Greene	10	11	24	35	20	6.3	13	21	19	20	27	34	9	18	29	22	22	122	7	27	18	35	13	3.9
Hempstead	32	19	12	23	14	5.7	34	15	11	8	32	27	37	20	14	12	17	74	7	34	10	16	33	3.8
Hot Spring	27	24	21	22	6	5.7	7	15	11	15	52	56	22	21	17	12	28	105	11	22	11	20	36	5.0
Howard	49	22	12	10	7	5.4	8	4	4	4	80	156	15	15	17	19	34	136	6	12	4	22	56	10.0
Independence	16	20	24	24	16	6.0	9	13	16	17	45	46	18	24	27	13	18	97	21	30	10	19	20	3.0
Izard	21	22	24	19	14	5.9	9	14	11	11	55	65	18	27	21	16	18	97	12	29	8	20	31	4.1
Jackson	8	14	21	31	26	6.4	30	26	16	14	14	23	11	29	32	18	10	101	15	44	18	17	6	2.7
Jefferson	9	8	17	33	33	6.6	5	16	21	25	33	40	4	16	26	18	36	140	15	38	18	19	10	2.9
Johnson	24	23	26	18	9	5.8	8	12	12	14	54	57	11	22	23	18	26	122	6	22	12	32	28	4.9
Lafayette	41	9	15	16	19	5.7	15	7	15	12	51	55	13	16	17	22	32	141	15	21	15	24	25	4.0
Lawrence	5	10	25	37	23	6.4	25	29	21	15	10	24	9	22	33	21	15	112	9	38	19	25	9	3.2
Lee	6	6	12	36	40	6.8	7	13	18	26	36	42	5	16	29	24	26	131	24	39	14	21	2	2.4
Lincoln	19	12	25	24	20	6.1	9	10	9	12	60	62	7	17	19	17	40	145	14	27	14	24	21	3.7
Little River	5	8	21	28	38	6.6	15	20	17	19	29	34	1	10	27	21	41	152	20	45	16	17	2	2.5

continued

Table 6. Continued.

Geographic area	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	19	17	21	28	15	6.0	10	11	4	15	60	73	14	11	14	21	40	159	3	15	11	14	57	10.1
Logan, Paris	24	35	26	11	4	5.6	5	5	7	12	71	85	14	15	20	15	36	134	2	14	9	29	46	7.1
Lonoke	14	19	29	29	9	6.0	15	30	21	16	18	27	12	32	32	12	12	96	25	48	12	10	5	2.2
Madison	17	29	26	20	8	5.8	2	5	4	7	72	119	9	12	20	16	43	150	1	9	8	33	49	8.1
Marion	8	12	20	21	39	6.5	2	10	9	10	69	130	7	12	19	15	47	160	5	9	10	20	56	9.8
Miller	32	21	18	16	13	5.7	15	12	8	15	50	51	23	22	20	16	19	96	14	26	13	16	31	3.7
Mississippi	5	8	24	47	16	6.4	1	5	10	21	63	59	1	5	19	34	41	165	2	21	24	38	15	4.2
Monroe	6	6	15	31	42	6.8	29	24	18	16	13	25	9	24	34	24	9	110	18	33	13	25	11	3.0
Montgomery	25	19	19	25	12	5.8	9	10	9	7	65	77	16	15	26	11	32	118	8	19	13	24	36	5.4
Nevada	30	17	20	16	17	5.9	19	13	4	11	53	58	35	25	21	5	14	78	15	18	7	21	39	5.1
Newton	13	21	31	26	9	6.0	4	9	8	10	69	78	8	18	21	20	33	135	8	20	11	27	34	5.3
Ouachita	34	15	16	24	11	5.8	12	16	6	9	57	63	29	28	14	14	15	85	10	21	14	18	37	4.9
Perry	26	34	17	13	10	5.6	15	12	14	9	50	51	24	17	20	16	23	99	9	16	10	25	40	5.5
Phillips	8	7	14	42	29	6.6	4	14	20	28	34	41	2	13	38	28	19	128	20	41	16	19	4	2.6
Pike	51	24	17	7	1	5.3	8	7	5	7	73	125	24	24	18	16	18	93	8	13	13	23	43	6.5
Poinsett	4	6	16	37	37	6.7	15	28	24	18	15	28	8	20	26	18	28	122	6	28	21	31	14	3.8
Polk	32	20	15	19	14	5.7	3	14	7	8	68	90	15	23	20	15	27	112	7	18	10	20	45	6.5
Pope	31	22	21	16	10	5.7	19	11	7	10	53	53	12	21	25	19	23	118	6	22	12	25	35	5.2
Prairie, Des Arc	13	8	16	41	22	6.5	20	34	23	15	8	24	8	30	48	9	5	98	23	38	13	21	5	2.6
Prairie, De Valls Bluff	16	14	17	26	27	6.4	14	33	15	8	30	26	6	21	30	22	21	118	13	38	11	16	22	3.0
Pulaski	30	12	19	23	16	6.0	10	8	8	10	64	74	11	21	27	18	23	114	7	14	8	22	49	7.8
Randolph	4	13	31	42	10	6.3	16	31	23	16	14	27	15	34	22	16	13	92	10	28	19	30	13	3.6
Saline	26	19	23	20	12	5.8	7	7	8	14	64	69	13	15	28	23	21	124	7	23	16	29	25	4.4
Scott	19	24	35	11	11	5.8	9	9	9	12	61	64	25	19	15	15	26	107	6	17	14	22	41	5.7
Searcy	35	17	18	21	9	5.7	6	8	13	16	57	57	10	18	22	19	31	131	17	24	11	22	26	4.0
Sebastian	24	15	21	23	17	6.0	12	10	7	11	60	67	7	18	25	22	28	130	2	9	9	28	52	8.4
Sevier	37	25	15	15	8	5.5	7	8	4	6	75	113	15	16	11	19	39	150	6	12	7	19	56	9.9
Sharp	9	18	26	29	18	6.2	12	14	13	11	50	51	12	21	26	16	25	115	10	24	10	24	32	5.0
St. Francis	15	19	24	30	12	6.1	4	8	16	28	44	47	4	6	10	9	71	256	8	30	18	39	5	3.7
Stone	35	16	19	18	12	5.7	6	6	8	15	65	72	21	32	22	9	16	87	16	23	11	26	24	4.1
Union	31	16	24	19	10	5.8	12	9	8	9	62	70	30	21	24	10	15	88	12	15	8	18	47	6.9
Van Buren	27	26	26	16	5	5.7	9	10	11	14	56	58	17	19	28	15	21	108	15	29	10	24	22	3.6
Washington	10	16	27	27	20	6.2	3	6	7	8	76	108	8	12	20	21	39	153	2	10	8	26	54	9.2
White	22	18	21	26	13	6.0	11	11	10	14	54	58	18	24	24	15	19	99	11	22	10	28	29	4.7
Woodruff	23	14	29	22	12	5.9	11	23	37	16	13	29	8	26	43	13	10	100	5	37	37	16	5	3.2
Yell, Danville	29	32	25	12	2	5.6	7	7	8	9	69	107	17	16	20	16	31	126	4	11	8	27	50	8.1
Yell, Dardanelle	23	16	24	29	8	5.9	6	5	5	7	77	108	11	21	24	18	26	119	4	10	9	33	44	7.6
Average	21	17	21	23	18	6.0	11	14	12	14	49	60	14	19	23	17	27	123	10	24	13	24	29	5.1

[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 7. The percentage of sampled acres as distributed within five soil-test levels and median (Md) soil chemical property values by previous crop for soil samples submitted to the Soil Testing and Research Laboratory in Marianna from 1 January 2013 through 31 December 2013.

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
	---(% of sampled acreage) ---						--(% of sampled acreage) --					(ppm)
Corn	7	10	23	34	26	6.4	7	16	20	27	30	39
Cotton	7	7	19	40	27	6.5	4	5	13	25	53	53
Grain sorghum, non-irrigated	33	28	16	13	10	5.6	0	7	16	36	41	47
Grain sorghum, irrigated	7	9	15	32	27	6.7	16	19	27	22	16	30
Rice	7	10	16	37	30	6.6	22	34	23	14	7	23
Soybean	7	9	19	33	32	6.6	12	26	24	22	16	30
Wheat	27	19	20	15	19	5.9	13	16	21	16	34	36
Cool-season grass hay	16	25	27	24	8	5.9	8	13	11	13	55	56
Native warm-season grass hay	35	24	22	13	6	5.6	16	15	19	11	39	35
Warm-season grass hay	29	22	24	18	7	5.7	16	12	10	12	50	51
Pasture, all categories	25	25	25	19	6	5.7	12	10	9	11	58	69
Home garden	10	9	16	28	27	6.6	4	5	4	6	81	148
Turf	16	13	22	32	17	6.2	3	5	7	12	73	80
Home lawn	30	19	21	20	10	5.8	7	11	12	16	54	57
Small fruit	35	17	19	16	13	5.7	7	8	7	11	67	77
Ornamental	14	11	18	28	29	6.4	13	8	6	10	63	75
Average	19	16	20	25	20	6.1	10	13	14	17	46	57

Geographic area	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)---					(ppm)	---- (% of sampled acreage) ----					(ppm)
Corn	4	16	31	23	26	129	9	33	19	34	5	3.4
Cotton	1	11	22	25	41	158	23	36	19	20	2	2.7
Grain sorghum, non-irrigated	2	13	30	26	29	140	12	39	23	21	5	3.0
Grain sorghum, irrigated	25	29	25	9	12	85	11	59	16	12	2	2.4
Rice	7	24	27	12	30	116	9	43	21	22	5	3.0
Soybean	7	26	32	15	20	110	15	42	19	23	1	2.8
Wheat	11	21	22	14	32	122	24	47	13	10	6	2.1
Cool-season grass hay	23	22	22	13	20	98	10	25	13	26	26	4.2
Native warm-season grass hay	30	20	17	13	20	91	15	25	11	24	25	4.0
Warm-season grass hay	27	23	20	13	17	90	14	26	10	21	29	4.0
Pasture, all categories	16	18	19	15	32	124	8	20	10	22	40	5.9
Home garden	6	10	17	17	50	176	3	8	6	18	65	12.9
Turf	14	19	25	18	24	114	2	9	10	39	40	6.8
Home lawn	8	21	31	22	18	116	4	18	17	35	26	4.9
Small fruit	14	25	23	15	23	108	9	19	9	25	38	5.7
Ornamental	12	22	26	19	21	112	5	10	6	21	58	9.9
Average	13	20	24	17	26	118	11	29	14	23	23	4.9

[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 2013 through 30 June 2014[a].

County	Fertilizer sold	County	Fertilizer sold	County	Fertilizer sold
	(tons)		(tons)		(tons)
Arkansas	86,940	Garland	1,683	Newton	576
Ashley	16,569	Grant	288	Ouachita	48
Baxter	1,503	Greene	31,128	Perry	461
Benton	5,752	Hempstead	7,467	Phillips	51,394
Boone	3,082	Hot Spring	773	Pike	255
Bradley	1,253	Howard	660	Poinsett	72,558
Calhoun	148	Independence	10,592	Polk	543
Carroll	1,760	Izard	1,128	Pope	1,795
Chicot	35,068	Jackson	27,510	Prairie	37,350
Clark	482	Jefferson	33,605	Pulaski	10,286
Clay	56,638	Johnson	592	Randolph	19,221
Cleburne	1,268	Lafayette	6,313	Saline	1,225
Cleveland	68	Lawrence	31,851	Scott	175
Columbia	652	Lee	50,412	Searcy	1,145
Conway	5,533	Lincoln	13,035	Sebastian	2,593
Craighead	64,964	Little River	4,473	Sevier	800
Crawford	5,401	Logan	815	Sharp	765
Crittenden	26,560	Lonoke	51,574	St. Francis	28,652
Cross	43,573	Madison	2,808	Stone	892
Dallas	464	Marion	1,582	Union	817
Desha	35,387	Miller	4,945	Van Buren	6,547
Drew	8,812	Mississippi	60,285	Washington	5,564
Faulkner	4,120	Monroe	56,936	White	18,201
Franklin	1,364	Montgomery	318	Woodruff	31,702
Fulton	1,276	Nevada	508	Yell	318

[a] Arkansas Distribution of Fertilizer Sales by County, 1 July 2013 to 30 June 2014, 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 2013 through 30 June 2014[a].

Fertilizer	Container			Use		Totals
	Bag	Bulk	Liquid	Farm	Non-farm	
	(tons)					
Multi-nutrient	29,150	304,372	7,568	332,671	8,419	341,090
Nitrogen	72,744	427,331	71,884	570,967	991	571,958
Phosphate	61	53,024	345	53,416	15	53,431
Potash	535	122,318	511	123,138	226	123,364
Organic	48	1,060	0	1,057	51	1,108
Micronutrient	373	656	25	1,023	30	1,053
Lime	360	2,833	0	3,129	64	3,193
Miscellaneous	2,014	4,850	1,787	8,281	370	8,651
Totals	105,285	916,444	82,120	1,093,682	10,166	1,103,848

[a] Arkansas Distribution of Fertilizer Sales by County, 1 July 2013 to 30 June 2014, 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 10. Estimated cation exchange capacity (ECEC) percentage of sampled acreage distribution among seven ranges and median (Md) values by county for soil samples submitted to the Soil Testing and Research Laboratory in Marianna in 2011. Values based on 161,750 soil samples from field average and grid samples.

	ECEC Range ($cmol_c$/kg soil)							
County	<6	6-10	11-15	16-20	21-25	26-30	>30	Md
	---------- (% of samples) ----------							
Arkansas, DeWitt	0	24	55	13	3	2	3	12
Arkansas, Stuttgart	0	31	57	7	3	1	1	12
Ashley	3	71	15	5	2	2	2	9
Baxter	0	18	23	17	16	16	10	18
Benton	2	22	46	17	7	3	3	13
Boone	1	47	35	9	4	2	2	11
Bradley	0	71	20	5	3	0	1	9
Calhoun	5	85	10	0	0	0	0	8
Carroll	0	28	49	13	0	3	7	12
Chicot	1	38	21	9	7	8	16	13
Clark	3	57	22	9	4	1	4	10
Clay, Corning	2	59	26	9	3	1	0	10
Clay, Piggott	2	59	30	6	2	1	0	10
Cleburne	1	61	28	5	2	2	1	9
Cleveland	0	47	34	11	4	2	2	11
Columbia	7	67	16	4	2	1	3	8
Conway	0	56	25	6	3	4	6	10
Craighead	0	22	41	22	10	4	1	14
Crawford	1	61	27	5	3	1	2	10
Crittenden	0	8	25	25	17	11	14	19
Cross	0	16	52	19	6	2	5	13
Dallas	0	74	16	6	2	1	1	9
Desha	0	46	29	11	6	4	4	11
Drew	0	50	30	8	6	3	3	10
Faulkner	0	54	31	8	4	2	1	10
Franklin, Charleston	0	37	47	13	0	0	3	11
Franklin, Ozark	0	60	33	5	0	0	2	10
Fulton	0	68	17	6	4	4	1	9
Garland	1	41	38	12	5	2	1	11
Grant	4	74	11	8	1	1	1	8
Greene	0	36	37	18	7	2	0	12
Hempstead	1	69	17	6	1	1	5	9
Hot Spring	3	57	25	9	5	0	1	9
Howard	1	48	33	8	3	2	5	11
Independence	1	36	41	12	6	3	1	12
Izard	5	79	14	2	0	0	0	8
Jackson	2	47	28	15	7	1	0	11
Jefferson	0	49	24	9	6	5	7	11
Johnson	1	57	30	6	4	2	0	10
Lafayette	1	49	19	11	4	5	11	10
Lawrence	1	36	26	15	12	8	2	12
Lee	0	25	40	11	7	8	9	13
Lincoln	0	37	22	17	7	10	7	13
Little River	0	23	33	11	7	8	18	14
Logan, Booneville	0	68	24	5	1	1	1	9
Logan, Paris	1	60	26	6	4	2	1	10
Lonoke	0	55	26	8	4	4	3	10
Madison	0	46	44	8	1	1	0	11
Marion	2	49	23	7	5	7	7	10
Miller	2	62	25	7	3	0	1	9
Mississippi	0	47	33	12	5	2	1	11
Monroe	0	24	49	18	5	3	1	13
Montgomery	0	44	34	9	7	3	3	11
Nevada	0	48	27	17	5	2	0	11
Newton	1	52	27	14	4	2	1	10
Ouachita	11	75	7	3	3	0	1	7
Perry	1	50	36	9	3	1	0	10
Phillips	0	37	43	8	3	5	4	11
Pike	1	68	24	7	0	0	0	9
Poinsett	0	21	42	23	8	4	2	13
Polk	1	55	32	8	2	1	1	10
Pope	0	51	28	8	5	5	3	10
Prairie, Des Arc	0	44	48	3	3	2	0	11

continued

Table 10. Continued.

County	ECEC Range (cmol$_c$/kg soil)							
	<6	6-10	11-15	16-20	21-25	26-30	>30	Md
	(% of samples)							
Prairie, De Valls Bluff	0	47	34	6	6	5	2	11
Pulaski	1	37	38	16	6	2	0	12
Randolph	1	56	22	8	8	5	0	10
Saline	1	48	29	12	6	2	2	11
Scott	0	59	30	7	1	2	1	10
Searcy	0	52	31	7	5	4	1	10
Sebastian	3	40	36	8	4	4	5	11
Sevier	1	62	28	5	2	1	1	9
Sharp	1	49	25	8	7	5	5	11
St. Francis	0	41	34	11	6	5	3	11
Stone	0	38	35	16	5	3	3	12
Union	5	63	24	4	2	1	1	8
Van Buren	9	70	13	4	3	1	0	9
Washington	1	27	40	16	8	4	4	13
White	6	65	19	6	3	1	0	9
Woodruff	1	44	38	15	2	0	0	11
Yell, Danville	0	61	29	4	4	1	1	10
Yell, Dardanelle	0	57	29	14	0	0	0	10
Average	1	49	30	10	4	3	3	10.7

Table 11. Estimated cation exchange capacity (ECEC) percentage of sampled acreage distribution among seven ranges and median (Md) values by county for soil samples submitted to the Soil Testing and Research Laboratory in Marianna in 2012. Values based on 192,317 soil samples from field average and grid samples.

County	ECEC Range (cmol$_c$/kg soil)							
	<6	6-10	11-15	16-20	21-25	26-30	>30	Md
	(% of samples)							
Arkansas, DeWitt	0	27	53	13	3	2	2	12
Arkansas, Stuttgart	0	28	61	7	3	1	0	12
Ashley	1	77	17	4	1	0	0	9
Baxter	1	22	23	14	17	15	8	17
Benton	0	22	46	16	7	4	5	13
Boone	0	40	45	8	3	2	2	11
Bradley	0	59	32	6	0	2	1	10
Calhoun	6	88	0	3	0	0	3	8
Carroll	0	33	48	13	2	2	2	12
Chicot	0	26	20	11	9	7	27	17
Clark	5	46	19	10	5	4	11	10
Clay, Corning	1	62	27	8	2	0	0	10
Clay, Piggott	1	59	26	8	4	2	0	10
Cleburne	1	64	26	6	2	0	1	10
Cleveland	0	51	25	8	5	4	7	10
Columbia	7	77	10	3	1	1	1	8
Conway	0	68	23	7	1	1	0	9
Craighead	0	32	39	17	8	4	0	12
Crawford	1	45	28	12	7	5	2	11
Crittenden	0	8	22	23	20	14	13	20
Cross	2	16	49	20	6	4	3	13
Dallas	2	67	20	4	2	5	0	9
Desha	0	32	23	15	13	9	8	14
Drew	1	48	32	7	7	2	3	11
Faulkner	2	52	28	8	5	2	3	10
Franklin, Charleston	0	50	40	4	5	1	0	11
Franklin, Ozark	0	66	26	7	0	1	0	10
Fulton	1	56	22	10	4	4	3	10
Garland	0	32	42	16	5	3	2	12

continued

Table 11. Continued.

	ECEC Range (cmol$_c$/kg soil)							
County	<6	6-10	11-15	16-20	21-25	26-30	>30	Md
	(% of samples)							
Grant	2	66	19	7	6	0	0	9
Greene	1	47	29	14	6	2	1	11
Hempstead	0	58	15	8	4	4	11	10
Hot Spring	3	66	21	6	2	1	1	9
Howard	1	47	28	9	5	4	6	11
Independence	0	28	50	16	5	1	0	12
Izard	3	71	22	3	1	0	0	9
Jackson	2	56	26	11	4	1	0	9
Jefferson	0	48	25	11	6	6	4	11
Johnson	0	53	32	8	5	1	1	10
Lafayette	0	64	16	10	1	0	9	9
Lawrence	1	43	29	13	8		1	11
Lee	0	25	41	11	10	8	5	13
Lincoln	0	51	29	12	4	2	2	10
Little River	0	23	44	9	7	7	10	13
Logan, Booneville	0	51	41	5	1	1	1	10
Logan, Paris	0	58	35	4	2	1	0	10
Lonoke	0	55	28	6	4	3	4	10
Madison	0	42	43	9	3	1	2	11
Marion	0	34	37	14	8	5	2	12
Miller	1	51	30	8	5	2	3	10
Mississippi	0	40	30	15	9	4	2	12
Monroe	0	16	47	24		2	2	14
Montgomery	0	34	38	15	6	3	4	12
Nevada	1	53	27	8	3	1	7	9
Newton	0	52	31	10	2	2	3	10
Ouachita	9	71	16	2	0	0	2	8
Perry	0	41	46	9	1	1	1	11
Phillips	0	40	37	8	6	7	2	11
Pike	2	65	21	7	3	1	1	10
Poinsett	0	14	33	17	13	12	11	16
Polk	0	48	32	10	4	1	5	11
Pope	0	49	34	10	5	1	1	11
Prairie, Des Arc	0	56	36	4	3	1	0	10
Prairie, De Valls Bluff	0	29	54	15	1	1	0	12
Pulaski	0	35	35	15	10	3	2	12
Randolph	1	52	34	8	4	1	0	10
Saline	1	42	31	15	6	4	1	11
Scott	0	47	42	6	3	2	0	11
Searcy	0	53	30	13	2	0	2	10
Sebastian	0	38	38	14	5	1	4	11
Sevier	0	52	28	7	1	1	10	10
Sharp	1	50	28	7	5	4	6	10
St. Francis	0	37	37	12	7	4	3	12
Stone	0	46	35	11	4	2	2	11
Union	0	61	27	5	1	0	0	9
Van Buren	6	67	18	5	3	2	2	9
Washington	3	23	44	18	7	4	3	13
White	1	63	23	6	3	0	0	9
Woodruff	5	45	30	17	7	0	0	11
Yell, Danville	1	61	30	4	3	1	1	10
Yell, Dardanelle	0	67	13	3	11	3	0	9
Average	1	47	31	10	5	3	3	10.9

Table 12. Estimated cation exchange capacity (ECEC) percentage of sampled acreage distribution among seven ranges and median (Md) values by county for soil samples submitted to the Soil Testing and Research Laboratory in Marianna in 2013. Values based on 163,433 soil samples from field average and grid samples.

