2-1-2012

Wayne E. Sabbe Arkansas Soil Fertility Studies 2011

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ARKANSAS
SOIL FERTILITY STUDIES
• 2011 •

Nathan A. Slaton, Editor

DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

ARKANSAS AGRICULTURAL EXPERIMENT STATION

February 2012 | Research Series 599

This is a Web-only publication available on the internet at: http://arkansasagnews.uark.edu/1356.htm

Cover photo of wheat test plots at University of Arkansas System Division of Agriculture, Rice Research and Extension Center, Stuttgart, Arkansas. Photo taken by Fred Miller.

Layout and editing by Marci Milus
Technical editing and cover design by Gail Halleck

Arkansas Agricultural Experiment Station, University of Arkansas System Division of Agriculture, Fayetteville. Mark J. Cochran, Vice President for Agriculture; Clarence E. Watson, AAES Director and Associate Vice-President for Agriculture–Research. WWW/InddCS5.

ISSN: 1941-1553 CODEN: AKAMA6

WAYNE E. SABBE ARKANSAS SOIL FERTILITY STUDIES – 2011 –

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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 2011 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 2010. 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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ACKNOWLEDGMENT

Arkansas Fertilizer Tonnage Fees funded the publication of this research series.

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Soil-test and Fertilizer Sales Data: Summary for the 2010 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 System Division of Agriculture Soil Testing and Research Laboratory in Marianna between 1 January 2010 and 31 December 2010 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 System 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 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 2010 and 31 December 2010, 155,337 soil samples were analyzed by the Soil Testing and Research Laboratory in Marianna. After removing standard and check soils measured for quality assurance (12,970), the total number of client samples was 142,367. A total of 54,772 soil samples were collected using the field average sampling technique, representing a total of 1,677,654 acres for an average of 31 acres/sample, and had complete data for total acres and soil pH, P, K, and Zn (Table 1). The difference of 85,787 samples between the total samples and those with reported acreage were grid samples collected primarily from row crop fields (84,763) or special or research samples (1,024). The total acreage value does not include the acreage of grid soil samples, but each grid sample likely represents 2.5 acres.

Soil samples from the Bottom Lands and Terraces and Loessial Plains, primarily row-crop areas, represented 53% of the total field average samples and 78% of the total acreage (Table 1). The average number of acres represented by each soil sample (field average samples) ranged from 1 to 87 acres/sample (Table 2). Clients from Craighead (29,511, 78% from three clients); Clay (Corning and Piggott offices, 15,106, 69% from three clients); Crittenden (13,756, 89% from one client); Lawrence (11,354, 93% from one client); Monroe (5,170); and Mississippi (4,847, 66% from one client) counties submitted the most soil samples for analyses. The large percentage of the total samples processed through the Craighead, Clay, Crittenden, Lawrence, and Mississippi county offices were submitted by only a few clients and likely represent 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), 45 (Crowley-Stuttgart), 32 (Rilla-Hebert), 22 (Foley-Jackport-Crowley), 10 (Enders-Nella-Mountainburg-Steprock), and 15 (Linker-Mountainburg). However, the soil associations representing the largest acreage were 44, 45, 32, 24 (Sharkey-Alligator-Tunica), 22, 25 (Dundee-Bosket-Dubbs), and 29 (Perry-Portland) which represented 34%, 12%, 7%, 5%, 5%, 4%, and 2% of the total sampled acreage, respectively. Crop codes listed on the 54,772 field average samples indicate that land used for i) row crop production accounted for 81% of the sampled acreage and 50% of submitted samples, ii) hay and pasture production accounted for 9% of the sampled acreage and 14% of submitted samples, and iii) home lawns and gardens accounted for 1% of sampled acreage and 14% of submitted samples (Table 4). In row-crop producing areas, soil samples are most commonly collected following soybean in the crop rotation. The cumulative acreage soil sampled following soybean represents about one-third of the annual soybean acreage.

Soil-Test Data

Information in Tables 5, 6, and 7 pertains to the fertility status of Arkansas soils as categorized by GA, county, and the crop grown prior to collecting field average soil samples (i.e., grid samples not included, except by county), respectively. The soil-test levels and median (Md) nutrient availability index values relate to the potential fertility of a soil, but not necessarily to the productivity of the soil. The median is the value that has an equal number of higher and lower observations and may be a better overall indicator of a soil's fertility status than a mean value. Therefore, it is not practical to compare soil-test values among SAN without knowledge of factors such as location, topography, and cropping system. Likewise, soil-test values among counties cannot be realistically compared without knowledge of the SAN and a profile of the local agricultural production systems. Soil-test data for cropping systems can be carefully compared; however, the 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 pH of most soils in Arkansas ranges from 5.8 to 6.9; however, the predominant soil pH range varies among GA (Table 5), county (Table 6), and last crop produced (Table 7).

Table 7 summarizes the percentage of acreage from field-average soil samples that falls within selected soil-test levels (as defined by concentration ranges) and the median concentrations for each of the cropping system categories. Soil-test nutrient availability index values can be categorized into soil-test levels of 'Very Low', 'Low', 'Medium', 'Optimum', and 'Above Optimum'. Among row crops, the lowest median concentrations of P and K occur in soils used for the production of rice and soybean, whereas soils used for cotton production have among the highest median concentrations of P and K. Median soil K availability is lowest in soils used for warm- and cool-season hay production. The median soil-test K has decreased for several years and suggests that K inputs as fertilizer or manure have declined and K is now likely to be limiting forage yield. The highest median concentrations of 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, Mississippi, and Poinsett counties. Fertilizer tonnage does not account for the use of fresh animal manures, unprocessed biosolids or other by-products as a source of nutrients that may be applied to the land. Only processed manures or biosolids (e.g., pelleted poultry litter) are quantified in fertilizer tonnage data and are normally reported in the category of 'Organic.