	ECEC Range ($cmol_c$/kg soil)							
County	<6	6-10	11-15	16-20	21-25	26-30	>30	Md
	(% of samples)							
Arkansas, DeWitt	0	24	56	14	3	2	1	13
Arkansas, Stuttgart	0	33	41	10	5	4	7	12
Ashley	2	58	22	5	4	5	6	10
Baxter	0	26	23	12	17	13	9	16
Benton	1	21	48	15	7	3	5	13
Boone	1	43	37	12	5	2	0	11
Bradley	0	61	38	0	1	0	0	10
Calhoun	7	88	3	1	8	0	1	7
Carroll	0	35	43	15	4	1	2	12
Chicot	3	28	20	7	7	13	22	13
Clark	3	53	17	11	5	2	9	10
Clay, Corning	1	51	32	9	5	2	0	10
Clay, Piggott	3	65	24	6	1	1	0	9
Cleburne	1	61	27	6	3	1	1	10
Cleveland	0	37	26	11	11	6	9	12
Columbia	6	80	11	1	0	0	2	8
Conway	1	58	27	7	4	2	1	10
Craighead	0	28	33	18	10	6	5	13
Crawford	2	36	31	15	10	4	2	12
Crittenden	0	6	2	19	18	16	21	22
Cross	0	13	52	17	8	6	4	14
Dallas	3	71	19	3	1	1	2	9
Desha	0	26	18	13	10	8	25	17
Drew	0	54	27	7	4	4	4	10
Faulkner	2	55	26	9	5	2	1	10
Franklin, Charleston	0	57	27	9	5	2	0	10
Franklin, Ozark	1	73	21	4	1	0	0	9
Fulton	0	55	24	8	7	4	2	10
Garland	1	39	43	12	3	1	1	11
Grant	2	71	16	4	2	4	1	9
Greene	0	36	34	18	8	4	0	12
Hempstead	1	57	21	9	4	2	6	10
Hot Spring	1	65	22	5	3	2	2	9
Howard	1	55	33	5	1	1	4	10
Independence	0	51	33	9	4	2	1	10
Izard	2	81	11	3	3	0	0	8
Jackson	2	35	35	17	9	2	0	12
Jefferson	0	43	21	10	7	6	13	12
Johnson	0	63	24	9	2	1	1	9
Lafayette	1	47	26	8	5	3	10	11
Lawrence	0	28	32	17	12	7	4	14
Lee	0	25	52	12	6	3	2	12
Lincoln	0	52	28	9	6	3	2	10
Little River	0	20	33	12	9	8	18	15
Logan, Booneville	0	37	41	11	9	1	2	12
Logan, Paris	0	60	34	3	2	1	0	10
Lonoke	0	57	31	5	3	2	2	10
Madison	0	34	42	17	5	2	0	12
Marion	1	27	27	15	10	10	10	15
Miller	4	56	20	7	5	3	5	9
Mississippi	0	51	27	11	5	4	2	10
Monroe	0	20	47	25	6	2	0	14
Montgomery	0	42	30	16	4	4	4	11
Nevada	11	43	39	2	5	0	0	10
Newton	0	39	46	11	1	1	2	11
Ouachita	4	71	14	7	1	1	2	8
Perry	0	49	35	11	3	0	2	11
Phillips	0	32	49	11	5	2	1	12
Pike	0	71	21	6	1	1	0	9
Poinsett	0	21	31	20	11	7	10	15
Polk	1	47	27	9	9	5	2	11
Pope	1	47	38	9	4	1	0	11
Prairie, Des Arc	0	52	43	2	1	0	2	10

continued

Table 12. Continued.

County	ECEC Range ($cmol_c$/kg soil)							
	<6	6-10	11-15	16-20	21-25	26-30	>30	Md
	---------- (% of samples) ----------							
Prairie, De Valls Bluff	1	28	49	10	6	1	6	12
Pulaski	1	33	34	17	8	4	4	12
Randolph	1	56	25	7	6	4	1	10
Saline	0	49	36	9	3	2	0	11
Scott	0	51	35	8	2	3	1	10
Searcy	1	57	24	10	2	3	4	10
Sebastian	0	35	42	9	6	4	3	11
Sevier	1	52	30	6	2	1	8	10
Sharp	0	57	23	11	4	2	3	10
St. Francis	0	13	20	15	23	20	9	21
Stone	0	48	30	13	6	2	1	11
Union	6	67	20	4	3	0	0	9
Van Buren	1	75	16	5	2	1	0	9
Washington	1	29	41	17	7	3	2	13
White	2	71	21	4	2	0	0	9
Woodruff	0	44	42	11	2	1	0	11
Yell, Danville	0	57	36	4	2	0	1	10
Yell, Dardanelle	1	44	34	15	4	0	2	11
Average	1	47	30	10	5	3	4	11.2

Table 13. Number of soil samples analyzed by month per county submitted to the Soil Testing and Research Laboratory in Marianna in 2006. The soil sample number values include both field average and grid soil samples (n = 84,066).

	Number of samples analyzed by month in 2006											
County	January	February	March	April	May	June	July	August	September	October	November	December
Arkansas, DeWitt	647	82	881	195	17	21	13	32	48	49	4	18
Arkansas, Stuttgart	282	299	1141	485	32	11	6	128	29	65	326	7
Ashley	167	51	74	26	4	3	3	26	25	57	7	204
Baxter	38	110	40	56	18	32	10	31	53	62	16	10
Benton	1503	352	1067	1390	138	42	64	36	93	32	65	127
Boone	172	129	125	68	10	40	32	43	36	24	44	15
Bradley	31	11	14	19	5	5	4	12	11	12	11	12
Calhoun	5	8	1	12	5	1	6	0	1	0	3	0
Carroll	79	136	79	140	13	52	56	84	62	86	23	32
Chicot	48	32	102	117	19	10	5	2	21	75	160	157
Clark	65	27	41	67	14	4	33	17	8	15	21	2
Clay, Corning	622	67	43	185	1	0	8	1	302	258	3	182
Clay, Piggott	941	437	906	793	46	46	7	13	227	418	124	101
Cleburne	57	59	13	60	2	7	32	53	7	70	12	31
Cleveland	19	15	23	168	14	7	0	7	2	20	1	0
Columbia	10	33	22	37	16	16	5	23	13	20	8	1
Conway	35	86	56	71	37	22	33	11	10	24	11	10
Craighead	690	178	1149	825	73	39	33	34	121	1569	505	1337
Crawford	37	24	66	62	35	30	85	23	48	14	12	0
Crittenden	305	4	157	82	0	10	4	6	2	77	89	174
Cross	504	145	344	301	11	12	13	11	14	122	192	20
Dallas	0	3	70	20	2	2	3	12	0	0	1	0
Desha	59	57	334	7	34	6	2	6	66	17	32	510
Drew	38	20	30	24	29	3	6	14	38	180	48	1
Faulkner	48	84	71	96	41	61	39	32	36	62	13	14
Franklin, Charleston	3	3	4	1	2	0	0	0	2	0	4	0
Franklin, Ozark	0	30	31	32	17	17	25	5	20	20	11	11
Fulton	62	39	17	32	19	3	10	4	30	4	3	10
Garland	77	181	212	218	120	69	86	76	113	117	65	220
Grant	21	50	58	31	14	7	18	33	14	3	6	0
Greene	826	341	343	334	37	9	6	24	39	23	14	28
Hempstead	36	66	49	60	47	46	5	31	23	21	21	5
Hot Spring	32	37	45	62	10	29	26	11	18	18	23	2
Howard	30	14	51	35	69	45	13	39	33	15	29	8
Independence	71	38	56	210	17	10	69	20	23	17	4	12
Izard	14	20	31	50	5	6	6	32	54	28	24	3
Jackson	145	1061	972	210	9	17	9	117	113	1163	145	20
Jefferson	262	97	330	132	39	30	45	17	27	84	333	152
Johnson	14	74	75	119	10	6	41	26	47	4	54	14
Lafayette	107	40	16	26	17	4	2	5	5	47	17	4
Lawrence	972	80	1149	1730	99	84	10	21	85	531	3	105
Lee	246	123	1300	691	54	5	83	171	59	472	351	220
Lincoln	15	0	15	15	1	7	6	8	7	39	3	8
Little River	7	55	42	58	7	3	0	32	13	75	4	11
Logan, Booneville	6	5	14	12	11	25	5	21	7	4	2	0
Logan, Paris	48	9	39	51	16	36	1	12	38	33	26	27
Lonoke	593	270	305	293	39	26	58	78	67	238	52	58

continued

Table 13. Continued.

	Number of samples analyzed by month in 2006											
County	January	February	March	April	May	June	July	August	September	October	November	December
Madison	92	73	128	166	24	35	7	78	76	31	15	27
Marion	17	39	12	114	1	7	2	5	18	21	36	9
Miller	88	67	52	38	33	39	28	12	28	56	22	11
Mississippi	218	98	154	1160	297	1	0	9	2	499	283	190
Monroe	150	6	672	14	15	3	11	3	31	26	39	12
Montgomery	16	39	24	53	22	61	24	19	25	27	15	18
Nevada	8	10	15	9	4	8	15	14	12	6	0	1
Newton	26	28	9	34	7	7	1	15	12	11	6	1
Ouachita	24	30	11	28	15	16	1	16	7	11	2	5
Perry	19	11	64	36	37	16	8	6	1	69	5	0
Phillips	102	28	84	10	14	5	11	7	17	171	10	76
Pike	5	20	20	70	25	19	10	19	9	42	2	12
Poinsett	201	149	386	289	18	17	9	11	12	193	33	85
Polk	34	63	55	88	37	63	12	30	45	29	23	4
Pope	54	95	82	195	92	61	30	45	48	35	59	9
Prairie, Des Arc	41	10	90	51	4	5	1	5	23	14	2	50
Prairie, De Valls Bluff	55	18	25	41	1	1	7	26	14	13	34	3
Pulaski	151	324	152	446	168	52	168	110	200	118	47	28
Randolph	407	91	842	173	27	13	9	51	62	19	22	12
Saline	46	42	54	73	41	17	22	41	27	17	8	6
Scott	39	34	35	71	2	1	18	11	49	57	10	0
Searcy	87	28	50	42	0	93	4	34	0	16	16	0
Sebastian	606	261	151	445	36	49	34	41	33	116	18	33
Sevier	24	77	7	35	35	10	14	41	13	25	1	11
Sharp	15	25	30	40	13	39	8	32	20	17	7	35
St. Francis	158	43	62	124	21	5	7	10	12	26	2	41
Stone	45	24	22	53	17	18	5	20	32	20	3	6
Union	15	70	28	56	17	26	17	36	53	6	15	13
Van Buren	45	108	88	116	32	4	32	16	8	20	35	0
Washington	464	700	514	1070	330	984	187	253	135	223	52	280
White	310	461	227	188	127	60	47	56	14	114	23	50
Woodruff	43	24	89	89	191	0	4	0	10	7	78	41
Yell, Danville	21	0	64	53	40	25	16	31	43	55	15	18
Yell, Dardanelle	76	63	20	36	12	5	2	49	10	6	5	0
Total	13691	8241	16321	15214	3030	2731	1797	2592	3211	8400	3868	4970
% of Total	16	10	19	18	4	3	2	3	4	10	5	6

Table 14. Number of samples by month per crop submitted to the Soil Testing and Research Laboratory in Marianna in 2006. Sample numbers were determined using field-average soil samples (does not include grid soil samples, n = 60,867).

Crop	Number of samples submitted by month in 2006											
	January	February	March	April	May	June	July	August	September	October	November	December
Corn	221	84	140	66	8	13	28	1	131	142	49	131
Cotton	1457	276	1132	547	141	5	79	172	34	1489	1379	2244
Grain sorghum, non-irrigated	36	2	10	14	3	0	3	8	0	2	6	8
Grain sorghum, irrigated	33	3	29	3	1	0	0	1	22	87	8	13
Rice	1087	342	1547	1114	266	26	13	20	48	111	285	162
Soybean	3545	1217	4548	1906	84	28	55	209	219	877	465	706
Wheat	44	49	59	31	5	6	16	19	37	73	5	11
Cool-season grass hay	241	281	320	1060	295	208	106	186	83	190	64	180
Native Warm-season grass hay	67	71	74	73	16	48	37	13	41	35	37	3
Warm-season grass hay	493	496	493	832	300	287	192	207	183	242	201	134
Pasture, all categories	485	846	937	1354	487	564	331	514	680	595	286	224
Home garden	391	507	544	570	210	183	175	182	214	208	98	164
Home lawn	2094	1202	1499	2416	409	834	300	193	304	390	121	339
Small fruit	61	251	87	83	15	10	67	32	52	23	19	13
Ornamental	196	278	291	324	123	138	99	148	110	180	69	63
Total	10451	5905	11710	10393	2363	2350	1501	1905	2158	4644	3092	4395
% of Total	17	10	19	17	4	4	2	3	4	8	5	7

Table 15. Number of samples by month per county submitted to the Soil Testing and Research Laboratory in Marianna in 2013. The soil sample number values include both field-average and grid soil samples (n = 163,874).

	Number of samples analyzed by month in 2013											
County	January	February	March	April	May	June	July	August	September	October	November	December
Arkansas, DeWitt	126	537	804	51	1	7	9	20	6	10	193	181
Arkansas, Stuttgart	15	20	95	24	30	6	15	0	1	1	99	36
Ashley	112	28	53	20	18	21	13	9	97	78	134	36
Baxter	22	57	76	66	33	17	35	32	18	36	20	12
Benton	75	256	173	160	82	50	50	68	114	44	55	31
Boone	67	113	78	131	104	46	41	51	51	21	52	67
Bradley	3	10	12	6	7	3	6	7	7	3	0	2
Calhoun	2	5	32	6	6	0	0	5	3	12	1	3
Carroll	188	195	196	140	102	73	48	92	123	88	127	61
Chicot	19	13	11	103	6	0	2	15	18	6	5	137
Clark	65	41	35	68	26	20	12	22	19	3	29	29
Clay, Corning	31	15	86	41	8	2	31	0	716	1329	2132	2061
Clay, Piggott	814	1016	582	1231	49	48	124	13	155	1971	1874	2259
Cleburne	18	25	40	47	110	10	24	28	26	44	13	9
Cleveland	0	5	737	231	9	12	6	4	1360	626	527	5
Columbia	7	43	17	60	17	18	4	19	23	10	17	3
Conway	61	203	72	106	46	14	19	16	40	127	27	18
Craighead	1229	941	2009	491	94	31	42	35	268	6453	5674	7011
Crawford	62	180	31	80	31	40	29	31	145	438	10	26
Crittenden	1	27	1482	454	71	201	7	4	1509	7302	7221	1630
Cross	252	295	380	79	6	10	6	15	6	28	23	80
Dallas	4	18	1	23	0	1	0	6	6	12	4	3
Desha	259	135	292	187	23	42	4	101	72	355	550	262
Drew	143	49	63	20	26	8	9	5	44	44	27	1
Faulkner	27	127	99	136	115	43	50	29	58	16	23	112
Franklin, Charleston	7	11	10	26	17	8	22	9	11	5	2	4
Franklin, Ozark	72	38	59	55	49	10	9	30	8	12	5	31
Fulton	13	27	27	48	29	17	21	13	17	9	11	58
Garland	37	109	238	236	124	48	57	75	230	239	94	81
Grant	9	7	29	22	22	5	9	5	10	6	9	3
Greene	142	694	231	615	128	10	20	6	86	778	95	327
Hempstead	62	127	53	59	34	63	39	75	28	59	30	3
Hot Spring	5	17	32	62	29	4	6	9	5	2	6	2
Howard	78	14	17	38	10	14	60	23	34	5	49	30
Independence	24	62	53	116	46	13	27	17	78	15	7	6
Izard	16	41	55	28	15	15	42	73	23	32	16	4
Jackson	143	92	1995	1387	19	4	1	9	17	977	430	718
Jefferson	484	368	259	192	64	95	97	33	49	2119	1740	909
Johnson	87	72	45	68	13	8	22	15	15	47	7	20
Lafayette	8	8	11	10	7	1	2	4	5	3	13	4
Lawrence	20	432	1414	341	21	45	39	35	471	3645	2450	3354
Lee	26	254	267	120	56	122	132	73	223	1860	1635	464
Lincoln	12	43	38	46	12	0	4	27	6	20	20	2
Little River	1579	265	13	84	50	46	5	519	5	1599	2578	1202
Logan, Booneville	5	21	18	4	12	7	3	11	0	0	0	0
Logan, Paris	30	21	40	58	42	39	23	120	12	16	1	13

continued

Table 15. Continued.

County	Number of samples analyzed by month in 2013											
	January	February	March	April	May	June	July	August	September	October	November	December
Lonoke	846	551	998	209	64	42	67	31	116	33	35	135
Madison	51	49	30	57	6	1	86	70	35	24	19	19
Marion	30	13	32	33	10	1	4	9	5	19	8	1
Miller	28	41	87	61	40	16	12	38	20	71	47	6
Mississippi	287	80	1518	507	53	16	7	64	57	2655	3275	2414
Monroe	9	163	632	143	44	4	2	16	432	810	677	12
Montgomery	11	25	35	12	21	1	2	4	11	11	7	0
Nevada	3	9	20	8	22	3	2	3	12	8	0	5
Newton	15	52	24	15	31	11	23	31	9	13	4	19
Ouachita	32	14	17	15	13	16	3	15	5	14	0	5
Perry	8	17	10	32	37	4	6	2	5	2	0	7
Phillips	56	110	144	15	4	12	1	1	2	42	494	65
Pike	0	32	8	51	34	17	23	4	30	6	0	7
Poinsett	4	387	1087	566	10	6	39	2	12	389	634	325
Polk	18	52	47	35	37	16	21	5	5	13	7	0
Pope	131	87	133	102	85	51	47	60	62	53	18	5
Prairie, Des Arc	0	57	61	1	14	1	2	18	3	27	48	8
Prairie, De Valls Bluff	1	23	20	16	9	5	0	1	13	4	3	4
Pulaski	152	187	151	155	121	74	68	69	77	58	61	65
Randolph	599	66	164	216	10	8	7	23	20	57	11	2
Saline	47	112	112	63	37	19	23	28	96	265	8	42
Scott	16	16	14	34	21	12	6	6	8	8	4	6
Searcy	0	16	4	22	23	0	17	0	0	45	0	0
Sebastian	58	100	62	71	61	40	62	29	40	24	38	37
Sevier	45	8	24	70	46	0	11	39	18	0	17	6
Sharp	32	71	57	53	16	1	6	21	42	29	8	7
St. Francis	75	1496	121	87	14	50	11	5	129	80	452	5
Stone	28	72	58	46	17	3	41	4	12	8	16	42
Union	20	41	29	36	10	4	5	9	7	8	25	1
Van Buren	94	50	48	33	37	8	18	10	12	11	3	2
Washington	400	420	570	301	198	210	162	225	93	121	217	128
White	87	488	279	265	109	70	17	55	33	47	39	39
Woodruff	4	3	18	9	1	0	0	0	16	2	0	51
Yell, Danville	15	36	47	19	58	29	19	20	45	2	42	6
Yell, Dardanelle	24	9	5	21	13	9	0	0	0	1	0	0
Total	9687	12030	19026	10955	3145	2057	2046	2725	7700	35465	34252	24786
% of Total	6	7	12	7	2	1	1	2	5	22	21	15

Table 16. Number of samples by month per crop submitted to the Soil Testing and Research Laboratory in Marianna n 2013. Sample numbers were determined using field-average soil samples (does not include grid soil samples, n = 42,210).

	Number of samples submitted by month in 2013											
Crop	January	February	March	April	May	June	July	August	September	October	November	December
Corn	245	298	278	119	14	6	1	97	149	1255	556	300
Cotton	85	182	244	195	20	135	140	45	25	142	375	530
Grain sorghum, non-irrigated	2	8	3	10	6	0	0	0	1	29	2	0
Grain sorghum, irrigated	17	45	30	7	0	1	0	0	5	2	48	12
Rice	414	268	722	604	25	29	5	13	40	187	347	269
Soybean	1400	1813	2484	548	125	31	45	35	105	824	1250	1051
Wheat	2	49	59	27	32	2	35	104	96	38	17	12
Cool-season grass hay	34	100	78	70	54	16	6	37	21	42	10	26
Native Warm-season grass hay	35	71	28	61	28	7	12	10	20	24	7	5
Warm-season grass hay	209	303	313	339	182	124	70	72	61	80	82	80
Pasture, all categories	722	993	843	1274	845	594	461	736	607	411	555	300
Home garden	322	931	937	763	312	201	225	210	185	223	162	141
Turf	233	420	250	195	47	28	22	39	22	35	16	138
Home lawn	270	268	524	537	491	259	227	211	432	617	226	260
Small fruit	72	146	51	59	18	13	52	49	27	44	25	62
Ornamental	200	175	158	167	151	77	94	63	106	104	52	37
% of total	10.1	14.4	16.6	11.8	5.6	3.6	3.3	4.1	4.5	9.6	8.8	7.6

Pine Woodchip Biochar Impact on Corn Yield in a Silt Loam Soil

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Biochar is a charcoal product produced by the anaerobic thermal decomposition of biomass (Lehmann and Joseph, 2009), which can provide agronomic benefits when soil applied. Although many benefits of biochar have been observed in tropical soils, less research has been conducted to examine whether the benefits of biochar also occur in temperate regions. Research results are accumulating regarding biochar addition to soils and resulting agronomic implications in the United States (Gaskin et al., 2010; Rajkovich et al., 2012; Rogovska et al., 2014), but research results have been inconsistent concerning the effects of biochar application in the field environment, specifically in terms of corn (*Zea mays* L.) production.

Corn is an important commodity crop in the United States. In 2013, nearly 87.7 million acres were harvested for grain, with grain production at a record high of almost 13.9 billion bushels (NASS, 2014). Corn requires substantial nitrogen (N) inputs, with recommendations recently updated from fertilizing with 1 to 1.5 lb N/bu to meet yield goals (Espinoza and Ross, 2003) to 220 lb N/acre and 290 lb N/acre for loamy and clayey soils, respectively, for irrigated corn in Arkansas (Slaton et al., 2014). If biochar can enhance soil fertility of corn production systems in temperate agroecosystems, there is potential to improve soil quality characteristics, increase yields, and reduce commercial fertilizer-N inputs, thereby improving the sustainability of production systems. The objective of this study was to determine the effects of pine (*Pinus* spp.) woodchip biochar addition to soil in combination with N fertilizer (added at 200, 100, or 0 lb N/acre) on corn yield under field conditions in the first growing season after biochar addition.

PROCEDURES

Pine woodchip biochar (Waste to Energy Solutions Inc., Destin, Fla.), which was produced through pyrolysis at 930 °F, was selected for this field study. Dried and ground (40-mesh screen) biochar and field soil (0- to 4-in. depth) were analyzed prior to the experiment for pH and EC (1:2 wt:vol). Recoverable minerals (acid digestion for biochar) and extractable minerals (Mehlich-3 for soil) were analyzed using an ARCOS inductively coupled plasma (ICP) spectrophotometer (SPECTRO Analytical Instruments Inc., Mahwah, N.J.). Biochar was analyzed for total N and total carbon (C) by combustion with an Elementar Variomax (Elementar Americas, Inc., Mt. Laurel, N.J.). Soil particle-size analysis was determined using an adaptation of the 12-hr hydrometer method, and soil organic matter was determined by weight loss-on-ignition.

The field experiment was conducted in summer 2013 at the University of Arkansas System Division of Agriculture, Agricultural Research and Extension Center in Fayetteville, Ark., on a Razort silt loam soil (fine-loamy, mixed, active, mesic Mollic Hapludalf; NRCS, 2014). The 0.65-acre field (36.09780719 N, 94.16717458 W) was planted the previous two years in cotton (*Gossypium hirsutum* L.). The old cotton stalks had been mowed in fall 2012.

The experimental design was a 3 (biochar rates) by 3 (N rates) factorial randomized complete block with 4 blocks for a total of 36 plots that were each 20-ft long and 12-ft wide with four 36-in. rows. Pine woodchip biochar was added at rates of 0, 2.2, and 4.5 tons biochar/acre. These rates are within the range used in soils, but are less than reported in other temperate region woodchip biochar studies (Jones et al., 2012; Sun et al., 2014; Vaccari et al., 2011). Thus, these rates were chosen to investigate if the application of lesser biochar rates would still result in observed differences. Biochar was manually applied on 28 May and was incorporated with mechanical tillage into approximately the top 2 in. before rows were bedded and knocked down for planting. Corn, DEKALB hybrid DKC64-69 with the Genuity VT Triple PRO value-added trait, was planted at 30,000 seeds/acre on 29 May with a four-row planter. Full seedling emergence occurred after one week, and watering by furrow irrigation was conducted as needed with the use of the Arkansas online irrigation scheduler (University of Arkansas, 2014).

Untreated urea fertilizer (46-0-0) was applied at 0, 100, or 200 lb N/acre in a split application. The 200 lb N/acre rate is in agreement with previous recommendations to achieve a theoretical corn yield of 200 bu/acre (Espinoza and Ross, 2003), but less than current recommendations of 220 lb N/acre for loamy soils (Slaton et al., 2014). The first urea application was manually applied 20 June, and the split application was applied 9 July and incorporated by irrigation.

Because of limited harvest area (the middle two rows in the plot), ten ear leaves were harvested from the outer two rows of each plot at the VT stage for leaf tissue-N analysis. Dried

(150 °F) and ground (40-mesh screen) ear leaves were weighed and analyzed for ear-leaf total N by combustion using a Model Rapid N III (Elementar Americas, Inc., Mt. Laurel, N.J.). Grain was harvested from the center five feet of the center two rows in each plot on 28 September once physiological maturity had been reached. Yield was calculated based on 15.5% moisture content, and total grain N was measured by combustion. Nitrogen use efficiency (NUE), defined here as percent applied fertilizer N recovered in the grain, was calculated using the difference method, where NUE was equal to the difference between N removed in grain and the N removed in the unamended control grain divided by the fertilizer-N rate applied. The N removed in grain was calculated by multiplying the N concentration by the mass of grain (yield), assuming 56 lb/bu. A two-way ANOVA was performed to determine the effects of biochar, fertilizer, and their interaction on ear-leaf weight and N concentration, corn grain yield, grain total N, and NUE. Least significant difference test was used to separate treatment means at $\alpha = 0.05$.

RESULTS AND DISCUSSION

The pine woodchip biochar had an alkaline pH, EC over 5 dS m^{-1}, and a C:N ratio of 366:1 (Table 1). The soil surface texture was confirmed to be silt loam (Table 2). The soil possessed a near-neutral pH of 6.4 and EC of 0.16 dS m^{-1}. The initial soil pH fell within the ideal pH range for corn growth, 5.8 to 7.0 (Espinoza and Ross, 2003). Urea was the only fertilizer added and initial Mehlich-3 extractable soil nutrient concentrations suggested that P and/or K could have been limiting for corn production (Table 2; Espinoza and Ross, 2003).

Corn yield differed among fertilizer-biochar treatments (interaction *P*-value = 0.011), with the 200 lb N/acre fertilizer and 4.5 tons biochar/acre treatment resulting in greater yield (250 bu/acre) than the yield produced by treatments with no fertilizer N or no biochar (Fig. 1). Yields were similar between the 4.5 tons biochar/acre combined with either the 100 or 200 lb N/acre. The 100 lb N/acre and 2.2 tons biochar/acre treatment produced lower yields than the 200 lb N/acre and 4.5 tons biochar/acre treatment, but otherwise the 2.2 tons biochar/acre resulted in similar yields among fertilized treatments. When no fertilizer was applied, 4.5 tons biochar/acre reduced yield (182 bu/acre) compared to the no-N and no-biochar treatment (210 bu/acre). It is possible that biochar, which had a wide C:N ratio, increased microbial immobilization of soil N.

Despite the differences in corn yield among fertilizer-biochar treatments, grain N concentrations differed only among fertilizer rates ($P = 0.014$). Corn fertilized with 200 lb N/acre, averaged across biochar treatments, produced greater grain N than corn fertilized with 100 lb N/acre and the no-N treatment (Table 3). The addition of N fertilizer at either rate increased ear-leaf weight and ear-leaf N concentrations compared to the no-N treatment (Table 3). While biochar did not significantly affect ($P > 0.05$) grain N concentrations, ear-leaf weight, or ear-leaf N concentration, NUE was greatest ($P = 0.003$) with the 4.5 tons biochar/acre treatment compared to the 2.2 or 0 tons biochar/acre treatments (Fig. 2).

PRACTICAL APPLICATIONS

Biochar application to temperate soils has resulted in mixed outcomes based on the biochar products used, soil textures, and the specific crops grown in temperate region studies (Jones et al., 2012; Vaccari et al., 2011; Zheng et al., 2013). Pine woodchip biochar applied at rates of 2.2 and 4.5 tons biochar/acre in combination with N fertilizer to a fertile silt loam in northwest Arkansas numerically increased corn yields compared to N fertilization without biochar. However, 4.5 tons biochar/acre decreased yield in the absence of N fertilizer. Nitrogen use efficiency (i.e. fertilizer N recovery in the grain) was greatest with 4.5 tons biochar/acre. Biochar potentially altered N availability in soil, although the exact mechanisms require further investigation to identify. Pine woodchip biochar can improve corn NUE in a fertile, temperate, alluvial soil and can increase corn yields in combination with urea-N fertilizer. Additional experimentation regarding biochar application in major corn producing regions in Arkansas, such as the Mississippi River Delta, will provide valuable insight into potential agronomic effects.

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Table 1. Initial mean [± standard error (SE)] pH, electrical conductivity (EC), total carbon (C), total nitrogen (N), C:N ratio, and total recoverable mineral concentrations determined using a nitric acid digest for pine (*Pinus* spp.) woodchip biochar (n = 2).

Biochar property	Mean (± SE)
pH†	8.7 (0.03)
EC (dS/m)†	5.3 (0.2)
Total C (%)	24.5 (2.1)
Total N (%)	0.07 (0.02)
C:N ratio	366:1 (64)
Potassium (g/kg)	2.1 (0.1)
Calcium (g/kg)	10.1 (0.5)
Magnesium (g/kg)	2.7 (0.2)
Phosphorus (mg/kg)	771 (17)
Sulfur (mg/kg)	129 (1.5)
Sodium (mg/kg)	322 (13)
Iron (mg/kg)	868 (57)
Manganese (mg/kg)	421 (30)
Copper (mg/kg)	6.5 (0.04)
Boron (mg/kg)	10.4 (0.7)
Zinc (mg/kg)‡	0.01 (0)

† pH and EC were determined using a 1:2 soil:water mixture.
‡ Zinc in the woodchip biochar was below the detection limit of the method. Therefore, the detection limit of 0.01 was used for statistical analysis.

Table 2. Initial mean [± standard error (SE)] of particle-size distribution, pH, electrical conductivity (EC), organic matter, and Mehlich-3 extractable nutrient concentrations for the Razort silt loam prior to treatment applications (n = 36).

Soil property	Mean (± SE)
Particle-size distribution (g/g)	
Sand	0.3 (0.3)
Silt	0.6 (0.3)
Clay	0.1 (0.2)
pH†	6.4 (0.03)
EC (dS/m)†	0.2 (0.1)
Organic matter (%)	2.7 (0.04)
Phosphorus (mg/kg)	31.7 (1.1)
Potassium (mg/kg)	104 (4.7)
Calcium (mg/kg)	923 (13)
Magnesium (mg/kg)	46 (0.8)
Sulfur (mg/kg)	5.5 (0.2)
Iron (mg/kg)	51.1 (1.7)
Manganese (mg/kg)	162 (3.7)
Copper (mg/kg)	1.9 (0.1)

† pH and EC were determined using a 1:2 soil:water mixture.

Table 3. Mean corn grain total nitrogen (N), ear-leaf weight, and ear-leaf N concentration as affected by N-fertilizer rate.

	Fertilizer rate		
Corn property	0	100	200
	------------- (lb N/acre) ---------------		
Grain total N (g/kg)	11.1 b†	11.4 b	12.4 a
Ear-leaf weight (g)	14.0 b	15.7 a	16.7 a
Ear-leaf N (g/kg)	23.1 b	26.7 a	28.0 a

† Means followed by different letters in the same row are statistically different ($P < 0.05$).

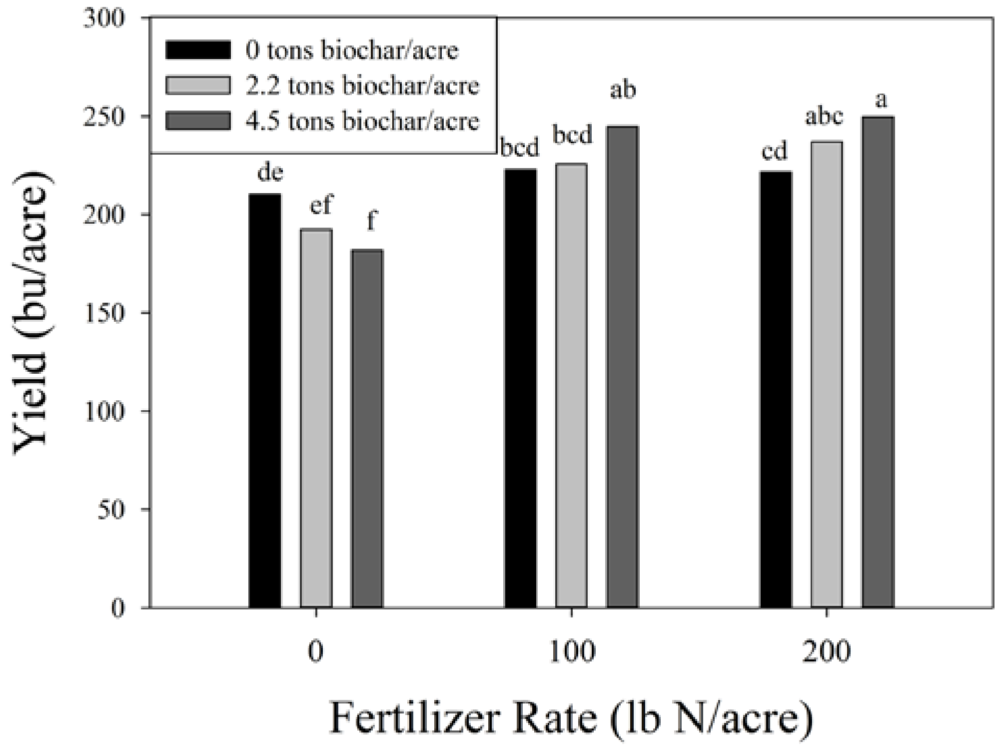

Fig. 1. Corn yield as influenced by pine woodchip biochar and fertilizer rates. The fertilizer rates are 0, 100, and 200 lb N/acre rates. The biochar treatments are displayed in the shaded boxes at rates of 0, 2.2, and 4.5 tons biochar/acre. Bars with different letters are statistically different from each other (*P* < 0.05).

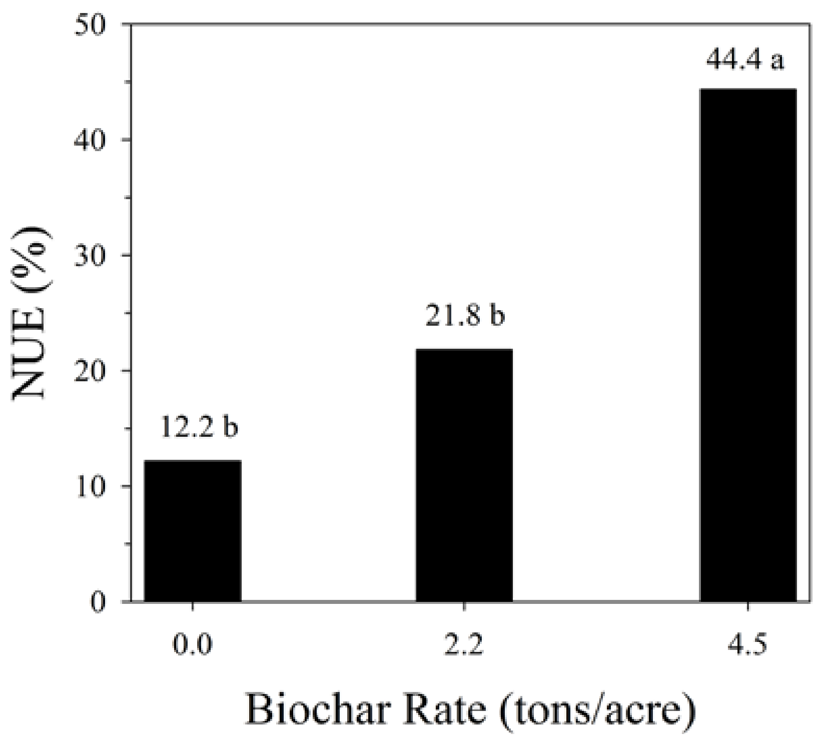

Fig. 2. Corn nitrogen use efficiency (NUE) as influenced by pine woodchip biochar. The biochar rates are 0, 2.2, and 4.5 tons biochar/acre. Numbers above bars represent the NUE (defined in this experiment as percent N- fertilizer recovery in the grain) for the respective biochar application rate. Bars with different letters are statistically different from each other (*P* < 0.05).

Field-Grown Cotton Yield Response of Nitamin® in Comparison to Foliar Urea and Soil-Applied Nitrogen

J.M. Burke, D.M. Oosterhuis, and T.B. Raper

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Effective nitrogen (N) management in cotton (*Gossypium hirsutum* L.) production is essential to achieve proper growth and development. Soil-incorporated N fertilizer can undergo a series of chemical conversions along with numerous loss mechanisms (leaching, volatilization and denitrification) that can make N unavailable to the plant. Soil-applied N fertilizer has faced much scrutiny for its role in degradation of water quality. Methods to reduce the amount of soil-applied N, such as foliar fertilization, have been examined. From root and vegetative growth to reproductive development, N is vital in every phase of cotton development and plant demand is high.

For over a century, foliar fertilization has been utilized as a source for correcting nutritional imbalances and supplementing soil-incorporated fertilizers to achieve proper plant development (Oosterhuis and Weir, 2010). However, foliar fertilization of cotton has only become popular within the last 20 years (Oosterhuis and Weir, 2010). The rationale and theory supporting the use of foliar-N fertilization is primarily based on the numerous loss mechanisms that soil-applied N fertilizers can endure and the high demand of N by cotton during the reproductive stage (Thompson et al., 1976). Boll development requires a substantial amount of N that is mainly provided by the leaves (Zhu and Oosterhuis, 1992) and any deficiencies in leaf N can result in decreased boll growth and overall yield (Bondada et al., 1997). Therefore, N applied to cotton via foliar fertilization is viewed as an option for correcting leaf N deficiencies (Craig, 2002). The objective of this study was to evaluate the effectiveness of foliar-N fertilization on the yield of field-grown cotton in conditions of limited soil-N availability.

PROCEDURES

The 2013 field experiment was conducted at the Lon Mann Cotton Research Station in Marianna, Ark., in a Memphis silt loam (fine-silty, mixed, active, thermic Typic Hapludalfs) soil. The experiment was a randomized complete block design consisting of three treatments and four replications. A total of 12 plots, each composed of 4 rows, 50-ft long by 3.17-ft wide, were used for the experiment that was planted with cotton cultivar Stoneville 4288 B2RF on 16 May 2013 at a seeding rate of approximately 3 seeds/ft. Furrow irrigation was performed as needed for ideal growth and adequate soil moisture throughout the growing season. Urea-ammonium nitrate (UAN 32) was applied to the soil in all treatment plots on 20 June 2013 at a rate of 45 lb N/acre. Foliar applications of urea (46-0-0) and Nitamin (30-0-0; Koch Agronomic Services, LLC, Wichita, Kan.), at rates equivalent to 6 lb N/acre, occurred approximately 1 week after first flower using a pressurized CO_2 backpack sprayer at 30 psi and 4-nozzle spray boom equipped with 8002VS spray tips calibrated to deliver 20 gal/acre. No stabilizers were used with either UAN 32 or foliar-applied urea. Seedcotton yield was determined with a mechanical picker.

Analysis of variance methods were used to determine significant differences between treatment means at the $P \leq 0.05$ and $P \leq 0.10$ levels using the "Fit Model" platform provided by JMP Pro 10.0 software (SAS Institute, Cary, N.C.).

RESULTS AND DISCUSSION

Seedcotton yield was different among the three treatments ($P = 0.0018$, Table 1). Interpretation of results at the 0.05 level of significance showed the foliar urea and Nitamin treatments were not significantly different, but had significantly greater yields than the no-foliar-N control. When the analysis was interpreted at the $P \leq 0.10$ level, all treatments were significantly different from each other with cotton fertilized with Nitamin having significantly greater yields than cotton fertilized with foliar urea.

PRACTICAL APPLICATION

This one experiment showed a positive yield response to foliar-applied N by cotton grown under field conditions of limited or low N fertility regardless of the foliar-N source. The 45 lb N/acre of soil-incorporated UAN was well below the N rates typically recommended for cotton production in Arkansas (90-100 lb N/acre). In this experiment, no N deficiencies were observed before foliar-N applications were made. However, if N deficiencies are observed in cotton plants at the growth stage of first flower, foliar applications of N can be advantageous due to the absorption and provision of foliar-applied N imparted by subtending leaves into the developing bolls. Additionally, foliar urea is considered beneficial as a result of its rapid rate of absorption and relatively inexpensive cost (Oosterhuis and Weir, 2010). Repeated studies need to be performed to ascertain if Nitamin can consistently produce significantly greater seedcotton yields than foliar-applied urea. Since Nitamin is still a relatively new foliar-N fertilizer source, additional inquires need to be made to determine if Nitamin's slow-release technology and viscous nature can be as favorable in cotton production as a foliar-N fertilizer standard such as urea.

ACKNOWLEDGMENTS

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Table 1. Harvest yield means per treatment for the 2013 Marianna yield study.

Treatment	Yield
	(lb/acre)
UAN	2862
Foliar Urea + UAN	3080
Nitamin + UAN	3184
$LSD_{0.05}$	122
$LSD_{0.10}$	97

Effect of Delaying the Sidedress-Nitrogen Fertilization on Corn Yields

L. Espinoza, M. Ismanov, and P. Ballantyne

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Nitrogen (N) is the nutrient required in the largest amount by a corn plant. In Arkansas, the total amount of N is normally applied in a 2- or 3-way split, with the majority of N fertilizer applied at the V6 growth stage. The larger portion is applied around V6 to correspond with the period of rapid growth, and it is believed to be the practice that results in the highest N uptake and yield potential (Wells and Blitzer, 1984). Timely N applications are critical to optimize yield potential; however timely application is sometimes compromised by weather and can conflict with other cultural practices. Delaying the sidedress-N application until the time when the corn is experiencing substantial biomass accumulation is reported to be detrimental to corn yields (Varvel et al., 1997; Binder et al., 2000). Scharf et al. (2002) reported that N fertilization could be delayed as late as the V11 growth stage without significant yield loss. There is a lack of data to quantify how delayed N fertilization influences corn yield under Arkansas growing conditions. The objective of this study was to assess the yield implications associated with sidedressing N at different growth stages.

PROCEDURES

Research plots were established at the Northeast Research and Extension Center (NEREC) near Keiser during 2013, and the Rohwer Research Station (RRS) near Rohwer during 2013 and 2014. The soils are mapped as Sharkey silty clay for the NEREC and RRS trials conducted in 2013 and as Desha silt loam for the RRS trial in 2014. The preceding crop at both locations was soybean in 2013, while corn was the preceding crop in 2014 at RRS.

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-in. soil depth was collected from each location each year. The soil was extracted for plant-available nutrients using the Mehlich-3 procedure (Table 1). Nitrate-N was determined with an ion-selective electrode, and pH was measured in a 1:2 soil:water (vol:vol) mixture. Soil fertility levels were optimal. During 2014, 0.5 lb Zn/acre was applied after emergence at each site.

Treatments consisted of an application of 100 lb N/acre at emergence, followed by a sidedress-N application of 100 or 140 lb N/acre, depending on soil texture, at one of four different growth stages including V4 to V6, V6 to V8, V8 to V10, and V10 to VT. Plots received an additional application of 46 lb N/acre at VT. The date of each post-emergence N application is listed in Table 2. The total-N applied was 286 lb N/acre for clayey soils (NEREC in 2013 and RRS, 2014) and 246 lb N/acre for the silt-loam soil (RRS, 2013). Urea amended with a recommended rate of an NBPT-based urease inhibitor to reduce ammonia volatilization loss was used for each N application. The urea fertilizer was applied manually to each plot.

The planting date at each site is listed in Table 2. Each trial included two hybrids. Pioneer 1615HR and DeKalb 64-69 hybrids were planted in 2013 while Pioneer 1319HR and DeKalb 64-69 were used in 2014. Corn was planted to achieve an intended population of 32,000 plants/acre. 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.

Statistical analysis was performed by site using the GLM procedure in SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.). At the RRS, treatments were arranged as a 2 (hybrid) × 4 (sidedress-N times) factorial. At the NEREC, sidedress-N treatments were arranged as a randomized complete block design with the two hybrids planted as separate tests and ANOVA was performed by hybrid. Treatments were replicated five times. Mean separations were performed using the Fisher's protected least significant difference method at a significance level of 0.10.