PRACTICAL APPLICATIONS

The data presented, or more specific data, can be used in county- or commodity-specific educational programs on soil fertility and fertilization practices. Comparisons of annual soil-test information can also document trends in fertilization practices or areas where nutrient management issues may need to be addressed. Of the soil samples submitted in 2010, 90% of the samples and 64% 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. Fertilizer and soil amendment tonnage for on-farm use was sold, in decreasing order, as N (52%), multi-nutrient blends (34%), K (8%), P (3%), and miscellaneous (1%). Five counties in eastern Arkansas (Arkansas, Mississippi, Poinsett, Craighead, and Phillips) accounted for 32% of the total fertilizer sold.

ACKNOWLEDGMENTS

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

Table 1. Sample number and total acreage by geographic area for soil samples submitted to the Soil Testing and Research Laboratory in Marianna from 1 January 2010 through 31 December 2010.

Geographic area	Acres sampled	No. of samples	Acres/ sample
Ozark Highlands - Cherty Limestone and Dolomite	94,374	7,703	12
Ozark Highlands - Sandstone and Limestone	8,239	517	16
Boston Mountains	22,735	2,313	10
Arkansas Valley and Ridges	48,848	4,154	12
Ouachita Mountains	25,672	2,883	9
Bottom Lands and Terraces	535,790	15,127	35
Coastal Plain	34,349	3,060	11
Loessial Plains	780,091	13,773	57
Loessial Hills	10,075	1,307	8
Blackland Prairie	2,734	151	18

Table 2. Sample number and total acreage by county for soil samples submitted to the Soil Testing and Research Laboratory in Marianna from 1 January 2010 through 31 December 2010.

County	Acres sampled	No. of samples	Acres/ sample	County	Acres sampled	No. of samples	Acres/ sample
Arkansas, DeWitt	164,236	2,951	57	Lee	74,389	4,252	18
Arkansas, Stuttgart	26,027	797	33	Lincoln	20,005	421	48
Ashley	23,616	864	27	Little River	3,027	2,275	1
Baxter	1,939	279	7	Logan, Booneville	901	119	8
Benton	11,710	970	12	Logan, Paris	5,067	339	15
Boone	11,909	609	20	Lonoke	80,863	2,918	28
Bradley	786	81	10	Madison	9,451	648	15
Calhoun	793	44	18	Marion	2,869	133	22
Carroll	20,941	1,076	20	Miller	3,259	358	9
Chicot	34,735	660	53	Mississippi	28,255	4,847	6
Clark	1,185	161	7	Monroe	450,689	5,170	87
Clay, Corning	17,455	6,421	3	Montgomery	3,480	210	17
Clay, Piggott	13,498	8,685	2	Nevada	1,000	80	13
Cleburne	6,601	473	14	Newton	4,711	224	21
Cleveland	370	52	7	Ouachita	1,282	177	7
Columbia	3,509	214	16	Perry	3,170	310	10
Conway	12,671	493	26	Phillips	18,074	1,398	13
Craighead	35,099	29,511	1	Pike	5,380	255	21
Crawford	6,288	410	15	Poinsett	50,872	3,434	15
Crittenden	44,589	13,756	3	Polk	6,077	387	16
Cross	73,522	1,347	55	Pope	12,268	777	16
Dallas	95	50	2	Prairie, Des Arc	16,356	406	40
Desha	4,251	1,107	4	Prairie, De Valls Bluff	8,623	169	51
Drew	3,665	332	8	Pulaski	5,216	1,188	4
Faulkner	4,844	565	9	Randolph	20,669	2,327	9
Franklin, Charleston	525	33	16	Saline	912	335	3
Franklin, Ozark	5,046	334	15	Scott	2,468	157	16
Fulton	3,897	276	14	Searcy	3,304	265	13
Garland	1,863	1,243	2	Sebastian	2,522	475	5
Grant	407	102	4	Sevier	7,205	293	25
Greene	33,565	3,475	10	Sharp	3,459	350	10
Hempstead	6,312	352	18	St. Francis	7,905	2,469	3
Hot Spring	855	143	6	Stone	1,605	254	6
Howard	9,270	509	18	Union	402	112	4
Independence	5,281	262	20	Van Buren	1,210	204	6
Izard	5,358	326	16	Washington	24,079	3,313	7
Jackson	8,527	4,528	2	White	5,861	1,105	5
Jefferson	73,073	3,342	22	Woodruff	4,667	79	59
Johnson	2,672	217	12	Yell, Danville	5,375	312	17
Lafayette	12,910	304	43	Yell, Dardanelle	1,118	89	13
Lawrence	76,614	11,354	7				

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 2010 through 31 December 2010.