RESULTS AND DISCUSSION

The grain yields of both hybrids at the NEREC during 2013 may have been affected by the relatively late planting date (16 May). Results show significant yield loss when the sidedress-N application was delayed after the V8 to V10 growth stage (Table 3). The reason for the abnormally low yield of 144 bu/acre for the DeKalb 64-69 hybrid receiving the sidedress-N at the V8 to V10 stage is unknown.

For the RRS in 2013, the statistical analysis showed that hybrid and the hybrid by sidedress-N application time had no significant effect ($P > 0.10$) on grain yield (Table 3). A significant yield loss occurred when sidedress-N application was delayed until after the V6 to V8 growth stage. Overall, grain yields from both trials in 2013 were probably affected by adverse weather conditions that did not allow planting until mid-May (Table 2), a month later than normal. Corn planted at Rohwer in mid-May normally yields 15% to 20% lower than corn planted in mid-April (Jason Kelley, pers. comm.).

During the 2014 season, weather conditions were very favorable to grow corn at the RRS, and the test was planted on a soil with good yield potential in April (Table 2). The statistical analysis of grain yields at the RRS during 2014 showed no difference between hybrids and both hybrids responded to sidedress-N application timing the same (non-significant interaction, Table 3). Corn yields were reduced by 8% when the sidedress-N application was delayed until after the V6 to V8 stage compared to the conventional application timing (V4 to V6).

PRACTICAL APPLICATIONS

The purpose of these studies was to quantify the yield loss potential when the sidedress-N application was delayed beyond the V4 to V6 growth stage. Weather conditions, native or residual soil-N availability, and the amount of N applied before or by planting could affect the outcome of a study of this nature. Under the conditions of these studies, delaying the sidedress-N application beyond the V8 growth stage increases the risk of significant yield loss. These studies will continue during the 2015 season.

ACKNOWLEDGMENTS

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Table 1. Selected soil chemical properties from the 0- to 6-in. soil depth at the Northeast Research and Extension Center (NEREC) and at the Rohwer Research Station (RRS). Composite soil samples were collected in the spring before planting.

Location	Year	pH	NO_3-N	P	K	Zn	Ca
			---------- (ppm) ----------				
NEREC	2013	6.5	9	69	298	7.1	4088
RRS	2013	6.3	11	81	211	5.6	3842
RRS	2014	6.7	16	75	285	6.1	2048

Table 2. Dates of planting and preplant, sidedress, and pretassel N application in trials conducted at the Northeast Research and Extension Center (NEREC) and Rowher Research Station (RRS) in 2013 and 2014.

			N fertilizer application times[a]					
Location	Year	Planted	Emergence	V4-V6	V6-V8	V8-V10	V10-VT	VT
NEREC[b]	2013	16 May	29 May	7 June	17 June	24 June	2 July	16 July
RRS[c]	2013	11 May	24 May	5 June	14 June	25 June	5 July	10 July
RRS[b]	2014	19 April	29 April	9 May	20 May	3 June	12 June	17 June

[a] Nitrogen fertilizer was applied at 100 lb N/acre preplant, 100-140 lb N/acre at one of the four sidedress application treatment times (V4-V6, V6-V8, V8-V10, and V10-VT), and 46 lb N/acre at VT.
[b] Fertilized with a total of 286 lb N/acre.
[c] Fertilized with a total of 246 lb N/acre.

Table 3. Corn grain yield means as affected by fertilizer sidedress-N application time in four trials conducted at the Northeast Research and Extension Center (NEREC) and Rowher Research Station (RRS) in 2013 and 2014.

	NEREC 2013		RRS 2013	RRS 2014
Sidedress-N time	P1615HR	DeKalb 64-69	Hybrid mean	Hybrid mean
	(bu/acre)			
V4-V6	162	169	177	296
V6-V8	165	160	173	283
V8-V10	163	144	162	272
V10-VT	153	153	155	271
LSD0.10	7.2	8.3	5.7	15.2
C.V., %	5.9	9.9	6.3	7.2
N Time	0.010	0.004	0.002	0.034
Hybrid	--	--	0.111	0.530
Interaction	--	--	0.644	0.772

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

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

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Routine soil testing to determine soil phosphorus (P) and potassium (K) availability to plants is the best available science for soil and crop nutrient management. Soil testing has been an advancing science since the early 1900s and has played a vital role in crop fertilization and increasing crop yields (Stewart et al., 2005). The precision agricultural practice known as variable-rate fertilization is commonly used in production agriculture and its adoption is increasing (Holland et al., 2013). Precision agriculture technologies are valuable agronomic tools and have a place in nutrient management, but these tools are only as valuable as the accuracy of the fertilizer rates.

Information from soil-test correlation and calibration research is used to interpret soil-test values and develop crop fertilizer recommendations. The literature contains numerous examples showing the relationship between relative crop yield and soil-test nutrient availability (Fageria et al., 1997; Mallarino, 2003; Dodd and Mallarino, 2005; Slaton et al., 2010; Barbagelata and Mallarino, 2013). Unfortunately, research has not examined how accurate the interpretations of the soil-test P and K indices are in predicting crop yield response to fertilization. Farmers and consultants expect or assume that soil-test-based fertilizer recommendations are accurate. Our research objective was to develop an independent database of irrigated-soybean [*Glycine max* (L.) Merr.] response to P and K fertilization based on existing soil-test-based fertilizer recommendations to assess their accuracy. The overall research goal was to improve soil-test-based fertilizer recommendations for irrigated soybean.

PROCEDURES

Eight fertilization trials were established in experiment station fields across eastern Arkansas in 2014. 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.

Composite soil samples (0- to 4-in. depth) were collected in the early spring of 2014 to use as a guide for defining the recommended P and K fertilizer rates. Before fertilizer was applied to the research test, samples from the 0- to 12-in. (clayey soils) or 0- to18-in. (loamy soils) depths were taken from the no-fertilizer control plots in each replicate (n = 6-10) along with composite soil samples from the 0- to 4-in. depth. At each site, individual plots were 20- to 30-ft long by 6.5- to 12.7-ft wide. 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 fertilizer treatments that included 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. Boron 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, twelve 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 14- to 29-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 experiment contained six blocks except PTRS I10, which had ten blocks. For each trial, ANOVA was conducted by site with the MIXED procedure in SAS v.9.3 (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 yield increase, no change, or yield decrease. Our hypothesis for testing was that the yield of soybean grown on soils with i) Very Low or Low nutrient levels would respond positively to fertilization, ii) Medium nutrient levels would show small increases or no yield change, and iii) Optimum or Above Optimum nutrient levels would not change from the implemented fertilization. Table 3 shows a summary of the expected yield response and *P*-values of the three yield comparisons.

RESULTS AND DISCUSSION

Soybean yield increases due to fertilizer applications were expected at five of the eight sites according to the interpretation of the soil-test results. Soil-P levels at the eight locations were interpreted as Very Low at one site, Low at four sites, Optimum at one site, and Above Optimum at two sites. The soil-K levels were interpreted as Very Low at one site, Low at three sites, Optimum at two sites, and Above Optimum at two sites. No sites had Medium levels for either nutrient. Nutrient concentration ranges defined for each level are listed in Table 4, along with the number of sites in each level that had yields that differed from the no-fertilizer control plots. The level of significance had no effect on the interpretation of yield responses to P fertilization, but did influence the interpretation of response to K fertilization at two sites, which had Optimum [Rohwer Research Station (RRS)-Loam] or Above Optimum (Northeast Research and Extension Center, NEREC) soil-test K levels (Table 3).

The expected yield response to P fertilization at four of the eight sites was correctly predicted by the existing soil-test interpretations (Table 4). All of the error in predicting yield response to P fertilization occurred in the Low soil-test level (False Positive) where a yield increase was expected but did not occur (Table 3). Although P fertilizer is recommended at the Low and Medium soil-test levels, no yield response was measured (Table 4) suggesting that the Very Low, Low, and Medium P levels may need to be revised to improve the accuracy of the recommendations. Overall, the established soil-test P interpretations accurately predicted the yield response in 60% of the field trials when the observations in each category were equally weighted (Table 5).

The expected yield response to K fertilization was correctly predicted at seven ($\alpha = 0.05$) or five ($\alpha = 0.25$) of eight sites (Table 4). For the Optimum and Above Optimum soil-test K levels evaluated at $\alpha = 0.05$ and $\alpha = 0.10$, the interpretations were 100% accurate in predicting no yield response to K fertilization. When evaluated at $\alpha = 0.25$, a marginal yield increase to K fertilization was measured at the RRS-Loam site (Optimal soil-test K) and a yield decrease occurred at the NEREC (Above Optimum Soil-test K, Table 2). Overall, soil-test interpretations accurately predicted yield response to K fertilization at 88% ($\alpha \leq 0.10$) and 63% ($\alpha = 0.25$) of the sites (Table 5). The more liberal evaluation allows smaller yield differences to be significant which can increase or decrease the accuracy of the interpretations depending on the circumstances.

PRACTICAL APPLICATION

Soil-test P and K fertilizer recommendations for irrigated soybeans were relatively accurate at the eight sites established in 2014. The soil-test P concentrations that define the five fertility levels (Very Low, Low, Medium, Optimum, and Above Optimum) may need to be changed (e.g., lowered) to reduce the frequency of recommendations that predict a yield increase to P fertilization will occur, which is also known as false positive error. Soil-test K interpretations were mostly accurate in predicting soybean yield response to K fertilization, but the level of the significance that the data was evaluated influenced the accuracy and type of error that occurred. Issues such as spatial and temporal nutrient variability as well as previous cropping and fertilization practices may help explain some of the error.

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Table 1. Selected soil and agronomic information for P- and K-fertilization trails conducted in 2014.

Site[a]	Soil series	Cultivar	Previous crop	Row width	Plant date
				(in.)	
NEREC	Sharkey	Halo 4:94	Soybean	38	18 June
PTRS-D12	Calloway	Armor 55-R22	Soybean	15	17 June
PTRS-D20	Calloway	Armor 55-R22	Soybean	15	17 June
PTRS-F4	Calloway	Pioneer 94Y-82	Soybean	30	23 May
PTRS-I10	Calloway	Armor 49R-56	Soybean	15	23 May
RREC	Dewitt	Armor 47R-13	Soybean	30	2 May
RRS-Clay	Sharkey/Desha	Armor 55-R22	Soybean	38	20 May
RRS-Loam	Sharkey/Desha	Armor 55-R22	Soybean	38	20 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= 6 to 10) of soil from the unfertilized control in P- and K-fertilization trials conducted at multiple sites during 2014.

	4-in. sample							12- or 18-in. sample		
Sitea	pH	P[b]	K[b]	Ca	Mg	Mn	Zn	pH	P[b]	K[b]
		(ppm)							(ppm)	
NEREC[12]	7.2	23 (1)	267 (12)	4777	1281	51	4	7.3	24 (2)	287 (54)
PTRS-D12	7.6	19 (3)	76 (4)	2183	320	335	1	5.9	8 (0)	55 (8)
PTRS-D20	6.9	9 (1)	78 (4)	1482	334	506	2	5.3	6 (0)	57 (8)
PTRS-F4	7.3	72 (14)	161 (21)	1691	323	298	3	5.6	72 (14)	59 (8)
PTRS-I10	7.2	19 (2)	60 (8)	1813	301	323	2	5.6	6 (1)	50 (11)
RREC	6.2	16 (2)	72 (7)	845	144	248	1	6.2	7 (1)	60 (6)
RRS-Clay[12]	7.6	50 (5)	201 (12)	3347	949	134	3	7.5	41 (5)	206 (10)
RRS-Loam	7.3	78 (1)	146 (17)	2562	684	124	2	6.0	69 (7)	170 (19)

[a] NEREC, Northeast Research and Extension Center; PTRS, Pine Tree Research Station; RREC, Rice Research Extension Center; and RRS, Rohwer Research Station. The superscripted number '12' for NEREC and RRS-Clay 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 in.

[b] The values in parentheses are the standard deviation of the mean soil-test P or K for the research area.

Table 3. Soybean yield response to P, K, or P and K fertilization compared to a no P and K control at eight research sites established during 2014.

	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)]----		
NEREC	I	NC	56	0.53	--	0.25	-0.9	--	-1.1
PTRS-D12	I	I	62	0.45	0.45	0.56	-1.7	+1.7	+1.1
PTRS-D20	I	I	56	<0.01	0.05	0.07	+5.5	+4.0	+3.0
PTRS-F4	NC	NC	68	0.73	0.93	--	+0.7	+0.1	--
PTRS-I10	I	I	51	0.71	<0.01	<0.01	-0.8	+13.3	+11.2
RREC	I	I	53	0.49	<0.01	0.02	+1.4	+7.1	+4.0
RRS-Clay	NC	NC	65	0.87	0.56	--	+0.4	+0.9	--
RRS-Loam	NC	NC	53	0.50	0.13	--	+1.7	+3.0	--

[a] NEREC, Northeast Research and Extension Center; PTRS, Pine Tree Research Station; RREC, Rice Research Extension Center; and RRS, Rohwer Research Station. Information after the dash is a field identifier.

[b] Expected yield response to fertilization: I, increase when soil-test level is Very Low, Low, or Medium; NC, no change when soil-test level is Medium, Optimum, or Above Optimum; and D, decrease (not expected at any soil-test level but a possible outcome).

[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 only; K Fert., single-degree-of-freedom contrast comparing the yield with no P or K to K fertilizer only; 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 responses 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[a]	≤15	≤60	1/1	1/1	1/1	1/1	1/1	1/1
Low[a]	16-25	61-90	0/4	0/4	0/4	2/3	2/3	2/3
Medium	26-35	91-130	0/0	0/0	0/0	0/0	0/0	0/0
Optimum[b]	36-50	131-175	0/1	0/1	0/1	0/2	0/2	1/2
Above Optimum[b]	≥51	≥176	0/2	0/2	0/2	0/2	0/2	1/2
Correct interpretation of response			4/8	4/8	4/8	7/8	7/8	5/8

[a] Yield increase expected for soils with Very Low and Low sol-test levels.

[b] No yield change from fertilization expected for soils with Optimum and Above Optimum soil-test levels.

Table 5. The accuracy of soil-test prediction of soybean yield response to fertilization at eight research sites in 2014 as defined by soil-test P and K level and the level of significance at which statistical comparisons were made.

			Interpreted at *P*-value ≤0.10[b]			Interpreted at *P*-value ≤0.25		
Nutrient	Soil-test range[a]	Total trials	Test success	False positive	False negative	Test success	False positive	False negative
			---(% of sites) --					
P	≤25	5	20	80	0	20	80	0
P	26-35	0	--	--	--	--	--	--
P	≥36	3	100	0	0	100	0	0
P summary[c]	8	60	40	0	60	40	0	
K	≤90	4	75	25	0	75	25	0
K	91-130	0	--	--	--	--	--	--
K	≥131	4	100	0	0	50	25	25
K summary[c]	8	88	12	0	63	25	12	

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

[b] False Negative Errors occur 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 Errors occur 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.

[c] P and K summary percentages are a weighted total of the numbers of all the sites in each soil-test level

Urea and an Enhanced Efficiency Nitrogen Fertilizer Increase Cotton and Corn Yields in Arkansas

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

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Nitrogen (N) fertilization will increase cotton (*Gossypium hirsutum* L.) and corn (*Zea mays* L.) yields in many Arkansas soils. Relatively high Fertilizer-N rates are required to produce economically sustainable crop yields in Arkansas, because the soil organic matter (SOM) content of many of our agricultural soils is low (<2.0%). Additionally, several biogeochemical and transport processes such as runoff, leaching, and denitrification contribute to the loss of soil and fertilizer N. Reducing Fertilizer-N loss to the environment will increase the growers' profit margins and reduces potential environmental risks associated with N fertilization.

A polymer-coated urea (44% N, Agrium Wholesales, Denver, Colo.) has become available to Arkansas producers and is marketed 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 typical Arkansas agricultural soils.

PROCEDURES

Cotton Experiment

A field experiment was conducted to evaluate the effect of preplant application of urea, ESN, and their combinations on cotton yield in a Loring silt loam at the Lon Mann Cotton Research Station (LMCRS) in Marianna, Ark. Before applying any fertilizer, soil samples were collected from the 0- to 6-in. depth and composited by replication. Soil samples were oven-dried, crushed, soil pH, organic matter, NO_3-N, and Mehlich-3 extractable nutrients were measured. Average soil properties in the 0- to 6-in. depth were: 1.8% SOM, 12 ppm NO_3-N, 28 ppm P, 121 ppm K, and 6.2 pH. Selected agronomic information is presented in Table 1. Current University of Arkansas System Division of Agriculture's Cooperative Extension Service soil-test-based, irrigated-cotton-fertilization guidelines recommend application of 90 lb N/acre.

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 five 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 fertilizer-N treatments) were hand applied onto the soil surface and mechanically incorporated immediately into the top 2- to 3-in. of soil. After 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-in. wide rows. We furrow-irrigated the cotton as needed and closely followed the Cooperative Extension Service cultural recommendations. 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

Corn N-fertilization trials were conducted at the LMCRS on a Loring silt loam and at the Pine Tree Research Station (PTRS) near Colt, Ark., on a Calhoun silt loam. The corn experiment treatments, structure, design, and preplant soil sampling were similar to the cotton experiments. The average soil chemical properties at LMCRS were: 1.8 % SOM, 7.3 pH, 18 ppm NO_3-N; 55 ppm P, and 129 ppm K. At PTRS, soil property means were 2.1% SOM, 6.9 pH, 19 ppm NO_3-N; 18 ppm P, and 74 ppm K.

The preplant-applied N rates for both corn experiments ranged from 0 to 300 lb N/acre and increased in 60 lb N/acre increments. Each treatment was replicated six times. Applications of muriate of potash, triple superphosphate and $ZnSO_4$ were made to supply 90 lb K_2O, 60 lb P_2O_5, 10 lb Zn, and 5.0 lb S/acre. All fertilizers, including the N treatments, were hand applied onto the soil surface, immediately incorporated into the top 2- to 3-in. of soil, beds were pulled with a hipper, and corn was planted (33,000 seeds/acre) on top of the beds. Selected agronomic information is listed in Table 1.

Corn was furrow-irrigated as needed and the Cooperative Extension Service recommended cultural practices were closely followed. The plots were 25-ft long, 12.6-ft wide at LMCRS and 10-ft wide at PTRS allowing for four rows of corn planted in 38- and 30-in. wide rows, respectively. At LMCRS, we hand harvested one 12-ft long section of corn plants from each of the two center rows of each plot. At PTRS, corn plants in the two center rows of each plot were harvested with a plot combine. Grain yields were adjusted to 15.5% moisture content.

We obtained monthly precipitation data from each research station. 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 and site using the GLM and MIXED procedures of SAS. The data from the no-N 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 both locations, the monthly precipitation amounts in May and June were above the long-term average and were conducive for early-season N loss via leaching, runoff or denitrification (Table 2). Additional N loss could have occurred during irrigation events.

Cotton Experiments

The main effects of N source and N rate both significantly ($P \leq 0.05$) influenced seedcotton yield, but the N source × N rate interaction was not significant ($P > 0.10$, Table 3). The significant effect of N rate is consistent with our previous findings (Mozaffari and Slaton, 2014; Mozaffari et al., 2013). However, we did not observe a significant N-source effect in a similar experiment conducted in 2013, perhaps because the early-season precipitation in 2013 was below average. The significant N-source effect suggests that ESN-N was more available for plant uptake than conventional urea in 2014 when the amount of early-season rainfall was above normal and conducive to early-season N loss. Furthermore, in 2014, the fertilizer-N treatments were applied about two weeks in advance of planting (Table 2).

Seedcotton yield for the cotton that received no N was 1990 lb/acre, which was numerically (25%) lower than the yield of cotton that received the lowest N rate of 30 lb N/acre, averaged across N sources (Table 3). Averaged across the five N rates, cotton fertilized with 100%-urea-N produced significantly lower seedcotton yield (2675 lb/acre) than cotton fertilized with 25% urea-N plus 75% ESN-N (2892 lb/acre) or 100% ESN-N (2815 lb/acre). Averaged across the four urea and ESN blends, application of 90 lb N/acre maximized seedcotton yield. When urea was the sole N source, maximum numeric seedcotton yield was produced by application of 120 lb N/acre, but when ESN was the sole source of N, the maximum numeric yield was produced with 90 lb N/acre. Similar to the 2013 growing season we observed that at N rates of 60 to 120 lb N/acre, ESN-fertilized cotton appeared more vigorous during the growing season.

Corn Experiment

The average grain yields of corn that received no-N fertilizer were 92 bu/acre at LMCRS (Table 4) and 77 bu/acre at the PTRS (Table 5) indicating relatively low native soil-N availability at the two sites and suggesting the corn would be responsive to N fertilization. At both locations and averaged across all N-source combinations, N rate significantly influenced corn grain yield ($P < 0.0001$). Nitrogen source did not significantly influence corn grain yield at either site, but the N source × N rate interaction significantly ($P = 0.0393$) influenced grain yield at PTRS (Tables 4 and 5). The lack of a significant N source effect is not consistent with our previous research (Mozaffari et al., 2013). Averaged across all four N sources, the minimum N rate that maximized yield was 240 lb N/acre at LMCRS and 180 lb N/acre at PTRS. The recommended N rate for high-yielding corn at these two sites would be 220 lb N/acre.

PRACTICAL APPLICATION

The amount of early-season precipitation during the 2014 growing season was above the long-term average at both locations and was likely conducive for loss of preplant-applied N fertilizer. Seedcotton yields were maximized by application of 90 lb N/acre and treatments that included 25% to 100% of the N as ESN produced greater yields than cotton fertilized preplant with 100% urea. Nitrogen fertilization significantly increased corn grain yield and maximal yields were produced with 180 to 240 lb N/acre. Although the N source × N rate interaction significantly ($P = 0.0393$) influenced grain yield at PTRS, there was no obvious yield trend among the treatments. 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 agronomic information for cotton and corn N-fertilization trials established at the Lon Mann Cotton Research Station (LMCRS) and Pine Tree Research Station (PTRS) during 2014.

Site ID	Previous crop	Soil series	Cultivar or hybrid	Planting date	N-application date	Harvest date
LMCRS-cotton	Wheat[a]	Loring	ST4946	5 June	23 May	21 Oct
LMCRS-corn	Soybean	Loring	Pioneer1615HR	9 May	8 May	19 Aug
PTRS-corn	Soybean	Calhoun	Pioneer1615HR	24 April	24 April	29 Aug

[a] Wheat was planted in the fall of 2012 and harvested in June 2013

Table 2. Actual rainfall received by month in 2014 and the long-term (1960-2007) average monthly mean rainfall data at Lon Mann Cotton Research Station (LMCRS) and Pine Tree Research Station (PTRS).

Site ID	Precipitation	May	June	July	August	September	Total
		---------- (inches) ----------					
LMCRS[a]	2014	6.32	9.77	2.55	4.67	1.33	24.64
	Average[b]	5.90	3.90	3.90	2.80	3.20	19.70
PTRS[c]	2014	7.48	12.60	2.54	0.19	0.20	23.01
	Average[b]	5.02	3.42	3.33	3.46	3.02	18.25

[a] At LMCRS, cotton was planted on 5 June and harvested on 25 Oct, corn was planted on 9 May and harvested on 19 August.
[b] Long-term average for 1960-2007.
[c] At PTRS, corn was planted on 24 April and harvested on 29 Aug.

Table 3. Seedcotton yield as affected by N source, averaged across N rates, and N rate, averaged across N sources and the non-significant N source × N rate interaction for a N-fertilization experiment conducted at the Lon Mann Cotton Research Station during 2014.

	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)	----------Seedcotton yield (bu/acre) ----------						(bu/acre)
0		1900[b]				None	1900 [b]
30	2361	2555	2695	2593	2543	100% Urea-N	2675
60	2569	2607	2767	2787	2682	50%Urea-N, 50%ESN-N	2748
90	2767	3000	3030	2949	2937	25% Urea-N,75% ESN-N	2892
120	2888	2873	3010	2841	2903	100% ESN-N	2815
150	2787	2705	2917	2903	2828		
$LSD_{0.10}$		NS[c] (interaction)			137[d]	$LSD_{0.10}$	123
P-value		0.9683			<0.0001	*P*-value	0.0530

[a] ESN, Environmentally Smart N, polymer coated urea.
[b] The no-N control is listed for reference only as it was not included in the ANOVA.
[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 N rate, averaged across N sources, and the non-significant N source and N source × N rate interaction for a N-fertilization experiment conducted at the Lon Mann Cotton Research Station during 2014.

	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)	-------------------- Corn grain yield (bu/acre) ----------------------						(bu/acre)
0		92[b]				None	92[b]
60	151	164	158	145	154	100% Urea-N	201
120	192	181	189	198	190	50%Urea-N, 50%ESN-N	207
180	215	214	228	224	220	25% Urea-N,75% ESN-N	211
240	219	240	233	236	232	100% ESN-N	212
300	227	235	246	255	241		
$LSD_{0.10}$		NS[c] (interaction)			11[d]	$LSD_{0.10}$	NS
P-value		0.6416[e]			<0.0001	*P*-value	0.2355

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

Table 5. Corn grain yield as affected by the N source × N rate interaction for a N-fertilization experiment conducted at the Pine Tree Research Station during 2014. Main effect means are also listed for easy observation of general trends.

	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)	-------------------- Corn grain yield (bu/acre) ----------------------						(bu/acre)
0		77[b]				None	77[b]
60	165	159	123	166	153	100% Urea-N	214
120	216	217	217	201	213	50%Urea-N, 50%ESN-N	207
180	212	236	234	232	228	25% Urea-N,75% ESN-N	206
240	247	221	241	240	237	100% ESN-N	215
300	244	207	231	235	227		
$LSD_{0.10}$		26[c] (interaction)			10[d]	$LSD_{0.10}$	NS[e]
P-value		0.0393[f]			<0.0001	*P*-value	0.5156

[a] ESN, Environmentally Smart N, polymer coated urea.
[b] The no-N control is listed for reference only as it was not included in the ANOVA.
[c] LSD compares the means for each N source × N rate interaction at ($P = 0.1$).
[d] LSD compares the yield of treatments that received N, averaged across all N sources.
[e] NS, not significant at $P > 0.10$.
[f] *P*-value for the N source × N rate interaction.

Corn Response to Soil-Applied Phosphorus and Potassium at Multiple Locations in Arkansas

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Corn (*Zea mays* L.) was planted on approximately one million acres in Arkansas during 2013. A corn grain yield of 175 bu/acre removes the equivalent of 60 lb P_2O_5 and 45 lb K_2O/acre (International Plant Nutrition Institute, 2012). Between 1992 and 2013 the average corn grain yield in Arkansas increased from 130 to 187 bu/acre, which represents a substantial increase in phosphorus (P) and potassium (K) export from commercial fields. Phosphorus and/or K deficiency may limit corn yield in many agricultural soils if the nutrients removed by the harvested grain are not replenished by fertilization.

Phosphorus transport from agricultural soils has been implicated as one of the 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 minimize P loss into the surrounding landscape. Reliable soil-test-based fertilizer recommendations are the key to applying the correct P and or K fertilizer rates. Unfortunately, very little information is available describing corn response to P or K fertilization under current Arkansas production practices that reflects the current high yields and P and K removal rates. In 2010, we initiated replicated field experiments to evaluate corn response to P and K fertilization in Arkansas. Additional data from multiple site-years will increase the reliability and applicability of such information. The specific objective of this research was to evaluate corn-leaf tissue and grain yield response to soil-applied P or K fertilizer rates at multiple locations in Arkansas.

PROCEDURES

Phosphorus Experiments

Six P-fertilization trials were conducted in 2014 including sites at the University of Arkansas Lon Mann Cotton Research Station (LMCRS) in Lee County (LEZ43), Pine Tree Research Station (PTRS) in St. Francis County (SFZ43), and commercial production fields in Clay (CLZ41), Green (GRZ41), Poinsett (POZ41), and St. Francis (STZ41) counties on representative silt loams. The soil series and selected agronomic information for each site are listed in Table 1. The previous crop was soybean [*Glycine max* (L) Merr.] at all sites except at LEZ43 and SFZ43 where corn followed corn in rotation.

Prior to P application, a composite soil sample was taken from the 0- to 6-in. depth of each 0 lb P_2O_5/acre plot of each P-fertilization trial. The LEZ43 and SFZ43 trials were established in 2011 and the same P rates have been applied to the same plots annually. The remaining four trials were one-year trials that had been fertilized uniformly in prior years and treatments were implemented only in 2014. 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. 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 applied as triple superphosphate. The experimental design was a randomized complete block where each treatment was replicated five (CLZ41, GRZ41, POZ41) or six (LEZ43, SFZ43, and STZ41) times. Phosphorus treatments were applied onto the soil surface in a single application 9 to 40 days after planting. Blanket applications of muriate of potash and $ZnSO_4$ supplied 60 to 90 lb K_2O, ~5 lb S, and ~10 lb 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-lf stage and/or pre-tassel) depending on the location. Corn was grown on beds and furrow irrigated as needed either by research station staff or the cooperating producer. Each plot was 25-ft long and 10- to 12.6-ft wide allowing for four rows of corn spaced 30 (CLZ41, POZ41, SFZ43, STZ41) or 38 (GRZ41 and LEZ43) inches apart. Corn management closely followed University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations.

When corn was at the early- to mid-silk stage (R1), ear-leaf samples were collected from 10 plants/plot at five of the six research 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 two middle 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

Field experiments were conducted in 2014 at seven sites including LMCRS (LEZ44), PTRS (SFZE42), the Rohwer Research Station in Desha County (DEZ42) and four commercial production fields in Clay (CLZ42), Green (GRZ42), Poinsett (POZ42), and St. Francis (STZ42) counties.

Each K trial was located adjacent to the P-rate trial with the exception of DEZ42 and SFZE42. The agronomic information for K trials is listed in Table 1. The previous crop was soybean at all sites except LEZ44 and SFZE42 where corn followed corn in the rotation. Soil samples were collected as described for the P trials, and soil property means are listed in Table 3. The LEZ44 trial was established in 2011 and the same K-fertilizer rates have been applied to the same plots annually since 2011.

Potassium application rates ranged from 0 to 200 lb K_2O/acre in 40 lb K_2O/acre increments at all sites except SFZE42 where the rate increased in 50 lb K_2O/acre increments. All K treatments were applied as muriate of potash onto the soil surface 9 to 40 days after planting (Table 1). Triple superphosphate and $ZnSO_4$ were broadcast to supply 40 to 80 lb P_2O_5, ~10 lb Zn, and ~5 lb S/acre. Nitrogen fertilizer management was the same as described for the P trials.

At DEZ42, the plots were 40-ft long and 12.6-ft wide allowing for four rows of corn planted in 38-in. wide rows. At the other locations, plots were 25-ft long and either 10- (CLZ42, POZ42, SFZE42, STZ42) or 12.6-ft (LEZ44, DEZ42, GRZ42) wide allowing for four rows of corn planted in 30- or 38-in. wide rows respectively. All experiments had a randomized complete block design and each treatment contained four (SFZE42), five (CLZ42, GRZ42, POZ42), or six (DEZ42, LEZ44, STZ42) blocks.

Analysis of variance was performed for P or 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, or the average yield of all fertilized corn using orthogonal contrasts.

RESULTS AND DISCUSSION

Phosphorus Experiments

The soil pH ranged from 6.2 to 8.0 (Table 2) and all soils were mapped as silt loam soils (Table 1). Mehlich-3 extractable P ranged from 17 to 45 ppm. According to the current Cooperative Extension Service interpretation, the soil-test P level was Low (16 to 25 ppm) at GRZ41, SFZ43, and STZ41; Medium (26 to 35 ppm) at CLZ41 and LEZ43; and Optimum (36 to 50) at POZ41. The Low, Medium, and Optimum soil-test P levels receive recommendations of 110, 80, and 0 lb P_2O_5/acre, respectively.

Ear-leaf P concentrations in corn that did not receive any P fertilizer ranged from 0.25% to 0.37% P compared to 0.30% to 0.40% 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 sites where ear-leaf tissue was collected, the ear-leaf P concentration was increased by P fertilization at CLZ41, GRZ41, and LEZ43. Ear-leaf P concentration of corn receiving no P was numerically lowest at GRZ41 and greatest at SFZ43, which both had Low soil-test P levels.

Phosphorus fertilization significantly influenced corn grain yields only at LEZ43 where the same P rates had been applied to the same plots since 2011 (Table 4). Lack of P response at CLZ41 rated Medium and POZ41 rated Optimum are consistent with the current interpretation of Mehlich-3 extractable soil-test P for corn production in Arkansas. The lack of response to P fertilization at GRZ41, SFZ43, and STZ41 suggest that the current thresholds for the Low soil-test P level may need to be modified. At LEZ43, application of 40 lb P_2O_5/acre produced statistically greater grain yields as compared to corn that received no P fertilizer. The yield response to P fertilization at LEZ43 is perhaps a reflection of the substantial soil-test P variability among the zero P plots as indicated by the high standard deviation of the soil Mehlich-3 extractable P (Table 2). Orthogonal contrasts indicated a significant (P = 0.0021) linear response to P fertilization and grain yield, averaged across all P rates, was significantly greater (P = 0.0034) than corn that received no P fertilizer.

Potassium Experiments

The average Mehlich-3 extractable K ranged from 48 to 140 ppm among the seven sites (Table 3). According to the Cooperative Extension Service soil-test interpretation, soil-test K was Very Low (< 61 ppm) at DEZ44 and LEZ44; Low (61 to 90 ppm) at SFZE42; Medium (91 to 130 ppm) at CLZ42, GRZ42, and POZ42; and Optimum (131 to 175 ppm) at STZ42. Current fertilization guidelines for corn with a yield goal of >200 bu/acre would have recommended 160, 115, 80, and 50 lb K_2O/acre for the Very Low, Low, Medium, and Optimum soil-test K levels, respectively. At sites where corn ear-leaf samples were collected, the leaf K concentration ranged from 0.92% to 2.26% K for corn that received no K and 1.85% to 2.50% 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 increased ear-leaf K concentration at all the sites that were sampled (Table 5), which had Very Low to Medium soil-test K levels (Table 3). 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 of 1.80%, yield increases from K fertilization were expected at DEZ42, GRZ42, and LEZ44 (Table 5).

Potassium fertilization significantly affected corn grain yields at DEZ42, LEZ44, and SFZE42 (Table 6). Lack of yield response to K fertilization at sites with Medium (CLZ42, GRZ42, POZ42) and Optimum (STZ42) soil-test K levels (Table 2) is consistent with current Cooperative Extension Service recommendations for soil-test based K fertilization. Grain yield of corn that received no K fertilizer ranged from 156 to 269 bu/acre and grain yield of corn that received any K ranged from 200 to 269 bu/acre (Table 6). Orthogonal comparisons indicated that there was a significant linear or quadratic relationship between K rate and corn grain yield at DEZ42, LEZ44, and SFZE42 ($P < 0.10$). At these sites, the mean yield of corn receiving 0 lb K_2O/acre was significantly lower than the grain yields of corn fertilized with 120 lb K_2O/acre or the average of all treatments that received K.

PRACTICAL APPLICATIONS

Phosphorus fertilization did not increase corn grain yield when Mehlich-3 extractable P in the 0- to 6-in. depth was Low or Medium with the exception of one site in a multi-year trial. At the P responsive site, there was a significant linear relationship between P rate and corn grain yield. Lack of grain yield response to P fertilization at three Low-P testing sites suggest that current thresholds for the Low soil-test P level may need to be reevaluated. Potassium fertilization significantly increased corn grain yield at three sites, which had Very Low or Low soil-test K levels, but failed to influence corn yield at three sites that had Medium and one site that Optimum soil-test K levels. 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 do not respond to P and K fertilization (e.g., Optimum and Above Optimum levels) and with reasonable accuracy identify soils that respond to K fertilization. The current interpretation of soil-test P does not accurately predict soils that will respond to P fertilization.

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Table 1. Site identification code, test nutrient(s), soil series, corn hybrid; and planting, fertilizer application, and harvest dates for fertilization rate trials conducted in Clay (CLZ41-42), Desha (DEZ42), Green (GRZ41-42), Lee (LEZ43, LEZ44), Poinsett (POZ41-42), and St. Francis (SFZ43, SFZE42, STZ41-42) counties during 2014.

Site	Test nutrient	Soil series	Hybrid	Planting date	Fertilizer application date	Harvest date
CLZ41&42	P, K	Dundee silt loam	Pioneer1615HR	1 April	14 April	26 Aug
DEZ42	K	Hebert silt loam	Pioneer1319HR	5 May	22 May	17 Sep
GRZ41&42	P, K	Hillemann silt loam	Armor 1155	8 May	5 June	18 Sep
LEZ43&LEZ44	P, K	Calloway silt loam	Pioneer1319HR	16 April	25 April	21 Aug
POZ41&POZ42	P, K	Henry silt loam	Agrigold 06-59	11 April	21 May	18 Aug
SFZ43	P	Calloway silt loam	Pioneer1319HR	12 April	12 May	3 Sep
SFZE42	K	Calloway silt loam	Pioneer1319HR	12 April	12 May	22 Aug
STZ41&STZ42	P, K	Calloway silt loam	Pioneer1319HR	18 April	7 May	10 Sep

Table 2. Selected chemical property means of soil samples collected from the 0- to 6-in. depth before P-fertilizer application for six P-fertilization trials established in Clay (CLZ41), Green (GRZ41), Lee (LEZ43), Poinsett (POZ41), and St. Francis (SFZ43, STZ41) counties during 2014.

Site ID	Soil pH[a]	Mehlich-3-extractable nutrients						
		P[b]	K	Ca	Mg	Mn	Cu	Zn
		(ppm)						
CLZ41	6.5	26	97	703	121	165	1.1	4.0
GRZ41	6.2	19	99	1007	333	237	1.2	2.0
LEZ43	6.3	26	91	768	200	157	1.2	17.4
POZ41	6.7	45	124	1224	214	111	1.0	4.1
SFZ43	8.0	17	95	3161	352	367	1.8	16.9
STZ41	6.9	18	106	1573	378	297	2.0	2.3

[a] Soil pH was measured in a 1:2 (weight: volume) soil-water mixture.

[b] Standard deviation of Mehlich-3 extractable soil-test P means: 4 ppm for CLZ41, 2 ppm for GRZ41, 8 ppm for LEZ43, 3 ppm for POZ41, 2 ppm for or SFZ43, and 2 ppm for STZ41.

Table 3. Selected chemical property means of soil samples taken from the 0- to 6-in. depth before K-fertilizer application for seven K-fertilization trials conducted in Clay (CLZ42), Desha (DEZ42), Green (GRZ42), Lee (LEZ44), Poinsett (POZ42), and St. Francis (FSZE42, STZ42) counties during 2014.

Site ID	Soil pH[a]	Mehlich-3-extractable nutrients					
		P	K[b]	Ca	Mg	Cu	Zn
		(ppm)					
CLZ42	6.4	20	101	834	148	1.1	3.7
DEZ42	6.2	37	48	744	109	0.8	1.8
GRZ42	6.0	25	117	974	322	1.0	2.3
LEZ44	6.3	47	58	847	217	1.5	16.0
POZ42	6.9	38	111	1249	215	1.3	3.9
SFZE42	7.3	19	66	2107	314	1.3	3.2
STZ42	6.9	18	140	1510	380	2.3	3.5

[a] Soil pH was measured in a 1:2 (weight: volume) soil-water mixture.

[b] Standard deviation of Mehlich-3 extractable soil-test K in the 0- to 6-in. depths: 8 ppm for CLZ42; 4 ppm for DEZ42; 6 ppm for GRZ42, 7 ppm for LEZ42, 6 ppm for POZ42, 5 ppm SFZE42, and 27 ppm for STZ42.

Table 4. Effect of P-fertilization rate on ear-leaf P concentration at the silking (R1) stage and corn grain yield for six P-fertilization trials established in Clay (CLZ41), Green (GRZ41), Lee (LEZ43), Poinsett (POZ41), and St. Francis (SFZ43, STZ41) counties during 2014.

P rate	CLZ41		GRZ41		LEZ43		POZ41		SFZ43		STZ41	
	Ear-leaf P	Grain yield	Ear-leaf P	Grain yield	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)	(% P)	(bu/acre)	(% P)	(bu/acre)
0	0.29	189	0.25	239	0.33	226	0.35	233	0.37	222	ND[a]	237
40	0.31	195	0.27	246	0.35	247	0.36	238	0.37	216	ND	239
80	0.31	200	0.26	253	0.37	240	0.35	237	0.39	215	ND	253
120	0.31	207	0.29	247	0.38	255	0.37	254	0.37	234	ND	237
160	0.33	202	0.30	239	0.40	253	0.36	260	0.37	226	ND	255
CV[b]	3.70	11.4	6.10	5.7	6.60	5.1	4.70	6.4	6.40	4.3	-	6.8
P-value	0.0020	0.8038	0.0151	0.3995	0.0019	0.0266	0.6274	0.1701	0.4523	0.1527	--	0.2172
$LSD_{0.10}$[c]	0.01	NS[d]	0.02	NS	0.03	15	NS	NS	NS	NS	--	NS

[a] ND, No data; ear-leaf samples were not collected at this research site.

[b] CV, 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 (R1) stage for five K-fertilization trials conducted in Clay (CLZ42), Desha (DEZ42), Green (GRZ42), Lee (LEZ42), and Poinsett (POZ42) counties during 2014.

	Ear-leaf K				
K rate	CLZ42	DEZ42	GRZ42	LEZ42	POZ42
(lb K_2O/acre)	----------	----------	(% K)	----------	----------
0	2.26	1.33	1.73	0.92	1.84
40	2.27	1.59	1.86	1.35	1.84
80	2.35	1.64	1.88	1.45	1.75
120	2.55	1.80	1.95	1.56	2.03
160	2.50	1.92	1.90	1.70	2.04
200	2.50	1.85	1.95	1.88	2.14
CV[a]	5.0	7.1	5.0	9.3	5.7
P-value	0.0005	<0.0001	0.0573	<0.0001	0.0003
$LSD_{0.10}$[b]	0.12	0.12	0.09	0.14	0.13

[a] CV, Coefficient of variation.
[b] LSD, Least significant difference at *P* = 0.10.

Table 6. Effect of K-fertilization rate on corn grain yield for seven K-fertilization trials conducted in Clay (CLZ42), Desha (DEZ42), Green (GRZ42), Lee (LEZ44), Poinsett (POZ42), and St. Francis (SFZE42 and STZ42) counties during 2014.

	Grain yield							Grain yield
K rate	CLZ42	DEZ42	GRZ42	LEZ44	POZ42	STZ42	K rate	SFZE42
(lb K_2O/acre)	----------	----------	(bu/acre)	----------	----------	----------	(lb K_2O/acre)	(bu/acre)
0	205	167	243	156	241	269	0	182
40	208	217	245	243	248	266	50	222
80	206	201	243	266	258	267	100	244
120	223	205	245	250	245	256	150	249
160	208	200	251	265	256	253	200	244
200	217	217	243	257	245	262	-	-
CV[a]	8.4	5.3	7.0	8.1	8.9	6.1	CV	8.2
P-value	0.5108	<0.0001	0.9707	<0.0001	0.9205	0.7832	*P*-value	0.0092
$LSD_{0.10}$[b]	NS[c]	12	NS	22	NS	NS	$LSD_{0.10}$	28

[a] CV, coefficient of variation.
[b] LSD, least significant difference at *P* = 0.10.
[c] NS, not significant (*P* > 0.10).

Potassium Uptake and Partitioning in Determinate and Indeterminate Soybean Genotypes Differing in Maturity Group

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Understanding the uptake and distribution of nutrients among plant structures and across time is required to develop diagnostic information to assess plant nutritional health. A recently matured trifolioliate leaf potassium (K) concentration of soybean [*Glycine max* (L.) Merr.] at the R1-2 stage is reportedly well correlated to relative yield potential (Yin and Vyn, 2004; Clover and Mallarino, 2013). The relationship between soybean trifoliate leaf K concentration and seed yield may be different for determinate and indeterminate soybean cultivars. If so, it is reasonable to assume that dry matter and K accumulation and distribution; critical leaf K concentration; the proper plant part to sample for tissue analysis; and 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 cultivars of different maturity groups (MG) allocate nutrients among plant parts. Our objective was to evaluate season-long dynamics of dry matter accumulation and K uptake and allocation to the aboveground plant structures in representative determinate and indeterminate glyphosate-resistant soybean cultivars of different maturity groups under the same growing condition.

PROCEDURES

A field experiment was conducted at the Pine Tree Research Station near Colt, Ark., on a Calhoun silt loam (Typic Glossaqualfs) in 2013. A composite soil sample from the 0- to 4-in. soil depth was collected from each of four blocks before fertilizer application. 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 include a pH of 7.2, organic matter of 2.2%, and Mehlich-3 nutrient availability indices of 58 ppm phosphorus [P, 9 ppm standard deviation (SD)], 96 ppm K (15 ppm SD), 1762 ppm calcium (Ca), 287 ppm magnesium (Mg), 11 ppm sulfur (S), 152 ppm manganese (Mn), and 2.7 ppm zinc (Zn).

The research area consisted of four adjacent blocks that accommodated 3, 50-ft long strips of each soybean cultivar with each strip containing 20, 15-in. wide rows. Three glyphosate-resistant soybean cultivars having different maturity were randomized within each block. The cultivars included Armor 39-R16 (Armor Seed LLC, Jonesboro, Ark.), Armor 48-R40, and Armor 55-R22 to represent an indeterminate MG 3.9, an indeterminate MG 4.7, and a determinate MG 5.5, respectively. The trial was fertilized with 75 lb K_2O/acre as muriate of potash to ensure plant K was not yield limiting. The field was also fertilized with 0.5 lb boron (B)/acre after seeding. The seeding rate, irrigation, and pest management were done following the recommendations of the University of Arkansas System Division of Agriculture's Cooperative Extension Service.