		Acres	No. of	Acres/	Median			
SAN	Soil association	sampled	samples	sample	pH	P	K	Zn
1.	Clarksville-Nixa-Noark	17,329	1,023	17	6.1	71	130	7.8
2.	Gepp-Doniphan-Gassville-Agnos	7,953	750	11	6.5	56	124	7.3
3.	Arkana-Moko	26,898	1,406	19	6.1	113	140	13.3
4.	Captina-Nixa-Tonti	38,623	4,315	9	6.4	96	150	10.5
5.	Captina-Doniphan-Gepp	1,838	113	16	6.4	46	126	8.0
6.	Eden-Newnata-Moko	1,733	96	18	5.8	60	99	4.3
7.	Estate-Portia-Moko	753	49	15	6.1	56	104	5.5
8.	Brockwell-Boden-Portia	7,486	468	16	6.2	32	97	5.4
9.	Linker-Mountainburg-Sidon	3,465	252	14	5.9	63	99	8.1
10.	Enders-Nella-Mountainburg-Steprock	19,270	2,061	9	5.9	69	103	7.5
11.	Falkner-Wrightsville	715	39	18	5.6	55	101	6.5
12.	Leadvale-Taft	13,626	1,518	9	5.9	58	105	8.0
13.	Enders-Mountainburg-Nella-Steprock	8,823	418	21	6.0	46	102	6.2
14.	Spadra-Guthrie-Pickwick	4,050	196	21	5.8	58	94	8.1
15.	Linker-Mountainburg	21,634	1,983	11	5.8	76	104	9.0
16.	Carnasaw-Pirum-Clebit	7,621	817	9	5.7	86	100	8.1
17.	Kenn-Ceda-Avilla	3,086	200	15	5.7	55	89	7.5
18.	Carnasaw-Sherwood-Bismarck	9,212	1,506	6	5.7	84	102	7.4
19.	Carnasaw-Bismarck	2,087	95	22	5.7	46	94	4.5
20.	Leadvale-Taft	1,124	59	19	5.4	45	66	8.7
21.	Spadra-Pickwick	2,542	206	12	5.7	70	117	8.7
22.	Foley-Jackport-Crowley	84,622	2,761	31	6.3	28	101	4.7
23.	Kobel	61,321	1,040	59	6.3	28	99	4.8
24.	Sharkey-Alligator-Tunica	90,575	1,547	59	6.3	42	208	4.7
25.	Dundee-Bosket-Dubbs	62,551	1,936	32	6.4	50	145	5.0
26.	Amagon-Dundee	38,727	1,928	20	6.4	53	137	5.3
27.	Sharkey-Steele	8,267	255	32	6.6	37	266	7.7
28.	Commerce-Sharkey-Crevasse-Robinsonville	13,432	390	34	6.2	56	179	6.4
29.	Perry-Portland	38,798	1,001	39	6.3	43	155	4.9
30.	Crevasse-Bruno-Oklared	1,201	29	41	6.2	45	157	6.0
31.	Roxana-Dardanelle-Bruno-Roellen	5,760	179	32	6.1	49	123	4.8
32.	Rilla-Hebert	112,698	3,593	31	6.5	45	137	4.2
33.	Billyhaw-Perry	11,763	226	52	6.9	39	348	3.8
34.	Severn-Oklared	4,725	109	43	6.6	55	117	7.0
35.	Adaton	324	23	14	6.0	63	120	8.4
36.	Wrightsville-Louin-Acadia	728	78	9	5.6	32	84	4.8
37.	Muskogee-Wrightsville-McKamie	298	32	9	6.4	72	157	8.4
38.	Amy-Smithton-Pheba	984	126	8	5.7	58	78	5.8
39.	Darco-Briley-Smithdale	53	5	11	6.3	155	78	9.0
40.	Pheba-Amy-Savannah	502	93	5	5.9	77	87	6.2
41.	Smithdale-Sacul-Savannah-Saffell	12,896	1,232	11	5.7	99	95	8.9
42.	Sacul-Smithdale-Sawyer	11,427	1,259	9	5.8	62	92	6.6
43.	Guyton-Ouachita-Sardis	8,487	345	25	5.5	90	85	8.2
44.	Calloway-Henry-Grenada-Calhoun	574,484	9,948	58	6.6	31	98	4.7
45.	Crowley-Stuttgart	205,607	3,825	54	6.6	25	92	4.9
46.	Loring	1,324	73	18	6.1	47	95	4.5
47.	Loring-Memphis	8,531	1,206	7	5.9	33	116	5.2
48.	Brandon	220	28	8	5.4	9	88	3.2
49.	Oktibbeha-Sumter	2,734	151	18	5.8	61	130	7.7
	Average				6.1	58	121	6.7

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 2010 through 31 December 2010.

Crop	Acres sampled	No. of samples	Acres/ sample
Corn	105,001	1,982	53
Cotton	176,283	4,169	42
Grain sorghum, non-irrigated	853	59	15
Grain sorghum, irrigated	15,156	198	77
Rice	191,107	4,408	43
Soybean	861,602	16,597	52
Wheat	8,774	216	41
Cool-season grass hay	8,492	440	19
Native warm-season grass hay	3,826	215	18
Warm-season grass hay	31,144	1,566	20
Pasture, all categories	103,577	5,380	19
Home garden	5,559	4,066	1
Home lawn	4,581	3,692	1
Small fruit	616	512	1
Ornamental	2,408	1,368	2

Table 5. Soil-test data (% of sampled acres) and median (Md) values by geographic area for soil samples submitted to the Soil Testing and Research Laboratory in Marianna from 1 January 2010 through 31 December 2010.

	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	9	16	25	29	21	6.3	4	8	9	11	68	88	8	14	22	20	36	142	1	8	6	25	60	10.0
Ozark Highlands - Sandstone and Limestone	10	17	28	28	17	6.2	19	20	13	10	38	34	16	29	28	13	15	97	3	18	15	28	36	5.4
Boston Mountains	19	22	23	25	11	5.9	8	10	10	12	60	69	18	23	23	14	22	102	2	12	10	28	48	7.5
Arkansas Valley & Ridges	23	21	23	21	12	5.9	10	12	9	10	59	65	18	22	24	15	21	104	2	13	10	26	49	8.1
Ouachita Mountains	28	25	23	17	7	5.7	6	8	8	10	68	80	19	24	22	15	20	101	2	12	9	30	47	7.6
Bottom Lands & Terraces	7	11	25	39	18	6.4	8	15	18	24	35	42	6	16	26	20	32	135	3	20	17	40	20	4.7
Coastal Plain	31	21	19	20	9	5.7	10	9	9	10	62	79	25	24	20	12	19	92	3	13	9	27	48	7.5
Loessial Plains	7	10	19	32	32	6.6	15	27	20	16	22	28	11	34	31	14	10	95	5	22	15	35	23	5.7
Loessial Hills	23	19	22	24	12	5.9	20	17	15	17	31	34	10	21	32	18	19	114	3	19	15	32	31	5.2
Blackland Prairie	25	24	21	8	22	5.8	12	13	5	13	57	61	19	15	17	19	30	130	3	8	13	29	47	7.7
Average	18	19	23	24	16	6.0	11	14	12	13	50	58	15	22	25	16	22	111	3	15	12	30	40	6.8

[a] Analysis by electrode in 1:2 soil volume:deionized water volume.
[b] Analysis by ICAP in 1:10 soil volume:Mehlich-3 volume.
[c] Md = median.

Table 6. Soil-test data (% of sampled acres) and median (Md) values by county for soil samples submitted to the Soil Testing and Research Laboratory in Marianna from 1 January 2010 through 31 December 2010.

County	Soil pH[a]						Mehlich-3 soil P[b] (ppm)						Mehlich-3 soil K[b] (ppm)						Mehlich-3 soil Zn[b] (ppm)					
	<5.4	5.4-5.7	5.8-6.2	6.3-6.9	>6.9	Md[c]	<16	16-25	26-35	36-50	>50	Md	<61	61-90	91-130	131-175	>175	Md	<1.6	1.6-3.0	3.1-4.0	4.1-8.0	>8.0	Md
	---(% of sampled acreage) ---						--(% of sampled acreage) --					(ppm)	-- (% of sampled acreage)---					(ppm)	---- (% of sampled acreage) ----					(ppm)
Arkansas, DeWitt	3	6	13	27	51	7.0	18	35	24	14	9	25	7	42	34	9	8	91	2	15	16	46	21	5.3
Arkansas, Stuttgart	14	15	25	27	19	6.2	21	36	22	12	9	24	9	46	30	6	9	87	9	26	15	34	16	4.0
Ashley	4	8	20	48	20	6.5	5	14	14	20	47	49	10	15	31	27	17	122	8	24	19	34	15	4.0
Baxter	4	10	12	23	51	7.0	5	8	10	11	66	81	6	14	26	20	34	141	0	7	7	22	64	11.5
Benton	11	16	25	33	15	6.2	3	4	6	7	80	149	14	15	17	16	38	139	0	6	5	19	70	12.3
Boone	5	19	35	28	13	6.1	3	8	12	11	66	78	12	11	17	14	46	161	1	11	7	27	54	8.9
Bradley	15	16	27	21	21	6.2	1	4	4	4	87	228	6	20	20	26	28	144	0	5	4	24	67	15.2
Calhoun	43	23	21	9	4	5.4	21	2	14	9	54	54	32	25	16	11	16	81	16	27	7	18	32	3.8
Carroll	6	18	37	31	8	6.1	1	4	6	9	80	142	9	9	18	18	46	167	0	3	2	15	80	16.1
Chicot	5	11	17	33	34	6.7	7	14	21	26	32	40	3	6	10	11	70	261	2	16	20	44	18	4.7
Clark	37	17	17	19	10	5.6	17	10	8	16	49	51	35	26	14	9	16	78	6	24	12	26	32	5.0
Clay, Corning	6	14	29	34	17	6.3	11	26	26	23	14	30	10	32	37	14	7	97	4	19	13	41	23	5.3
Clay, Piggott	10	10	21	43	16	6.4	2	8	13	22	55	54	3	15	34	26	22	128	4	23	21	41	11	4.2
Cleburne	24	17	21	24	14	5.9	12	15	13	13	47	47	25	26	24	13	12	88	5	17	12	27	39	5.9
Cleveland	39	19	17	25	0	5.6	19	6	10	12	53	69	21	23	23	19	14	95	4	21	12	17	46	7.0
Columbia	32	23	21	19	5	5.6	10	12	7	9	62	84	38	22	16	7	17	72	3	15	8	25	49	7.3
Conway	29	23	23	18	7	5.7	10	13	10	11	56	67	22	25	21	12	20	95	3	18	10	21	48	7.7
Craighead	7	10	20	33	30	6.5	9	16	17	20	38	41	7	17	24	19	33	134	2	21	20	44	13	4.4
Crawford	18	17	22	26	17	6.1	8	16	14	12	50	50	22	20	23	13	22	100	1	9	9	31	50	8.0
Crittenden	6	9	22	41	22	6.5	4	13	19	26	38	42	2	6	14	18	60	202	1	15	19	55	10	4.7
Cross	6	6	11	28	49	6.9	20	30	25	15	10	26	21	37	21	8	13	83	3	25	16	35	21	4.5
Dallas	28	16	22	22	12	5.9	14	8	4	26	48	49	44	36	10	6	4	64	8	6	14	38	34	5.8
Desha	4	4	18	56	18	6.5	1	4	13	31	51	51	3	8	30	20	39	144	5	12	13	47	23	5.4
Drew	20	22	28	23	7	5.9	14	12	10	13	51	53	24	22	21	12	21	100	7	16	9	18	50	8.1
Faulkner	30	17	20	19	14	5.8	15	14	14	14	43	42	20	23	26	17	14	98	3	21	11	26	39	5.9
Franklin, Charleston	18	15	9	24	34	6.5	3	18	9	21	49	47	21	15	15	15	34	130	6	12	6	42	34	5.8
Franklin, Ozark	24	30	26	16	4	5.7	9	8	7	8	68	96	9	16	23	18	34	134	0	8	7	21	64	10.8
Fulton	13	22	21	25	19	6.1	10	17	9	12	52	52	8	23	25	23	21	122	3	16	11	30	40	6.0
Garland	25	22	25	22	6	5.8	4	6	9	12	69	75	13	25	27	15	20	107	2	11	10	33	44	7.0
Grant	27	26	17	19	11	5.7	19	8	8	11	54	56	25	26	28	16	5	90	8	19	7	33	33	5.6
Greene	13	15	27	30	15	6.2	21	24	19	18	18	28	13	24	25	20	18	111	6	32	18	30	14	3.6
Hempstead	26	28	21	18	7	5.7	6	11	6	13	64	84	16	20	20	15	29	118	1	10	9	31	49	7.9
Hot Spring	23	15	26	33	3	6.0	6	11	5	6	72	123	22	23	20	11	24	99	2	10	9	25	54	8.4
Howard	33	31	22	6	8	5.5	5	5	5	4	81	157	18	19	17	14	32	122	2	9	6	24	59	11.5
Independence	13	19	20	28	20	6.2	8	13	13	15	51	51	15	25	28	15	17	103	0	15	9	33	43	6.6
Izard	16	26	26	21	11	5.9	7	13	13	14	53	55	19	26	28	16	11	97	2	19	8	30	41	6.5
Jackson	10	16	27	33	14	6.2	17	23	18	18	24	30	15	29	32	16	8	96	6	24	17	32	21	4.4
Jefferson	11	13	26	37	13	6.3	5	13	23	28	31	40	9	19	27	18	27	120	8	34	23	26	9	3.4
Johnson	24	18	27	20	11	5.9	9	15	11	12	53	54	11	23	30	13	23	107	2	16	18	24	40	5.8
Lafayette	8	9	12	27	44	6.8	5	13	15	18	49	50	3	12	18	14	53	195	0	16	16	32	36	5.6
Lawrence	8	17	28	31	16	6.2	26	31	20	14	9	23	14	31	30	15	10	96	4	32	19	32	13	3.8
Lee	5	7	22	44	22	6.5	4	8	15	27	46	48	2	10	28	29	31	143	12	44	17	21	6	2.8
Lincoln	6	10	24	30	30	6.5	3	9	13	24	51	52	5	9	22	21	43	156	1	18	13	41	27	5.2
Little River	6	6	14	31	43	6.8	7	16	17	19	41	42	4	18	23	19	36	140	3	37	22	31	7	3.5