After soybean emergence, 10, 4-ft long areas within each plot were selected for collecting plant samples and thinned to a uniform density of 15 plants/4 linear ft of row (equivalent to 130,000 plants/acre). Fifteen whole plant samples were collected 8 to 10 times at a 10 to 12 day interval during the season beginning 22 days after emergence (DAE; Fig. 1). A fully-expanded trifoliate leaf from one of the top three nodes of 12 plants surrounding each sample location was also collected. Each plant was examined and the number of nodes, branches, and the presence (or absence) of flowers at each node was recorded to determine the average plant development stage as described by Fehr et al. (1971). The sampled plants were divided into trifoliate leaves, petioles, stems, pods, and mature seeds; dried at 60 °C; weighed for dry matter; ground to pass a 1-mm sieve; digested; and analyzed for K concentration by ICP-AES. At maturity, a 40 to 50 ft^2 area within each block of each cultivar 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 structure 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 harvest index for both dry matter and K was calculated as the ratio of mature seed weight and seed K content at harvest to the maximum aboveground dry matter accumulation and K uptake, respectively, during the growing season (Schapaugh and Wilcox, 1980). The apparent seed and K harvest index was calculated as the ratio of mature seed weight and seed K content to the total plant dry matter and K content at harvest, respectively.

The seed yield and actual and apparent harvest index of seed and K data were statistically analyzed by analysis of variance (ANOVA) and means were separated using Fisher's protected LSD ($\alpha = 0.05$) using the Fit Model of JMP Pro 11 (SAS Institute, Cary, N.C.). Further analyses were conducted by regressing dry matter accumulation, K uptake, and dry matter and K distribution against DAE using a non-linear Gaussian peak model for leaves, petioles, stems, and whole plants and the Gompertz model for beans (pods with seeds). In the Gaussian and Gompertz models, the coefficient 'A' is the peak value or the asymptote (lb dry matter/acre or lb K/acre), 'B' is the critical or inflection point (DAE), and 'C' is the value that controls the width of the bell-shaped Gaussian curve or the steepness of the Gompertz curve (Archontoulis and Miguez, 2013). A linear model was used to predict the decline rate in trifoliate leaf K concentration after K concentration peaked. The studentized residuals for all dependent variables were examined to identify potential outliers. When appropriate, the model was refit by omitting the outliers.

RESULTS AND DISCUSSION

The growing season length (emergence to maturity) was 97 d for the MG 3.9, 107 d for the MG 4.7, and 118 d for the MG 5.5 cultivar. Blooming (R1) started at 22, 34, and 43 DAE for the MG 3.9, 4.7, and 5.5 cultivars, respectively. The entire reproductive period (R1-8) lasted 73 to 75 d for all three cultivars. Both the MG 3.9 and MG 4.7 cultivars bloomed (R1-2) for 12 d and the MG 5.5 cultivar bloomed for 9 d. The length of the seed-filling period (R5-7) lasted 32 d for the MG 3.9 and 4.7 cultivars, which was 9 d shorter than the MG 5.5 cultivar (41 d).

Soybean plants accumulated a total of 15 nodes for the MG 3.9, 17 nodes for the MG 4.7, and 16 nodes for the MG 5.5 cultivar (Fig. 1). Node accumulation peaked at the R5.5 stage for the MG 3.9 and 4.7 cultivars and at the R5 stage for the MG 5.5 cultivar. From blooming (R1) to the maximum node accumulation period (R5/5.5), the MG 3.9 and 4.7 cultivars took 32 d to set 6 to 7 nodes and the MG 5.5 cultivar took 23 d to set 4 nodes. Regardless of maturity group or growth habit, soybean plants required an average of 4 to 5 days per node during their entire life cycle. Node accumulation was faster during the vegetative stage (2.4 to 3.6 days/node) compared to the reproductive stage (4.6 to5.8 days/node).

The dry matter accumulation was rapid from the vegetative stage to the onset of the seed-filling period (R5) and declined as the leaves senesced and seed matured (Fig. 2). The maximum aboveground dry matter was similar for the MG 3.9 and 4.7 cultivars (6,657 to 7,137 lb/acre) but different from the MG 5.5 cultivar (8,636 lb/acre; Table 1). Regardless of growth habit or maturity group, dry matter accumulation peaked between the R6 and R7 stage, 82 to 95 DAE.

The predicted crop growth rate patterns were similar for the MG 3.9 and 4.7 cultivars, but different from the MG 5.5 cultivar (Fig. 3). Soybean plants accumulated dry matter at the maximum predicted rate of 136 lb/acre/day for the MG 3.9, 128 lb/acre/day for the MG 4.7, and 145 lb/acre/day for the MG 5.5 cultivar. The predicted rate of maximum crop growth occurred at the R4-5 stage for all three cultivars, which corresponded to 55 DAE for the MG 3.9 and 4.7 cultivars and 60 DAE for the MG 5.5 cultivar.

Before blooming, 58% of the aboveground dry weight of the MG 4.7 cultivar consisted of leaves; but with the onset of reproductive growth, the proportion of the total plant weight from leaves declined to 26% by the R5-6 stage (Fig. 4). The percentage of the plant total weight from petioles and stems showed less fluctuation than the leaves, but gradually increased in dry weight until pod set (R3). At the R5 stage, most of the dry matter was allocated to the developing beans (pods and seeds) and dry matter increased until physiological maturity (R7). At the R6.5 stage, the time of maximum dry matter accumulation, the beans, stems, leaves, and petioles of the MG 4.7 cultivar accounted for an average of 54%, 23%, 13%, and 10% of the dry matter, respectively. The MG 3.9 and 5.5 showed similar trends in dry matter distribution among plant structures (not shown).

The pattern of aboveground K uptake for the MG 3.9 and 5.5 cultivars was similar to the dry matter accumulation of the MG 4.7 cultivar throughout the growing season (Fig. 5). The maximum aboveground K uptake was similar for all three cultivars ranging from 115 to 118 lb K/acre but peak uptake occurred at different times (Table 1). Potassium uptake for all three cultivars peaked at the R5.5-6.0 stage, 74 to 78 DAE for the MG 3.9 and 4.7 cultivars and 91 DAE for the MG 5.5 cultivar. The peak K accumulation time coincided with the seed-filling period (R5-7) when the plant's K demand was greatest.

Like crop growth rate, the patterns of predicted K uptake rate were identical throughout the growing season for the MG 3.9 and 4.7 cultivars but vastly different from the MG 5.5 cultivar (Fig. 6). The predicted maximum K uptake rate for the MG 3.9 and 4.7 cultivars was 2.1 lb K/acre/day compared to 1.6 lb K/acre/day for the MG 5.5 cultivar. Regardless of maturity group or growth habit, the predicted rate of maximum K uptake occurred at the R3-4 stage which corresponded to 45 DAE for the MG 3.9 and 4.7 cultivars and 55 DAE for the MG 5.5 cultivar.

The distribution of K content among the soybean plant structures of the MG 4.7 cultivar was different for leaves, petioles, and stems and similar for beans (pods and seeds) to that of dry matter distribution (Fig. 7). Leaves contained about 42% 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 different during the early reproductive stage but similar during the seed-filling period. At the R2 stage, 28% of the total aboveground K content was located in the petioles and 40% in the stems, but as the soybean pods developed (R3-4) the K content gradually declined for both structures. The depletion of K in the leaves, petioles, and stems was attributed to the mobilization and subsequent translocation of K to the developing seeds. At the R5.5 stage, the maximum K uptake period, the K distribution among plant structures of the MG 4.7 cultivar was 21% in the leaves, 14% in the petioles, 15% in the stems, and 50% in the beans. Potassium distribution trends across the growing season for the MG

3.9 and 5.5 cultivars were similar to the trend described for the MG 4.7 cultivar.

The seasonal change of trifoliate leaf K concentration was different for all three soybean cultivars (Fig. 8). Regardless of maturity group or growth habit, the trifoliate K concentration peaked (2.0% to 2.2% K) between the transition period of vegetative and reproductive stages (R0). The linear models showed that after peak K concentrations were reached, the trifoliate leaf K concentration declined linearly with plant age at the rate of 0.015% K/day for the MG 3.9, 0.007% K/day for the MG 4.7, and 0.020% K/day for the MG 5.5 cultivar.

Soybean seed yield was statistically similar among soybean cultivars ranging from 42 to 46 bu/acre (Table 2). The actual harvest index of soybean seed was also similar among cultivars although the apparent harvest index was different (Table 2). Soybean seed comprised 61% to 62% of the maximum aboveground dry matter produced at harvest (apparent harvest index) for the MG 3.9 and 4.7 cultivars and 54% for the MG 5.5 cultivar. There was no difference in actual K harvest index among cultivars, but apparent K harvest index was different (Table 2). According to actual K harvest index, the proportion of K removed by the harvested soybean seed ranged from 50% to 64% of the maximum amount of K accumulated during the growing season (e.g., R5.5-6 stage). However, the seed K content accounted for 71% to 72% of the total aboveground K content at maturity (e.g., after leaf senescence, apparent K harvest index) for the MG 3.9 and 4.7 cultivars and 65% for the MG 5.5 cultivar.

PRACTICAL APPLICATIONS

Knowledge of the dry matter and K accumulation pattern among soybean plant structures of a range of soybean maturity groups is of value for developing diagnostic tissue sampling protocols to monitor the nutritional status of soybean. The results indicate that trifoliate leaf K concentration peaks during early reproductive growth and declines linearly during pod set and seed fill. Understanding the change of soybean trifoliate leaf K concentration across a range of K availability might enable us to interpret the plant's K nutritional status at stages beyond the R2 stage.

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Table 1. Coefficient and estimated parameter values for the Gaussian model for predicting aboveground dry matter accumulation (Fig. 2) and K uptake (Fig. 5) of three soybean cultivars of different maturity groups (MG) during the 2013 growing season.

	Gaussian model parameters†				
Cultivar MG	A	B	C	r^2	*P*-value
Total dry matter accumulation					
MG 3.9	7137 b‡	82 a	29.2 b	0.90	<0.0001
MG 4.7	6657 b	86 a	31.3 ab	0.93	<0.0001
MG 5.5	8636 a	95 a	34.7 a	0.89	<0.0001
Total K uptake					
MG 3.9	118 a	74 b	30.3 c	0.73	<0.0001
MG 4.7	115 a	78 b	32.7 b	0.88	<0.0001
MG 5.5	116 a	91 a	40.5 a	0.84	<0.0001

† In Gaussian peak model [Y= A*Exp(-0.5*((X-B)/C)^2)], the coefficient 'A' is the peak value (lb/acre), 'B' is the critical point (DAE), and 'C' is the value that controls the width of the bell-shaped curve.

‡ Values within a column followed by similar letters do not differ significantly at the 5% level of probability.

Table 2. Soybean seed yield, actual and apparent harvest indices of seed and K of three soybean cultivars of different maturity groups (MG) during the 2013 growing season at the Pine Tree Research Station.

		Harvest index			
		Seed		K	
Cultivar MG	Seed yield	Actual	Apparent	Actual	Apparent
	(bu/acre)				
MG 3.9	46 a†	0.52 a	0.62 a	0.51 a	0.71 a
MG 4.7	42 a	0.50 a	0.61 a	0.50 a	0.72 a
MG 5.5	45 a	0.46 a	0.54 b	0.64 a	0.65 b
$LSD_{0.05}$	NS‡	NS	0.03	NS	0.05
P-value	0.483	0.398	0.003	0.569	0.049

† Values within each column followed by similar letters do not differ significantly at the 5% level of probability.
‡ NS, not significant.

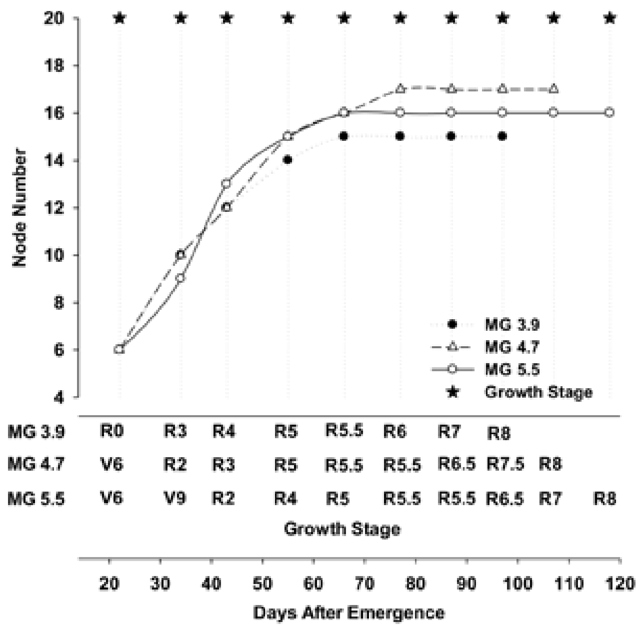

Fig. 1. Seasonal node accumulation of three soybean cultivars belonging to different maturity groups (MG).

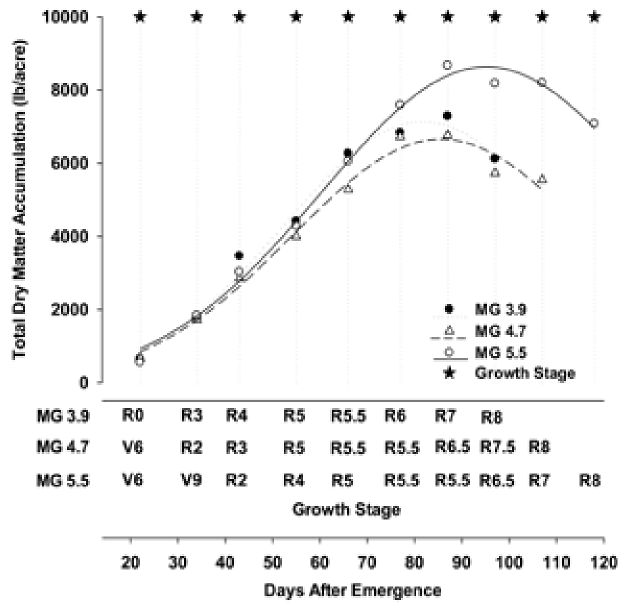

Fig. 2. Dry matter accumulation across time of three soybean cultivars belonging to different maturity groups (MG) as predicted with a Gaussian peak model. Coefficient and estimated parameter values are listed in Table 1.

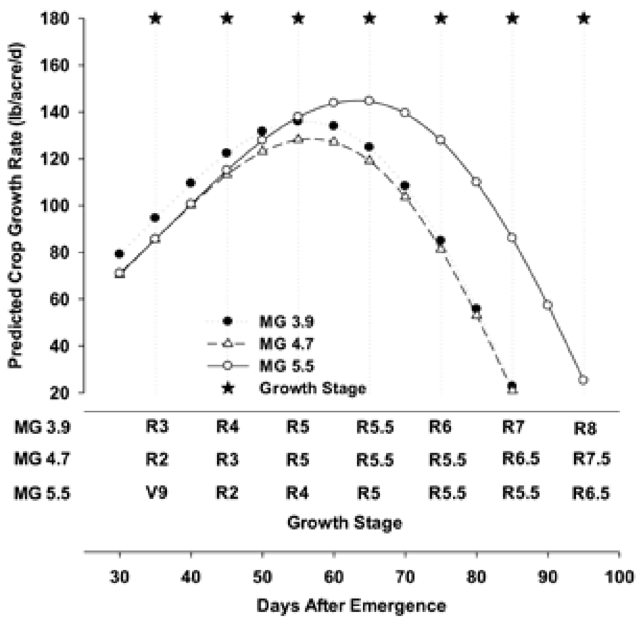

Fig. 3. Predicted crop growth rate across time of three soybean cultivars belonging to different maturity groups (MG).

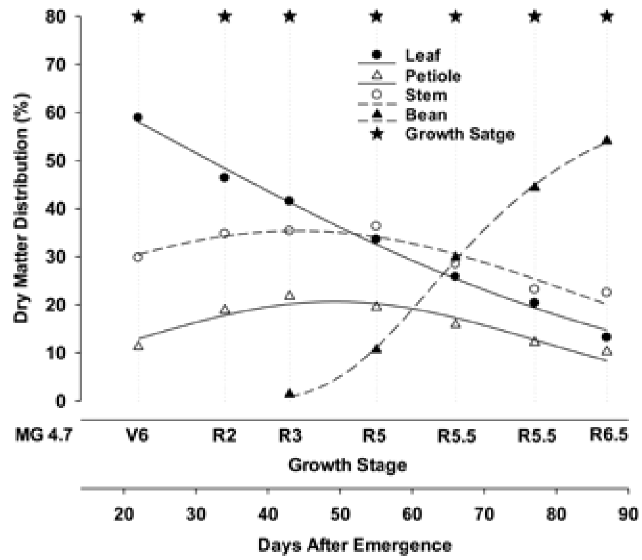

Fig. 4. Seasonal dry matter distribution of a maturity group (MG) 4.7 soybean cultivar.

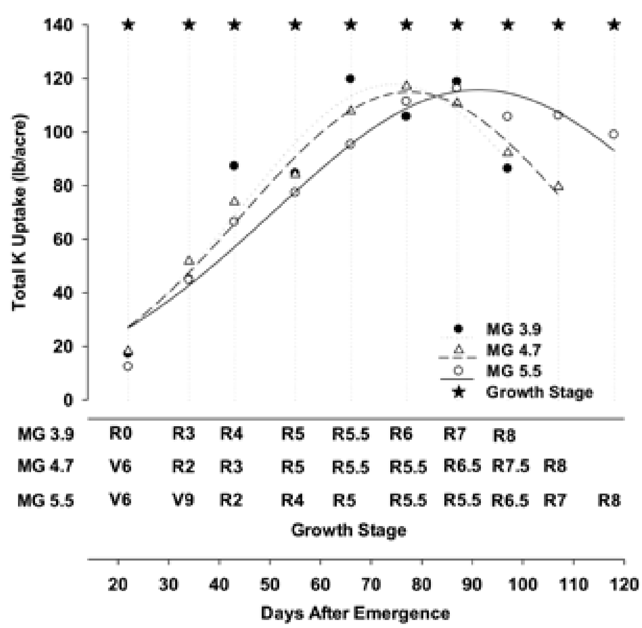

Fig. 5. Total K uptake across time of three soybean cultivars belonging to different maturity groups (MG) as predicted with a Gaussian peak model. Coefficient and estimated parameter values are listed in Table 1.

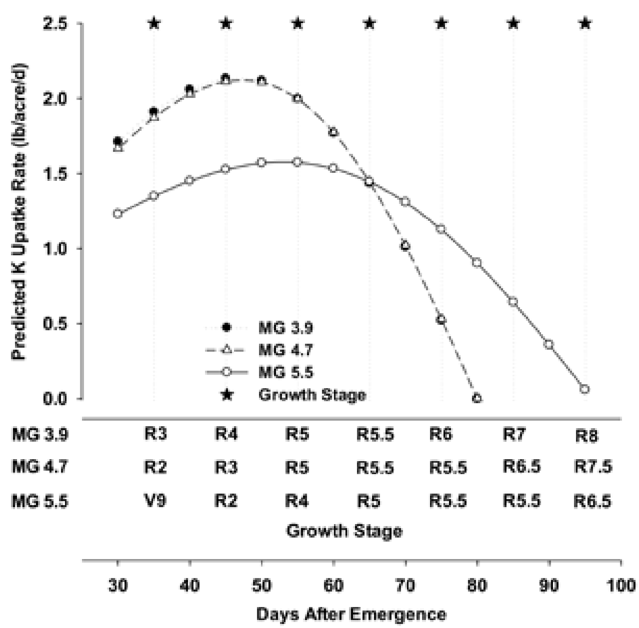

Fig. 6. Predicted K uptake rate across time of three soybean cultivars belonging to different maturity groups (MG).

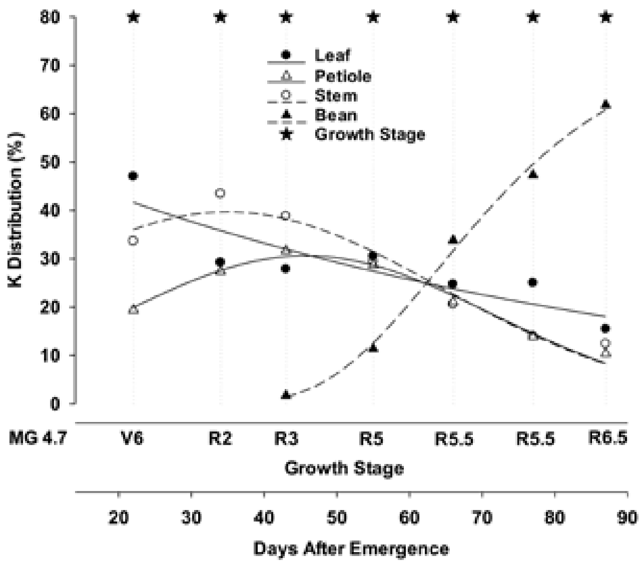

Fig. 7. Plant K distribution among plant parts across time of a maturity group (MG) 4.7 soybean cultivar.

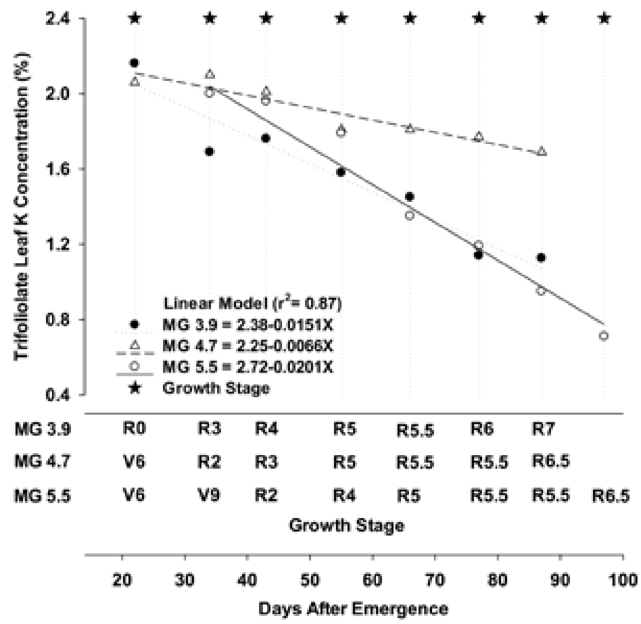

Fig. 8. Change of trifoliate leaf K concentration across time of three soybean cultivars belonging to different maturity groups (MG) as predicted with linear models.