continued

Table 6. Continued.

County	Soil pH[a]						Mehlich-3 soil P[b] (ppm)						Mehlich-3 soil K[b] (ppm)						Mehlich-3 soil Zn[b] (ppm)					
	<5.4	5.4-5.7	5.8-6.2	6.3-6.9	>6.9	Md[c]	<16	16-25	26-35	36-50	>50	Md	<61	61-90	91-130	131-175	>175	Md	<1.6	1.6-3.0	3.1-4.0	4.1-8.0	>8.0	Md
	---(% of sampled acreage) ---						--(% of sampled acreage) --					(ppm)	-- (% of sampled acreage)---					(ppm)	---- (% of sampled acreage) ----					(ppm)
Logan, Booneville	18	18	29	21	14	6.1	14	20	14	8	44	36	18	28	23	8	23	97	1	35	7	19	38	5.2
Logan, Paris	20	30	33	13	4	5.7	7	9	6	8	70	113	15	19	18	15	33	124	2	9	6	22	61	10.3
Lonoke	14	20	34	27	5	6.0	14	31	21	16	18	27	13	34	29	11	13	93	15	35	15	23	12	3.1
Madison	15	24	29	26	6	5.9	3	7	8	8	74	97	11	20	23	17	29	122	1	8	9	28	54	8.5
Marion	6	11	23	26	34	6.7	7	7	8	12	66	81	4	15	19	20	42	149	2	5	7	26	60	10.2
Miller	31	18	19	22	10	5.8	8	12	12	12	56	60	27	27	17	12	17	84	2	17	12	30	39	6.0
Mississippi	3	10	26	42	19	6.4	2	6	11	21	60	59	2	8	22	31	37	155	1	13	22	50	14	4.7
Monroe	7	11	22	32	28	6.4	21	24	18	17	20	27	13	28	29	16	14	98	7	20	13	33	27	4.7
Montgomery	31	29	24	13	3	5.6	5	7	9	9	70	77	33	22	18	17	10	85	2	15	8	34	41	7.2
Nevada	16	28	28	16	12	5.8	15	18	10	3	54	82	26	25	23	10	16	88	4	10	8	21	57	9.0
Newton	12	28	26	22	12	6.0	12	11	13	13	51	52	16	20	22	16	26	116	5	22	15	24	34	5.2
Ouachita	32	18	18	26	6	5.8	12	5	9	10	64	81	27	24	20	13	16	88	3	11	7	31	48	7.5
Perry	23	27	28	18	4	5.7	7	15	15	11	52	54	19	19	13	14	35	130	3	15	18	28	36	5.7
Phillips	6	6	12	50	26	6.7	1	6	13	21	59	57	2	17	38	31	12	125	8	27	17	32	16	3.8
Pike	39	29	18	12	2	5.5	7	7	2	7	77	150	36	27	17	9	11	76	0	13	7	29	51	8.6
Poinsett	3	6	13	24	54	7.0	22	31	21	15	11	24	12	47	28	10	3	84	2	12	10	32	44	7.2
Polk	36	28	18	12	6	5.5	4	10	8	9	69	90	30	26	15	10	19	84	3	12	9	28	48	7.6
Pope	22	21	27	20	10	5.8	9	10	8	8	65	80	21	21	24	15	19	102	2	13	8	27	50	8.2
Prairie, Des Arc	13	18	28	24	17	6.1	8	31	30	16	15	29	8	41	35	10	6	91	6	28	15	35	16	4.2
Prairie, De Valls Bluff	9	10	15	50	16	6.5	24	47	16	2	11	21	24	46	20	5	5	77	3	12	13	35	37	6.2
Pulaski	23	17	19	25	16	6.0	15	9	7	11	58	67	17	22	25	18	18	103	4	16	8	24	48	7.8
Randolph	15	18	25	30	12	6.1	36	26	17	11	10	20	16	26	25	15	18	100	5	29	19	33	14	3.8
Saline	26	19	19	23	13	5.9	10	12	11	15	52	52	25	26	21	13	15	89	2	15	8	32	43	6.7
Scott	18	34	25	17	6	5.7	15	9	6	10	60	72	21	21	19	15	24	104	1	9	9	29	52	9.3
Searcy	24	17	25	24	10	5.9	6	12	10	16	56	55	13	33	29	11	14	96	5	31	14	23	27	4.2
Sebastian	20	21	20	22	17	6.0	12	13	7	10	58	59	13	23	26	16	22	109	1	7	8	28	56	9.5
Sevier	42	28	18	10	2	5.5	10	9	8	10	63	90	35	17	15	9	24	88	2	11	8	30	49	7.8
Sharp	13	12	20	25	30	6.4	15	15	11	9	50	48	16	21	31	18	14	104	5	22	13	23	37	5.1
St. Francis	8	12	18	41	21	6.5	5	8	13	24	50	51	4	12	16	18	50	175	6	32	19	30	13	3.7
Stone	29	22	15	20	14	5.7	5	4	10	11	70	71	16	30	26	13	15	95	1	13	10	33	43	7.0
Union	21	15	14	33	17	6.1	14	7	5	7	67	70	25	18	26	15	16	95	2	9	7	20	62	12.0
Van Buren	20	21	26	25	8	5.9	10	8	12	16	54	60	23	22	25	10	20	98	3	15	11	25	46	7.4
Washington	7	14	21	29	29	6.5	3	7	9	12	69	84	3	11	24	25	37	152	1	6	6	28	59	9.8
White	20	18	23	28	11	6.0	8	15	11	15	51	52	23	23	22	12	20	95	3	14	11	29	43	6.6
Woodruff	29	15	22	29	5	5.9	9	20	11	22	3	41	8	22	32	19	19	113	4	34	17	24	21	3.7
Yell, Danville	22	34	27	14	3	5.6	12	9	6	6	67	106	23	15	15	15	32	120	1	5	10	24	60	10.4
Yell, Dardanelle	17	19	24	28	12	6.0	17	7	3	3	70	98	14	23	18	21	24	124	2	9	7	27	55	10.5
Average	18	18	22	26	16	6.1	10	14	12	14	50	64	16	22	23	15	24	113	4	17	12	30	37	6.8

[a] Analysis by electrode in an 1:2 soil weight:deionized water volume.
[b] Analysis by ICAP in an 1:10 soil weight:Mehlich-3 volume.
[c] Md = median.

Table 7. Soil-test data (% of sampled acres) and median (Md) values by previous crop for soil samples submitted to the Soil Testing and Research Laboratory in Marianna from 1 January 2010 through 31 December 2010.

	Soil pH[a]						Mehlich-3 soil P[b] (ppm)						Mehlich-3 soil K[b] (ppm)						Mehlich-3 soil Zn[b] (ppm)					
Geographic area	<5.4	5.4-5.7	5.8-6.2	6.3-6.9	>6.9	Md[c]	<16	16-25	26-35	36-50	>50	Md	<61	61-90	91-130	131-175	>175	Md	<1.6	1.6-3.0	3.1-4.0	4.1-8.0	>8.0	Md
	---(% of sampled acreage) ---						--(% of sampled acreage) --					(ppm)	-- (% of sampled acreage)---					(ppm)	---- (% of sampled acreage) ----					(ppm)
Corn	6	10	24	40	20	6.4	13	15	17	20	35	39	8	26	34	19	13	107	4	19	14	38	25	5.0
Cotton	5	9	25	49	12	6.4	3	7	12	21	57	56	3	6	28	35	28	146	8	23	17	36	16	4.2
Grain sorghum, non-irrigated	20	15	19	27	19	6.1	20	17	9	15	39	39	12	29	31	20	8	99	7	20	14	22	37	4.5
Grain sorghum, irrigated	6	20	44	27	3	6.0	2	2	15	39	42	47	2	6	19	17	56	196	2	15	20	49	14	4.7
Rice	6	12	23	32	27	6.4	20	30	23	16	11	26	12	26	24	13	25	107	3	24	21	37	15	4.2
Soybean	6	10	20	33	31	6.5	13	25	22	21	19	31	9	32	29	12	18	100	4	20	16	39	21	4.8
Wheat	26	21	22	20	11	5.8	7	18	19	19	37	39	7	17	31	18	27	124	7	30	17	33	13	3.7
Cool-season grass hay	18	25	32	21	4	5.9	12	7	9	11	61	69	22	23	22	16	17	99	3	11	9	26	51	8.2
Native warm-season grass hay	34	28	20	16	2	5.5	18	15	12	10	45	39	34	27	16	7	16	78	3	23	12	28	34	5.4
Warm-season grass hay	25	24	24	22	5	5.8	10	11	10	10	59	68	32	22	20	13	13	84	3	15	9	25	48	7.8
Pasture, all categories	22	26	29	19	4	5.8	12	12	10	10	56	63	18	21	22	14	25	110	2	14	10	27	47	7.6
Home garden	10	11	17	28	34	6.6	3	5	5	7	80	133	7	14	20	18	41	152	1	7	6	18	68	13.5
Home lawn	24	17	19	24	16	6.0	7	12	12	16	53	55	8	20	30	23	19	120	1	10	11	39	39	6.5
Small fruit	35	17	18	21	9	5.7	5	7	8	15	65	70	16	23	22	15	24	107	3	12	6	35	44	7.2
Ornamental	11	10	16	29	34	6.6	5	6	7	9	73	84	10	21	27	21	21	117	1	4	4	21	70	12.0
Average	17	17	24	27	15	6.1	10	13	13	16	48	57	13	21	25	17	24	116	4	17	12	32	35	6.6

[a] Analysis by electrode in 1:2 soil weight:deionized water volume.
[b] Analysis by ICAP in 1:10 soil weight:Mehlich-3 volume.
[c] Md = median.

Table 8. Fertilizer tonnage sold in each Arkansas county from 1 July 2010 through 30 June 2011[a].