Potassium Deficiency Effects on Nodal Seed Yield and Potassium Concentration of Determinate and Indeterminate Soybean

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

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Soybean [*Glycine max* (L.) Merr.] is responsive to potassium (K) fertilization on soils with low K availability. Potassium deficiency can cause substantial soybean yield loss by decreasing the number of pods/plant and seeds/pod (Coale and Grove, 1990). Soybean seed yield and seed K concentration are known to vary among the nodes of both determinate (Sadler et al., 1991) and indeterminate (Hanway and Weber, 1971) cultivars. Sadler et al. (1991) showed that the middle nodes (7-15th nodes of 20 total nodes) of a determinate soybean cultivar produced about 75% of the total reproductive (pods and seeds) dry matter. Their data also revealed that K concentration of mature beans (pods and seeds) gradually decreased from the bottom to the top of the plants. We could find no research that has investigated the effect of K deficiency on soybean seed yield and seed K concentration among nodes.

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 for the production of high yields and to develop efficient K-fertilization methods. Our research objective was to evaluate soybean seed yield and seed K concentration among nodes of an indeterminate and determine soybean cultivar as affected by annual K-fertilization rate.

PROCEDURES

An experiment was conducted on a Calhoun silt loam (Typic Glossaqualfs) in 2013 at the Pine Tree Research Station near Colt, Ark., in a long-term K-fertilization trial cropped with a 1:1 rice (*Oryza sativa* L.) soybean rotation. One composite soil sample per replicate was collected before the application of K-fertilizer treatments. The soil samples were oven-dried at 55 °C, 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 soil-test K values were 67 ppm (12 ppm standard deviation), 74 ppm (4 ppm), and 78 ppm (8 ppm) for soil collected from the 0, 80, and 160 lb K_2O/acre/year treatments, respectively. Soil pH averaged 7.6 and soil organic matter content averaged 2.9%.

Two glyphosate-resistant soybean cultivars, Armor 48-R40 [Indeterminate growth habit and maturity group (MG) 4.7; Armor Seed LLC, Jonesboro, Ark.] and Armor 53-R15 (determinate growth habit and MG 5.3) were selected for this study. The experiment was a strip-plot with five blocks where annual K rate was the main plot and soybean cultivar was the strip-plot. Each strip-plot contained 10, 38-cm wide rows of each cultivar. Soybean was planted into an untilled seedbed on 16 May 2013.

Three annual rates of 0, 80, and 160 lb K_2O/acre/year as muriate of potash were broadcast by hand to each main plot of each block after seeding. These or similar K rates have been applied to the same plots each year since 2001. To ensure that phosphorus (P) and boron (B) were not yield limiting, 60 lb P_2O_5/acre as triple superphosphate and 1 lb B/acre as granubor were also applied. The seeding rate, irrigation, 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 cultivar from each plot were collected at maturity to evaluate seed yield and seed K concentration as affected by main-stem node location and annual K fertilization. The nodes of the sampled plants were numbered from the topmost node (node 1) to the bottom node. The four plants were dissected from the top of the plant to the bottom and tissues from the four plants were composited into a single sample. Each plant was dissected by cutting immediately above nodes (from top to bottom) 3, 5, 7, 9, 11, 13, 15, 17, 19 so that each sample consisted of two nodes and two internodes. Tissues from each dissected node segment were separated into i) stem internodes, ii) pods, and iii) seeds. The seeds from each node segment were counted and weighed after discarding the aborted and/or malformed seed. Soybean field yield was measured by harvesting a 40 to 50 ft^2 area within each block of each cultivar with a small plot combine at maturity and seed yield was determined by adjusting the seed moisture to 13%.

Armor 48-R40 plants had an upright growth habit, no lateral branches, and up to 20 nodes/plant at maturity. Armor 53-R15 was a bushy plant, had up to 12 nodes/plant 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 main stem and separated into the same plant components as described previously. For evaluating seed K concentration at different main-stem node segments, a subsample of three whole soybean seeds from each main-stem and branch node segment was weighed, digested, and analyzed by ICP-AES. For Armor 53-R15, the determinate cultivar, some lower main-stem node segments did not contain any seed. The seed K concentration for those main-stem node segments was replaced by the seed K concentration of the branch node segment closest to that main-stem node segment.

Data of the four-plant seed yield and field-seed yield were analyzed by cultivar using the MIXED procedure of SAS v. 9.4 (SAS Institute, Cary, N.C.). The statistical model was a randomized complete block design that included the fixed effect of annual K rate and the random effect of block. Nodal-seed yield and seed K concentration data were analyzed by cultivar using a split-plot model that included the fixed effect of annual K rate and main-stem node segment and the random effect of block. When a significant F-test was obtained, the means were separated by Fisher's protected least significant difference test at the 0.05 probability level. The studentized residuals and Cook's D statistics were also tested to identify the potential outliers and influential data, respectively. When appropriate, the model was refit by excluding the outliers or influential data.

RESULTS AND DISCUSSION

The four-plant seed yield of both the indeterminate and determinate cultivars was significantly affected by annual K-fertilizer rate (Table 1). For the indeterminate cultivar (Armor 48-R40), four-plant seed yield decreased with each decrease in annual K-fertilizer rate. Plants grown with 0 lb K_2O/acre/year produced 29% to 45% lower yields than plants grown with 80 or 160 lb K_2O/acre/year. The four-plant seed yield of soybean receiving 80 lb K_2O/acre/year was 24% lower than soybean receiving 160 lb K_2O/acre/year. For the determinate cultivar (Armor 53-R15), soybean receiving 0 lb K_2O/acre/year produced 33% to 43% lower yield compared to soybeans fertilized with 80 or 160 lb K_2O/acre/year and seed yield was similar for plants grown with 80 or 160 lb K_2O/acre/year.

The field yield of both the indeterminate and determinate cultivars were also significantly affected by annual K-fertilizer rate (Table 1). However, the magnitude of field-yield loss associated with K deficiency was lower (19% to 20% for the indeterminate cultivar and 15% to 22% for the determinate soybean) than the yield loss measured from the four-plant yield. The magnitude of yield differences among annual K-fertilizer rates suggested that the plants would also show yield differences among nodes.

We evaluated four-plant seed yield across nodes of both the determinate and indeterminate cultivars under the three different annual K-fertilization regimes. The interaction between annual K rate and nodal position significantly influenced the seed yield across node segments for both the indeterminate (Table 2) and determinate (Table 3) cultivars. For the indeterminate cultivar (Armor 48-R40), seed yield on the bottom three node segments (15 + 16, 17 + 18, and 19 + 20) was similar among annual K rates (Table 2). Within each node segment, soybeans fertilized with 80 and 160 lb K_2O/acre/year produced equal yields on the upper three node segments (01 + 02, 03 + 04, and 05 + 06) and the lower four node segments (13 + 14, 15 + 16, 17 + 18, and 19 + 20), but yields on the middle segments (07 + 08, 09 + 10, and 11 + 12) were greater for soybean fertilized with 160 lb K_2O/acre/year. Regardless of the annual K rate, the largest proportion (56%) of the seed yield was produced on the middle three node segments (07 + 08, 09 + 10, and 11 + 12) where seed yield increased by 36% to 37% with each increase in annual K-fertilizer rate.

For the determinate cultivar (Armor 53-R15), the significant interaction showed that seed yield was different among annual K rates at the upper three node segments (03 + 04, 05 + 06, and 07 + 08) where seed yield was decreased by 45% to 53% for soybean fertilized with 0 lb K_2O/acre/year compared to 80 and 160 lb K_2O/acre/year (Table 3). Seed yield between soybean fertilized with 80 and 160 lb K_2O/acre/year was similar for node segments 03 + 04 and 07 + 08. At node segment 05 + 06, the yield of soybean fertilized with 80 lb K_2O/acre/year was intermediate. Regardless of the annual K-fertilizer rate, the largest proportion (90%) of the seed yield was produced on the top three node segments (01 + 02, 03 + 04, and 05 + 06) with two of these node segments (03 + 04 and 05 + 06) experiencing substantial yield loss (32% to 40%) due to K deficiency.

We also evaluated seed K concentration at each node segment of both the indeterminate and determinate cultivars to confirm the effect of K deficiency on seed yield. The seed K concentration was affected by the interaction between node segment and annual K rate for both the indeterminate (Table 4) and determinate (Table 5) cultivars. For the indeterminate cultivar, there was a significant change in seed K concentration within each K rate from the top to the bottom node segment. In general, seed K concentration increased as annual K rate increased when comparing the same node segment. Regardless of annual K rate, the lowest seed K concentration occurred on the top node segment and the greatest K concentration on the bottom node segment. The range of seed K concentration across node segments was greatest on soybean that received 0 lb K_2O/acre/year (1.12% to 1.78% K), intermediate for 80 lb K_2O/acre/year (1.56% to 1.88% K), and least for 160 lb K_2O/acre/year (1.79% to 1.97% K).

For the determinate cultivar, seed K concentration at each node segment was statistically similar between plants that received 80 and 160 lb K_2O/acre/year, but greater than plants that received no K fertilizer (Table 5). Like the indeterminate cultivar, seed K concentration across annual K rates was also lowest on the upper node segments and greatest on the lower node segments. The seed K-concentration range from the top to the bottom of the plant increased as annual K rate decreased suggesting K availability may limit soybean yield on the upper plant nodes.

PRACTICAL APPLICATIONS

Yield loss from K deficiency occurred on the upper nodes of both the indeterminate and determinate cultivars and seed produced on the lower nodes appear to receive K preferentially due to their position in relation to the location of K uptake and distribution. Although it is not clear from our research, we hypothesize that the number of nodes with decreased yield from K deficiency would increase as the severity and duration of K deficiency increases. Diagnosis of K deficiency at maturity by examining the seed K concentration on specific or among individual nodes may be possible but additional research is needed to develop a critical seed K concentration and to validate this hypothesis. Other important aspects from our research 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 fertility is high. If soybean seed accumulates K luxuriously, fertilizer recommendations that aim to maintain soil-test K at Optimal levels may need to be reconsidered.

ACKNOWLEDGMENTS

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Sadler, E.J., D.L. Karlen, R.E. Sojka, and H.D. Scott. 1991. Morphological, temporal, and nodal accumulation of nutrients by determinate soybean. J. Plant Nutr. 14:775-807.

Table 1. Soybean four-plant and field yields of indeterminate (Armor 48-R40) and determinate (Armor 53-R15) soybean cultivars as affected by annual K-fertilizer rate in the long-term, K-fertilization trial conducted at the Pine Tree Research Station in 2013.

	Four-plant yield		Field yield	
Annual K rate	Indeterminate	Determinate	Indeterminate	Determinate
(lb K_2O/acre/year)	------------- (g/four-plant) ------------		----------------(bu/acre) --------------	
0	60	54	43	46
80	84	80	53	54
160	110	95	54	59
P-value	0.002	0.006	0.020	0.001
LSD $_{0.05}$	15	21	8	5

Table 2. Seed yield of an indeterminate (Armor 48-R40) soybean cultivar 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 2013.

	Seed yield at different annual K-fertilization rates		
Node segment	0 lb K_2O/acre	80 lb K_2O/acre	160 lb K_2O/acre
	--------------------------------- (g/four-plant) ----------------------------------		
01 + 02 (top of the plant)	5.1	8.0	10.0
03 + 04	6.0	7.1	8.7
05 + 06	7.7	10.5	13.0
07 + 08	11.3	14.4	20.9
09 + 10	12.9	16.6	22.7
11 + 12	9.6	14.9	18.9
13 + 14	4.4	8.2	8.7
15 + 16	1.6	2.5	2.4
17 + 18	0.6	1.6	0.6
19 + 20 (bottom of the plant)	0.3	0.2	0.0
P-value (annual K rate × node segment)			<0.001
LSD $_{0.05}$ (compare among node segments within an annual K rate)			2.5
LSD $_{0.05}$ (compare among annual K rates within a node segment)			2.7
LSD $_{0.05}$ (compare among node segments and annual K rates)			2.9

Table 3. Seed yield of a determinate (Armor 53-R15) soybean cultivar 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 2013.

	Seed yield at different annual K-fertilization rates		
Node segment	0 lb K_2O/acre	80 lb K_2O/acre	160 lb K_2O/acre
	(g/four-plant)		
01 + 02 (top of the plant)	15.3	17.1	17.4
03 + 04	20.4	28.6	28.4
05 + 06	10.9	16.8	23.0
07 + 08	1.8	6.0	8.5
09 + 10	0.5	1.0	1.2
11 + 12 (bottom of the plant)	0.1	0.2	0.3
P-value (annual K rate × node segment)			<0.001
$LSD_{0.05}$ (compare among node segments within an annual K rate)			2.8
$LSD_{0.05}$ (compare among annual K rates within a node segment)			3.3
$LSD_{0.05}$ (compare among node segments and annual K rates)			3.6

Table 4. Seed K concentration of an indeterminate (Armor 48-R40) soybean cultivar 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 2013.

	Seed K concentration at different annual K-fertilization rates		
Node segment	0 lb K_2O/acre	80 lb K_2O/acre	160 lb K_2O/acre
	(% K)		
01 + 02 (top of the plant)	1.12	1.56	1.79
03 + 04	1.20	1.65	1.82
05 + 06	1.30	1.71	1.87
07 + 08	1.41	1.76	1.88
09 + 10	1.47	1.78	1.90
11 + 12	1.55	1.82	1.90
13 + 14	1.62	1.81	1.88
15 + 16	1.64	1.81	1.97
17 + 18	1.66	1.83	1.93
19 + 20 (bottom of the plant)	1.78	1.88	--
P-value (annual K rate × node segment)			<0.001
$LSD_{0.05}$ (compare among node segments within an annual K rate)			0.08
$LSD_{0.05}$ (compare among annual K rates within a node segment)			0.12
$LSD_{0.05}$ (compare among node segments and annual K rates)			0.14

Table 5. Seed K concentration of a determinate (Armor 53-R15) soybean cultivar 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 2013.

	Seed K concentration at different annual K-fertilization rates		
Node segment	0 lb K_2O/acre	80 lb K_2O/acre	160 lb K_2O/acre
	(% K)		
01 + 02 (top of the plant)	1.36	1.82	1.92
03 + 04	1.50	1.88	1.82
05 + 06	1.64	1.89	1.94
07 + 08	1.66	1.93	2.01
09 + 10	1.75	1.95	2.02
11 + 12 (bottom of the plant)	1.71	2.02	1.95
P-value (annual K rate × node segment)			0.035
$LSD_{0.05}$ (compare among node segments within an annual K rate)			0.12
$LSD_{0.05}$ (compare among annual K rates within a node segment)			0.12
$LSD_{0.05}$ (compare among node segments and annual K rates)			0.12

Predicting Nitrogen Rates for Wheat on Poorly Drained Silt Loam Soils

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Arkansas soft red winter wheat (*Triticum aestivum* L.) producers typically apply nitrogen (N) in the form of urea, urea-ammonium-nitrate, or ammonium sulfate in two split applications during late winter following green-up. Total-N rates for winter wheat in Arkansas are based on planting date, soil texture and previous crop (Roberts and Slaton, 2014). A common N-rate recommendation for wheat produced on silt loam soils is 120 lb N/acre and represents an optimum planting date following soybean (*Glycine max*. L.) in rotation with no fall applied N and a split application in late winter. Arkansas wheat producers will typically spend \$50.00 to \$60.00/acre annually on N fertilizer which is often their largest single item expenditure. Soil-N availability is a yield-limiting factor in the majority of wheat production settings. Therefore, optimizing N-fertilizer inputs for winter wheat production in Arkansas is crucial to ensure that production remains profitable across a range of commodity prices.

Success of the Nitrogen Soil Test for Rice (*Oryza sativa*, N-ST*R) has led researchers to investigate the potential benefit of this technology for wheat produced on similar soil textures in Arkansas. Work by Roberts et al. (2011) indicated N rates for wheat produced on poorly drained silt loam soils could be predicted using a 0- to 6-in. soil sample with an $r^2 = 0.90$, indicating a high probability of success. Prior to the widescale implementation of this site-specific N test for wheat, validation tests must be completed to ensure that the method is able to consistently predict yield-maximizing N rates over a wide range of conditions and previous crops. The objective of this research was to evaluate the accuracy of a site-specific N-rate recommendation for wheat using the N-ST*R program.

PROCEDURES

Four research sites were established in fall of 2013 with two located at the Pine Tree Research Station (PTRS) and two in producer fields (PF). The two research trials at PTRS were located on a Calhoun silt loam following recently cleared land that was summer fallowed (PTRS-F) and a Calloway soil series following soybeans (PTRS-S). The first PF was near Stuttgart, Ark., on a Dewitt silt loam following soybean (PF-S) and the second PF was near Batesville, Ark., on an Arrington silt loam following corn (*Zea mays*, PF-C). The Armor wheat variety Ricochet was used at both PTRS sites and PF-S and the wheat variety Dixie McAlister was seeded at PF-C. All locations were managed using current University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations for winter wheat, and phosphorus (P) and potassium (K) were added based on soil analysis. All trials were seeded during the optimum dates for planting winter wheat in Arkansas with planting dates of 10 October (PTRS-F), 24 October (PTRS-S), 11 October (PF-C), and 18 October (PF-S).

Trials were established in plots that were 20-ft long and 9-rows wide where the row spacing varied by location from 7.5 in. to 8.0 in. Four composite soil samples were collected from the 0- to 6-in. soil depth from each research site to characterize soil chemical properties and predict the site-specific N rate using N-ST*R (Roberts et al., 2009; 2011). The mean N-ST*R value for each site was 197 ppm (9.3 ppm standard deviation) at PTRS-F, 167 ppm (6.1) at PTRS-S, 158 ppm (4.9) at PF-S, and 171 ppm (5.7) at PF-C. The mean NH_4-N value for each site was 12 ppm (1.3 ppm standard deviation) at PTRS-F, 1.9 ppm (0.2) at PTRS-S, 3.5 ppm (0.7) at PF-S, and 16.3 ppm (2.9) at PF-C. The mean NO_3-N value for each site was 8 ppm (0.7 ppm standard deviation) at PTRS-F, 4.6 ppm (0.6) at PTRS-S, 1.8 ppm (0.3) at PF-S, and 6.9 ppm (0.9) at PF-C. The treatments at each site followed the same structure and differed only in the site-specific N rate predicted using N-ST*R. Treatments included a 1) no-N control (0 lb N/acre), 2) the N-ST*R 95% relative grain yield N rate, and 3) the standard N recommendation based on soil texture and previous crop. The N-ST*R recommended N rate for each site is listed in Table 1.

Nitrogen was applied in late winter when wheat began to break dormancy and the timing varied by location. The standard N rate of 120 lb N/acre was split applied, with the first application at green-up and the second application roughly 2 to 3 weeks later. Site-specific N rates predicted using the N-ST*R program varied by location, but were applied in a single early application when the total-N rate was ≤60 lb N/acre and split applied when the total N rate was >60 lb N/acre. All N fertilizer was applied as urea and treated with Agrotain Ultra (26% NBPT) at a rate of 3 qt/ton urea NBPT. The inner seven rows of each plot were harvested at maturity using a plot combine and grain yield was determined by adjusting the moisture to 13%.

Each experimental site was arranged as a randomized complete block design with four replications. A one-way ANOVA comparing N treatments (no-N control, N-ST*R 95% RGY, and the standard N recommendation of 120 lb N/acre) was conducted by site using JMP Pro v. 11.0 (SAS Institute, Inc., Cary, N.C.). A comparison of wheat yields amongst locations was not conducted due to the variability in wheat yields associated with differences in environment and the different site-specific N rate predictions using N-ST*R. When appropriate, mean separations were performed using Fisher's protected least significant difference (LSD) method at a significance level of 0.05.

RESULTS

Wheat yields varied across locations with maximum yields of 111, 112, 73, and 71 bu/acre for the PTRS-F, PTRS-S, PF-S, and PF-C locations, respectively (Table 1). The N-ST*R, N-rate recommendations for each of the locations were considerably lower than the standard recommendation that is based on soil texture and previous crop. Site-specific N-rate predictions using N-ST*R ranged from 15 to 60 lb N/acre and were one-half or less of the standard N-rate recommendation.

For all locations the addition of N fertilizer increased wheat yield over that of the no-N control. For PTRS-F, the N-ST*R recommendation was 15 lb N/acre indicating very high native soil-N availability and consequently wheat in the no-N control treatment yielded 96 bu/acre. Even with this high native soil N, wheat yields were increased to 110 bu/acre with as little as 15 lb N/acre. Comparison of yields for each of the locations indicated that there were no statistical differences between the standard N-rate recommendation (90 or 120 lb N/acre) and the N-ST*R site-specific recommendation except for the PTRS-S location. At PTRS-S, wheat yields were maximized with the N-ST*R, N rate of 50 lb N/acre and yield statistically declined by 9 bu/acre when the standard recommendation of 120 lb N/acre was applied.

Wheat yields in the two PF were numerically lower than yields reported for the PTRS fields and may be attributed to a lower number of drain furrows in close proximity to the plot areas or other differences in environmental factors. Similar to the results for the PTRS location, wheat yields in both PF were maximized with the site-specific N rate using the N-ST*R program and were similar to the yields obtained using the current standard N-rate recommendation.

PRACTICAL APPLICATION

Commodity and fertilizer prices dictate that producers be judicious in managing their input costs. With N fertilizer accounting for a substantial portion of a wheat producer's total input costs, profitability is tightly linked to N-fertilizer management. Previous research with N-ST*R in rice has indicated that site-specific N rates can increase profitability through both N fertilizer savings and yield increases. Although wheat does not respond to N fertilization to the same degree as rice, it is important that the correct N rate is used to maximize efficiency and profitability.

The site-specific N rates predicted for winter wheat in four fields using the N-ST*R program provided the yield maximizing N rate. For all four of the locations, wheat yields were maximized with N rates that were substantially lower than the N rate recommended using the conventional soil texture, planting date, and previous crop approach. Further work needs to be conducted to validate the N-ST*R, N-rate recommendation on soils with low native N and following other crops in rotation such as rice. Site-specific N rates for wheat using the N-ST*R program allow producers the opportunity to better manage their input costs and ensure that the correct N rates are being applied to produce maximal yields.

ACKNOWLEDGMENTS

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Table 1. The effect of site-specific or standard N-rate recommendations for winter wheat produced on poorly-drained silt loam soils on wheat grain yield at the Pine Tree Research Station (PTRS) and two producer fields (PF).

	PTRS-F[a]		PTRS-S[b]		PF-S[b]		PF-C[b]	
Treatment	N rate	Yield	N rate	Yield	N rate	Yield	N rate	Yield
	(lb N/acre)	(bu/acre)	(lb N/acre)	(bu/acre)	(lb N/acre)	(bu/acre)	(lb N/acre)	(bu/acre)
No-N control	0	96	0	75	0	32	0	47
N-ST*R[c]	15	110	50	112	60	73	45	71
Standard[d]	90	111	120	103	120	70	120	67
LSD $_{0.05}$		6.3		7.7		5.6		7.4

[a] PTRS-F was following summer fallow (F) resulting in a standard N-rate recommendation of 90 lb N/acre.
[b] PTRS-S, PF-S, and PF-C followed soybean (S), soybean, and corn (C), respectively, resulting in a standard N-rate recommendation of 120 lb N/acre.
[c] N-ST*R recommendation based on alkaline-hydolyzable N analysis from the 0- to 6-in. soil depth with the N rate predicted to produce 95% relative grain yield.
[d] Standard N-rate recommendation was based on soil texture and previous crop.