County	Fertilizer sold	County	Fertilizer sold	County	Fertilizer sold
	(tons)		(tons)		(tons)
Arkansas	89,202	Garland	2,846	Newton	533
Ashley	16,570	Grant	1,373	Ouachita	128
Baxter	1,340	Greene	28,984	Perry	735
Benton	12,753	Hempstead	2,882	Phillips	52,876
Boone	2,279	Hot Spring	840	Pike	377
Bradley	260	Howard	997	Poinsett	61,167
Calhoun	332	Independence	7,607	Polk	632
Carroll	1,655	Izard	1,202	Pope	1,997
Chicot	37,092	Jackson	23,505	Prairie	25,116
Clark	1,908	Jefferson	29,240	Pulaski	10,318
Clay	51,367	Johnson	894	Randolph	17,272
Cleburne	1,233	Lafayette	7,154	Saline	1,524
Cleveland	12	Lawrence	24,794	Scott	274
Columbia	660	Lee	25,943	Searcy	1,059
Conway	5,992	Lincoln	13,061	Sebastian	2,333
Craighead	59,581	Little River	5,112	Sevier	1,228
Crawford	3,680	Logan	1,004	Sharp	918
Crittenden	17,534	Lonoke	51,678	St. Francis	43,308
Cross	35,846	Madison	3,151	Stone	1,202
Dallas	133	Marion	1,470	Union	1,122
Desha	35,742	Miller	9,037	Van Buren	5,797
Drew	14,949	Mississippi	61,749	Washington	3,412
Faulkner	3,739	Monroe	31,800	White	24,421
Franklin	1,036	Montgomery	429	Woodruff	29,907
Fulton	1,023	Nevada	453	Yell	935

[a] Arkansas Distribution of Fertilizer Sales by County, 1 July 2010 to 30 June 2011, Arkansas State Plant Board, Division of Feed and Fertilizer, Little Rock, Ark., and University of Arkansas Division of Agriculture, Arkansas Agricultural Experiment Station, Fayetteville, Ark.

Table 9. Fertilizer nutrient, formulation, and use category sold in Arkansas from 1 July 2010 through 30 June 2011[a].

Fertilizer	Container			Use		Totals
	Bag	Bulk	Liquid	Farm	Non-farm	
	---------- (tons) ----------					
Multi-nutrient	48,501	296,675	8,204	345,050	8,296	353,380
Nitrogen	16,251	443,554	68,110	526,469	1,444	527,915
Phosphate	1,030	30,367	389	31,565	220	31,786
Potash	3,465	79,799	19	82,840	443	83,283
Organic	731	240	0	915	57	971
Micronutrient	2,264	1,564	109	3,873	64	3,937
Lime	591	5,028	0	5,159	460	5,619
Miscellaneous	12,406	1,551	851	14,461	347	14,808
Totals	85,239	858,778	77,682	1,010,332	11,331	1,021,699

[a] Arkansas Distribution of Fertilizer Sales by County, 1 July 2010 to 30 June 2011, Arkansas State Plant Board, Division of Feed and Fertilizer, Little Rock, Ark., and University of Arkansas Division of Agriculture, Arkansas Agricultural Experiment Station, Fayetteville, Ark.

Mehlich-III, Inorganic Nitrogen, and Alkaline Hydrolyzable Nitrogen Soil Analyses Across Sampling Depth

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

The migration of nutrients beyond the extent of the root system can result in decreased nutrient concentration within the portion of the soil profile that is occupied by plant roots. Fertilizer inputs are typically applied and incorporated at or near the soil surface; however, the ability of the plant to remove nutrients from soil is not limited to surface soil. Root morphology will determine the volume and 'depth of soil' that is accessible to plant roots. In Arkansas, Beyrouty et al. (1988) reported that approximately 100% of the total rice (*Oryza sativa* L.) root length could be accounted for to a 16-inch depth before early reproductive growth (i.e., panicle initiation), and at maturity approximately 50% of the root system was located below the 4- to 7-inch extent of the restrictive layer (i.e., traffic pan). The presence of rice roots below a restrictive layer as well as root growth below the volume of soil where plant nutrients are concentrated suggests that subsoil fertility may be important for proper plant nutrition.

The quantification of nitrogen (N) following alkaline hydrolysis (AH-N) has served as the basis for the development of chemical soil-test methods that assess N fertilizer responsiveness of agricultural crops including corn (*Zea mays* L.; Khan et al., 2001) and rice (Roberts et al., 2011a). The ability to accurately and reliably quantify AH-N allowed researchers to develop fertilizer rate recommendations on the basis of potentially mineralizable-N determined using either diffusion or steam distillation. Two AH-N soil-tests that have since been developed are a diffusion (DIF) method (Khan et al., 2001) and a direct steam distillation (DSD) method (Roberts et al., 2011b).

Limited information currently exists on the fertility status of clayey soils at depths greater than 6 inches in Arkansas. Research conducted to identify the distribution of AH-N at depths deeper than 6 inches has focused mainly on silt loam soils in Arkansas (Roberts et al., 2009). Therefore, the objective of this study was to quantify AH-N as well as 2 *M* KCl extractable inorganic ammonium (NH_4-N) and nitrate (NO_3-N) to a 2-ft depth on clayey-textured soils. The second objective of this study was to examine the concentration of selected Mehlich-3 nutrients to a 2-ft depth on clayey soils.

PROCEDURES

Nitrogen rate trials were conducted from 2009 to 2010 on Arkansas Agricultural Experiment Station fields and commercial production fields by broadcast applying urea (46% N) fertilizer in a two-way split using total N rates of 0, 90, 120, 150, 180, and 210 lb N/acre. Direct-seeded, delayed-flood, or water-seeded rice production systems were established and small plots measuring approximately 120 ft^2 were arranged as a randomized complete block with four blocks in each field. From each 0 lb N/acre plot, soil was sampled to a depth of 2 ft in successive 6-inch increments (0- to 6-, 6- to 12-, 12- to 18-, and 18- to 24-in.) using a Dutch auger (AMS, Inc., American Falls, Idaho). Soil was sampled at the 4- to 5-leaf growth stage of rice prior to the application of preflood N fertilizer and the establishment of a permanent flood. Year of sampling, soil series, taxonomic classification, and previously grown crop are listed for each site (Table 1). Soil cores were oven dried at 50 ºC for 24 hours, ground, sieved to pass a 2-mm screen, and placed in cardboard containers prior to chemical analysis. Soil samples were analyzed for NH_4-N and NO_3-N (Mulvaney, 1996), plant-available P, K, and Zn were determined using the Mehlich-3 extraction procedure (Mehlich, 1984) and AH-N was quantified using the DIF and DSD soil-test methods.