Soybean Yield as Affected by Chloride Rate and Cultivar Chloride Includer/Excluder Rating

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Chloride (Cl) toxicity, also known as 'leaf scorch' of soybean [*Glycine max* (L.) Merr.], is primarily a problem in the southern United States (Parker et al., 1983). The Cl toxicity problem is relatively common in Arkansas and the symptoms are similar to that described by Parker et al. (1983). The Cl accumulation (e.g., uptake and translocation within the plant) response by soybean cultivars is categorized into two categories known as Cl-includer and -excluder cultivars. Chloride toxicity problems occur to varying degrees in Arkansas soybean fields each year, but tend to be worst in fields having poorly drained soil and when minimal rainfall occurs during July and August. Season-long use of irrigation water from ground or surface sources results in Cl accumulation in soybean beds during the season, especially on the low areas and ends of fields. As a general observation, soybean grown on beds and furrow irrigated tend to show more Cl toxicity than flat-planted soybeans that are flood irrigated.

Research has developed screening methods to categorize newly released soybean cultivars as either 'includers' or 'excluders' (Lee et al., 2008; Valencia et al., 2008). Proper cultivar selection is the first step of managing Cl toxicity.

Diagnosis of Cl toxicity has relied on recognition of the visual leaf scorch symptoms. The visual diagnosis is often confirmed by tissue analysis that shows scorched leaves contain very high Cl concentrations. Despite our knowledge that soybean cultivars possess two different Cl accumulation traits, soil and plant information to monitor or diagnose Cl toxicity during the season have not been developed. Diagnostic leaf Cl concentrations might enable us to identify potential Cl problems before the visual symptoms appear. Limited field research has been conducted with soybean includer and excluder cultivars. Our research objective was to compare six cultivars, three within each Cl category, to develop soil, leaf tissue, and seed Cl concentrations that would enable us to diagnose Cl toxicity. We hypothesized that leaf Cl concentrations would be positively correlated with relative soybean yield, excluder cultivars would be more tolerant of high Cl concentrations, and chloride includer and excluder cultivars would have different critical leaf Cl concentrations with the critical Cl concentration being lower for excluder cultivars.

PROCEDURES

Trials were established at the Pine Tree Research Station (PTRS) and Rohwer Research Station (RRS) during 2014. Specific soil, agronomic, and research management information for each site is listed in Tables 1 and 2. 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 furrow irrigated with well water as needed.

Six cultivars were seeded in random positions of 16, 180-ft long strips that received one of four different Cl rates. Individual plots were 30-ft long and 4-rows wide. Cultivar characteristics are listed in Table 1. Three companies were each asked to provide one late maturity group IV Cl-includer and one Cl-excluder cultivar for the field trial. The six cultivars were intended to represent the range of Cl-includer and -excluder cultivars available to farmers in Arkansas.

Each Cl rate strip was separated by four rows of border soybean to ensure Cl from one strip did not influence soybean growth in the adjacent treatment. Both sites had near optimal soil fertility levels. The PTRS field's average soil chemical properties (n = 4 composite soil samples from 0- to 4-in. depth) included a mean pH of 7.1, 2.6% soil organic matter, 101 (±16 standard deviation) ppm Mehlich-3 phosphorus (P), 139 (±11) ppm Mehlich-3 potassium (K), 323 ppm Mehlich-3 magnesium (Mg), and 1844 ppm Mehlich-3 calcium (Ca). The mean soil properties from the RRS field, based on six composite samples collected from the shoulder of beds, was 7.3 pH, 2.4% soil organic matter, 82 (±6) ppm Mehlich-3 P, 208 (±20) ppm Mehlich-3 K, 537 ppm Mehlich-3 Mg, and 2542 ppm Mehlich-3 Ca. The P and K fertility at both sites was optimal or above optimal. A maintenance application of muriate of potash (60 lb K_2O/acre) was applied at the PTRS site after soybean emergence.

Chloride treatments were made using a combination of $CaCl_2 \cdot 2H_2O$ and $MgCl_2 \cdot 6H_2O$ salts (Bulk Reef Supply Co., Golden Valley, Minn.) applied in a 3:1 molar ratio, which approximated the molar ratio of Mehlich-3 exchangeable Ca and Mg in the soils common to each experiment station. Four Cl rates (0, 250, 500, and 750 lb Cl/acre) were applied in a total of five separate applications (Table 2). The Ca and Mg salts for each rate were preweighed for each replicate and Cl rate, dissolved in 3 gallons of deionized water (57 gal/acre at PTRS and 73 gal/acre at RRS), and applied to the plots on the dates indicated in Table 2. The salt solution was delivered using a 4-nozzle boom with drop nozzles (Teejet XR8004VS at the PTRS and the Teejet XR8006VS at the RRS; Teejet Technologies, Wheaton, Ill.) that applied two rows simultaneously or a single-nozzle boom later in the season when the canopy closed that allowed the spray to be directed onto the side of each bed to minimize Cl runoff from furrow irrigation.

Fifteen fully expanded trifoliate leaves from the third node from the top of the plant were collected at four different growth stages to monitor leaf Cl concentrations (Table 1). All plant samples were dried to a constant moisture, whole plant sample components were weighed, ground to pass a 1-mm sieve, digested with concentrated HNO_3 and 30% H_2O_2 (Jones and Case, 1990), extracted with water (Liu, 1998), and analyzed for elemental concentrations by inductively coupled plasma spectroscopy (ICPS, CIRROS model, Spectro Analytical Instruments Inc., Mahwah, N.J.).

Two composite soil samples were collected from each Cl rate treatment in August. The two composite samples per treatment represented the plots where either the Cl includer or excluder soybean cultivars were grown. Each composite sample consisted of six total cores with two 0- to 4-in. deep cores collected from the top of the bed of plots where cultivars with the same Cl rating were grown. Soil samples were oven-dried at 55 °C for three days, ground to pass a 2-mm sieve, and electrical conductivity ($EC_{1:2}$) was measured in 20 g soil and 40 mL deionized water mixture.

The two middle rows of each plot were harvested with a small-plot combine equipped with a moisture meter and scale. A subsample of seed from each plot was collected and stored in an air-conditioned laboratory for 45 days until seed moisture reached about 7.0%. The seed moisture was determined and 1000 seed were counted and weighed. Soybean moisture was adjusted to 13% for final yield calculations. Actual yields for each cultivar were converted to percent relative yield by dividing the yield from each Cl rate by the highest mean yield and multiplying by 100. Relative yield eliminates bias associated with yield potential differences among site-years and cultivars.

For all measured parameters, ANOVA was conducted by site with the MIXED procedure in SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.). Each experiment was a randomized complete block with a split-plot treatment structure where Cl rate was the whole plot. The subplot factor was subjected to two different ANOVA including where the subplot was i) the six cultivars or ii) the two cultivar-Cl ratings. When appropriate, mean separations were performed using Fisher's protected least significant difference (LSD) method at a significance level of 0.10. The R3 stage soybean leaf Cl concentrations were regressed against relative yield to determine a preliminary critical leaf Cl-concentration. Linear regression was conducted using the replicate data by cultivar-Cl rating or with cultivar-specific data using the REG procedure in SAS.

RESULTS

Rainfall at the PTRS site totaled 12.6 inches in June, 2.5 inches in July, and 0.19 inches in August with daily rain events greater than 1 inch occurring twice in June and once in July. At the RRS location, rainfall totaled 5.5 inches in June, 2.9 inches in July, and 6.1 inches in August with rainfall greater than 1 inch occurring twice in June, once in July, and three times in August. A two-day rainfall total of 4.5 inches was recorded on 9 and 10 of June and flooded plots for 36 to 48 hours but did not reduce stand. Rainfall events that result in runoff may flush Cl and other soluble salts from the soil and reduce Cl toxicity.

Soil $EC_{1:2}$ was measured at the R5 stage to determine soil salinity following the five Cl applications and help explain why visual symptoms of Cl damage appeared earlier and were more severe at the PTRS. Soil $EC_{1:2}$ increased significantly with each incremental increase in Cl rate at both locations (Table 3), but the soil $EC_{1:2}$ was numerically higher at the PTRS. The overall greater numerical $EC_{1:2}$ values at the PTRS were likely due to more frequent and larger rainfall events during July and August at the RRS. At the PTRS, the Cl rate × cultivar-Cl rating interaction ($P = 0.0683$) was numerically higher in soil where Cl-includer cultivars were planted in all Cl rates except the 250 lb Cl/acre rate. The overall effect of cultivar-Cl rating was highly significant ($P = 0.0182$). The reason for this occurrence is unknown, but it is likely an anomaly. Additional measurements can be taken in 2015 field trials to see if the results are consistent.

Three primary questions need to be answered regarding soybean yield response to Cl from this field research. First, does seed yield of each cultivar respond similarly across Cl rates? Second, how do cultivar yields compare within each Cl level? The third question is whether the yield of Cl-excluder cultivars is more stable across Cl rates than Cl-includer cultivars. Our hypothesis is that the yield of Cl-includer cultivars would decrease at a faster rate than the yields of Cl-excluder varieties as Cl rate increased, which would result in a significant Cl rate × cultivar interaction. These questions may best be answered by making two specific comparisons including how the yield of each cultivar responded i) across the main effect of Cl rate and ii) within each Cl rate. At the RRS, where soil $EC_{1:2}$ was relatively low at the R5.5-6.0 stage, soybean yield was affected only by the main effects of Cl rate ($P = 0.0177$) and cultivar (<0.0001), but not their interaction ($P = 0.8525$). Yield decreased numerically as Cl rate increased and followed the order of 0 > 500 = 250 ≥ 750 lb Cl/acre (Table 4). The yield ranking among the cultivars followed the order of Armor 49-R56 (excluder) > Pioneer 94Y82 (includer) > NK S45-V8 (includer) = Armor 48-R66 (includer) ≥ Pioneer 49T80R (excluder) = NK S46-L2 (excluder), which showed no trend for Cl-excluder cultivars to yield consistently more than Cl-includer cultivars when averaged across all Cl levels.

The Cl rate × cultivar interaction was significant at the PTRS ($P = 0.0106$) where the soil $EC_{1:2}$ concentrations were much higher and soybean from Cl-includer cultivars showed Cl-toxicity symptoms by the R5 stage. Maximal numerical yield for each cultivar was produced in the 0 or 250 lb Cl treatment and the lowest yield was produced in the 750 lb Cl treatment (Table 4). When cultivar mean yields were examined across Cl rates, the Cl-includer cultivar yields declined by an average of

13.4 (1.9 bu, standard deviation) bu/acre compared to 5.7 (1.4 bu, standard deviation) bu/acre for the Cl-excluder cultivars. A comparison of cultivar yield within the 0, 250, and 500 lb Cl/acre rates showed the yield difference between the highest and lowest yielding variety ranged from 9.1 (500 lb Cl) to 10.3 (0 lb Cl) bu/acre. Within the 750 lb Cl treatment, the yield difference increased to 19.9 bu/acre suggesting the cultivar sensitivity/tolerance to Cl toxicity was expressed only at the highest Cl rate. The numerical yield rank among cultivars within each Cl level changed minimally from one Cl rate to the next. No clear trend in yield performance among the cultivars used in this trial was observed in regards to Cl sensitivity. A second ANOVA on yield data was performed with the cultivars grouped into Cl-includer and -excluder categories and showed a significant Cl rate × cultivar-Cl rating interaction at the PTRS (Table 5). Within each Cl rate, the mean yield of Cl-excluder cultivars was statistically equal to Cl-includer cultivars at 0 and 500 lb Cl/acre; but Cl-excluder cultivars were numerically (500 lb Cl) or statistically greater than Cl-includer cultivars at 250 and 750 lb Cl rates.

The linear relationship between mean soil $EC_{1:2}$ and relative yield of each cultivar (n = 24) was examined using only the PTRS data (% relative yield = 110 – 0.0399x. where x = $EC_{1:2}$ in micromhos/cm). Predicted relative soybean yield was 100% when soil $EC_{1:2}$ = 295 micromhos/cm and declined by 3.4% for every 100 micromhos/cm increase in soil salinity. Late-season soil $EC_{1:2}$ as an indicator of potential yield loss from Cl toxicity would likely be useful only in years where rainfall was very limited during reproductive growth. Soybean tissue Cl concentration analysis might be a more stable parameter for assessing potential yield loss from Cl toxicity.

The strength of relationships between soybean relative yield and leaf Cl concentration at four different growth stages varied when Cl-cultivar rating, site-year, or both were considered, but the linear models were always statistically significant (P <0.05). For this report, replicate data from the RRS and PTRS were combined and linear regression was performed by Cl-rating category where the r^2 values were much weaker for Cl-excluder cultivars than for Cl-includer cultivars (Table 6).

The preliminary yield loss predictions listed in Table 7 suggest that the yield of Cl-excluder cultivars is more sensitive than Cl-includer cultivars. Different scales must be used to interpret leaf Cl concentrations because Cl accumulation in soybean leaves is quite different between Cl-includer and -excluder cultivars. The Cl-excluder cultivars have much lower leaf Cl concentrations. Leaf Cl concentrations were on average 6.7 times higher in Cl-includer cultivars than the Cl-excluder cultivars at the R3 stage. Linear regression of R3 stage Cl-includer cultivar leaf Cl concentrations against R3 stage Cl-excluder cultivar leaf-Cl concentrations produced a strong linear relationship (Cl-includer cultivar leaf Cl ppm = 3.9 + 1577x, where x = Cl-excluder cultivar leaf Cl concentration in ppm, r^2 = 0.89). Leaf Cl concentration changed slightly among growth stages and resulted in different yield loss predictions. More research is needed to determine the consistency and reliability of predictions derived from the 2014 results.

PRACTICAL APPLICATION

The Cl rates used in this trial are not indicative of how much Cl is required to cause Cl toxicity and should be considered only as supplemental Cl applied as an attempt to induce Cl toxicity. The amount of Cl needed to induce Cl toxicity in soybeans will likely vary among years, fields, irrigation systems, and cultivars. The first year of this research showed that, as a group, Cl-excluder cultivars produced greater yields than Cl-includer cultivars at the highest level of Cl addition. However, the ANOVA by cultivar showed that some Cl-includer cultivars may retain their yield potential across Cl rates as well as Cl-excluder cultivars. The frequency that this might occur among commercially grown cultivars is not known. These results suggest that unless cultivar-specific performance under high-Cl conditions is known, growers should plant an appropriate Cl-excluder cultivar in fields with prior Cl toxicity problems.

Collection of fully expanded soybean trifoliate leaf samples from one of the upper nodes during reproductive growth and soil samples from beds may be able to predict relative yield reductions caused by the gradual accumulation of Cl from irrigation water. A greater range of Cl toxicity is needed to strengthen the relationships outlined in this report and establish the consistency across sites and years of these preliminary predictions. The results also raise the question of whether early maturing cultivars are more susceptible to Cl toxicity than later maturing cultivars.

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Table 1. Selected soybean cultivar characteristics for two soybean Cl trials conducted in 2014.

			Arkansas Performance Test Yields			
			RRS		AS	
Cultivar	MG†	Cl-R‡	2013§	2014§	2013§	2014§
			(bu/acre)			
Armor 48-R66	4.8	Includer	58.7	64.6	67.1	63.3
Armor 49-R56	4.8	Excluder	62.2	66.5	68.2	68.9
NK S45-V8	4.5	Includer	50.1	59.7	64.3	62.9
NK S46-L2	4.6	Excluder	59.6	61.2	65.8	60.2
Pioneer 49T80R	4.9	Excluder	59.9	ND¶	64.4	ND
Pioneer 94Y82	4.9	Includer	ND	ND	ND	ND

† MG, Maturity group.
‡ Cl-R, Soybean Cl rating.
§ Yield data from Bond et al. (2013) and preliminary data for 2014 from http://arkansasvarietytesting.com/home/soybean/. RRS, Rohwer Research Station, Rohwer irrigated yield mean and AS, All-Site yield mean.
¶ ND, not determined.

Table 2. Selected soil and agronomic management information for soybean Cl fertilization trials conducted in 2014 in Arkansas.

Information or event	Pine Tree Research Station	Rohwer Research Station
Soil series	Calloway silt loam	Desha silt loam
Previous crop	Soybean	Soybean
Bed width (in.)	30	38
Seed rate (seed number/acre)	155,000	150,000
Seeding Date	23 May	21 May
Chloride application dates		
1	25 June (first bloom)†	26 June (first bloom)
2	3 July	2 July
3	9 July (R2)	9 July (R2)
4	24 July (R3)	23 July (R3/R4)
5	6 August (R5)	5 August (R5)
Tissue sample dates		
1	9 July (R2)	9 July (R2)
2	17 July (R3)	15 July (R3)
3	6 August (R5)	5 August (R5)
4	21 August (R5.5)	22 August (R5.5-6.0)
Soil sample date	14 August	22 August
Harvest date	7 October	24 September

† Date and (growth stage) of Cl solution application or tissue sample collection.

Table 3. Soil electrical conductivity ($EC_{1:2}$) at the R5 stage of soybean development as affected by Cl rate at the Rohwer Research Station (RRS) or the significant Cl rate × Cl rating (includer/excluder) interaction at the Pine Tree Research Station (PTRS).

	RRS			PTRS		
Cl Rate	Excluder	Includer	Mean	Excluder	Includer	Mean
(RRS)	(µmhos/cm)					
0	152	152	152	239	281	260
250	187	171	179	450	421	435
500	216	242	229	501	557	529
750	250	258	254	658	802	730
$LSD_{0.10}$				76§		
$LSD_{0.10}$	NS†		22‡	106¶		62‡

† NS, not significant.
‡ LSD to compare means, averaged across Cl-category, for the Cl rate main effect.
§ LSD to compare means within the same Cl rate.
¶ LSD to compare any two means.

Table 4. Soybean seed yield as affected by the significant Cl rate × cultivar interaction at the Pine Tree Research Station (PTRS) and by the main effect of Cl rate at Rohwer Research Station (RRS).

Cl Rate	Includer Armor 48-R66 (IN)	Excluder Armor 49-R56	Includer NKS45-V8	Excluder NKS46-L2	Excluder P49T80R	Includer P94Y82	Mean
(lb Cl/acre)	(bu/acre)						
RRS							
0	48	56	49	45	44	51	49.0 a†
250	45	54	46	43	44	49	46.8 bc
500	47	55	44	43	48	48	47.3 b
750	43	53	45	42	42	48	45.5 c
Mean	45.6 c	54.7 a	46.0 c	43.4 d	44.4 cd	48.9 b	--
PTRS	Armor 48-R66	Armor 49-R56	NKS45-V8	NKS46-L2	P49T80R	P94Y82	Mean
0	48	56	49	45	44	51	49.0 a†
0	65.4 a	64.9 a	58.4 ab	61.1 a	68.7 ab	70.8 a	64.9 a
250	60.3 b	64.1 a	59.7 a	62.9 a	69.0 a	65.3 b	63.5 a
500	59.9 b	59.2 b	54.9 b	61.3 a	64.0 b	60.8 c	60.0 b
750	51.2 c	58.9 b	44.9 c	56.0 b	64.8 ab	59.5 c	55.9 c
$LSD_{0.10}$			$LSD_{0.10}$ = 4.4‡				
$LSD_{0.10}$			$LSD_{0.10}$ = 4.0§				--

† Means within a column [for Cl-rate effect means (RRS) and cultivar-specific means (PTRS)] or row (RRS cultivar comparison) followed by the same lowercase letter are not statistically different.
‡ LSD to compare the same cultivar across Cl rates.
§ LSD to compare cultivars within the same Cl rate.

Table 5. Soybean seed yield as affected by the significant Cl rate × Cl rating (includer/excluder) interaction at the Pine Tree Research Station.

Cl rate	Excluder	Includer
(lb Cl/acre)	(bu/acre)	
0	64.9	64.9
250	65.3	61.7
500	61.5	58.5
750	59.9	51.1
$LSD_{0.10}$	$LSD_{0.10}$ = 3.6†	
$LSD_{0.10}$	$LSD_{0.10}$ = 4.9‡	
$LSD_{0.10}$	$LSD_{0.10}$ = 5.2§	

† LSD to compare cultivar-Cl rating within a Cl rate.
‡ LSD to compare Cl rates within a cultivar-Cl rating.
§ LSD to compare any two means.

Table 6. Regression coefficients describing the preliminary linear relationship between relative soybean yield and trifoliate leaf Cl concentrations at four growth stages for Cl-includer and Cl-excluder cultivars in trials conducted at the at the Pine Tree Research Station and Rohwer Research Stations in 2014.

Cl-rating	Growth stage	Intercept†	Linear slope	R^2
Excluder	R2	100	-0.0081	0.11
	R3	99	-0.0040	0.11
	R5	97	-0.0026	0.05
	R5.5-6.0	99	-0.0040	0.14
Includer	R2	106	-0.0031	0.32
	R3	106	-0.0030	0.40
	R5	106	-0.0034	0.42
	R5.5-6.0	104	-0.0014	0.28

† Coefficients for the linear equation y = mx + b, where y = percent relative soybean yield, b = intercept, m = linear slope, and x = leaf Cl concentration with units of ppm. All intercept and slope coefficients were significant ($P < 0.01$).

Table 7. Preliminary predictions of soybean relative yield loss caused by Cl-toxicity using trifoliate leaf Cl concentrations for Cl-includer and excluder cultivars at four different growth stages. Note the use of different Cl concentration scales for Cl-includer and Cl-excluder cultivars.

Predicted yield loss†									
Cl-excluder cultivars					Cl-includer cultivars				
Leaf Cl‡	R2	R3	R5	R6	Leaf Cl‡	R2	R3	R5	R6
(ppm Cl)	(%)				(ppm Cl)	(%)			
200	<2	<1	<1	<1	1,000	0	0	0	0
400	3	2	1	2	2,000	0	0	<1	0
600	5	2	2	2	4,000	6	6	8	<2
800	7	3	2	3	6,000	13	12	14	4
1,000	8	4	3	4	8,000	19	18	21	7
1,300	11	5	3	5	10,000	25	24	28	10
1,700	14	7	4	7	12,000	31	30	35	13
2,000	16	8	5	8	14,000	37	36	42	16

† The sampled trifoliate leaf was a fully developed leaf located at the third node from the top of the plant collected at the R3 stage from the indeterminate cultivars having a maturity group from 4.5 to 4.9.

‡ Predicted yield loss expressed as a percentage. Values shown were calculated by subtracting the predicted percent relative yield from equations listed in Table 6 from 100. When the predicted percent relative yield was > 100, the predicted yield loss was 0.

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