Analysis of variance was conducted using SAS v. 9.2 (SAS Institute, Cary, N.C.) and the GLM procedure to examine the influence of site and sampling depth on NH_4-N, NO_3-N, and AH-N concentration. Means were separated using the least significant difference (LSD) test and significance was assessed at $P < 0.05$. Mehlich-3 nutrient concentrations were determined from only one sample from each site. Therefore, no statistical analysis was performed on Mehlich-3 nutrient data; however, the numerical trend among depths is discussed.

RESULTS AND DISCUSSION

There was a non-significant site by depth interaction ($P = 0.06$) influence on soil NO_3-N concentration. However, NO_3-N concentration was significantly affected by the main effect of site and depth (Table 2). Nitrate concentration, averaged across depths, was greatest at site 7 (8.4 ppm) and was significantly greater than all of the sites sampled with the exception of site

9. Nitrate concentration, averaged across sites, was greatest (3.7 ppm) for the 0- to 6-in. depth and was significantly greater than the concentration of NO_3-N for the 12- to 18- and 18- to 24-in. depths. However, the range of NO_3-N concentration was 1.1 ppm over a 2-ft depth and this suggests that while the influence of depth on NO_3-N concentration was statistically significant, the change in NO_3-N with depth was within a narrow range of concentrations.

There was a non-significant site by depth interaction ($P = 0.67$) influence on NH_4-N concentration. The main effect of site had a significant influence on NH_4-N concentration (Table 2). The concentration of NH_4-N was greatest at site 6 (5.1 ppm) and was significantly greater than the other sites sampled with the exception of sites 7 and 10. The influence of depth on NH_4-N concentration was non-significant ($P = 0.16$) indicating that NH_4-N concentrations were similar over a 2-ft depth.

Alkaline hydrolyzable-N concentration was influenced by a significant site by depth interaction for both the DIF ($P < 0.0001$) and DSD ($P = 0.0001$) soil-test methods. The main effects of site and depth were also significant ($P < 0.0001$) for both soil-test methods. There were no significant differences among AH-N concentrations quantified using DIF for site 11 across depths. The concentration of AH-N at site 5 was greatest (154 ppm) at the 6- to 12-in. depth and was significantly greater than the AH-N concentration at the 18- to 24-in. depth (Table 3). There were no significant differences among AH-N concentrations quantified using DSD across depths for site 11, while for site 5 the concentration of AH-N was greatest (158 ppm) at the 6- to 12-in. depth and was significantly greater than the concentration of AH-N at the 18- to 24-in. depth.

An interesting find regarding the change in AH-N concentration with depth is the fact that both DIF and DSD values were greater than 100 ppm for sites 4, 5, 7, 11, and 12, regardless of sample depth. The presence of a substantial concentration of AH-N at sites 4, 5, 7, 11, and 12 within each soil depth analyzed suggests that in order to accurately quantify the amount of AH-N available for plant uptake using either DIF or DSD it may be necessary to sample deeper than 6 inches in the soil profile. A comparison of AH-N concentration at sites 11 and 12 indicated that the DIF soil-test value was greatest (147 ppm) at site 12 and was significantly greater than site 11 within the 0- to 6-in. depth. The concentration of AH-N quantified using DIF for sites 11 and 12 within the 6- to 12-in. depth and the 12- to 18-in. depth were not significantly different, while site 11 had a significantly greater concentration of AH-N compared to site 12 at the 18- to 24-in. depth. The AH-N concentration quantified using DSD for site 7 was significantly greater than the AH-N concentration at site 11 within the 0- to 6-in. depth. Alkaline hydrolyzable-N concentrations as determined using DSD were not significantly different between sites 7 and 11 within the remaining depths (6- to 12-, 12- to 18-, and 18- to 24-in.).

Mehlich-3 phosphorus (M3-P), potassium (M3-K) and zinc (M3-Zn) nutrient status of clayey soils was evaluated for soil sampled to a 2-ft depth (Table 4). The concentration of M3-P across soil depths ranged from 3 to 73 ppm. In Arkansas, P fertilization of rice would be recommended on low M3-P sites (< 25 ppm and soil pH < 6.5) and for sites with M3-P < 35 ppm and soil pH ≥ 6.5. Forty-two percent of the sites sampled exhibited a P concentration > 35 ppm and a mean (n = 4) soil pH ≥ 6.5 within the 0- to 6-in. depth. Among the sites with mean pH ≥ 6.5, sites 1, 3, 10, and 12 had M3-P < 35 ppm and among sites with mean pH < 6.5, sites 6, 7, and 8 had M3-P < 25 ppm within the 0- to 6-in. depth. For sites 2 and 11 the greatest concentration of M3-P was located in the surface 0- to 6-in. soil sample and then exhibited a numerical tendency to decrease to the 24-in. depth. Sites 1, 3, 4, and 10 exhibited a numerical tendency to decrease in M3-P across the 6-in. sampling increments to an 18-in. depth and then increased numerically between the 12- to 18- and 18- to 24-in. depths.

Clayey soils in Arkansas typically contain a substantial concentration of exchangeable K and this was confirmed across the 12 sites evaluated in this study over a 2-ft sampling depth (Table 4). Mehlich-3 K exhibited a numerical propensity to decrease for each successive 6-in. soil sample at site 2 and numerically increase for each successive 6-in. sample at sites 3 and 10 in response to sampling to a 2-ft depth. However, M3-K concentration exhibited an inconsistent numerical change as sampling depth increased to 2 ft for a majority (75%) of the sites sampled. For example, M3-K concentrations at sites 1, 4, and 11 tended to decrease numerically to an 18-in. depth and then increase numerically between the 12- to 18- and the 18- to 24-in. depths.

Zinc fertilization of clayey soils is generally not required, although when M3-Zn concentrations are very low (<1.6 ppm) current recommendations would stipulate that fertilizer be applied to increase the plant-available Zn concentration. The results obtained from the evaluation of M3-Zn concentrations suggest that 92% of the sites sampled would not require added fertilizer Zn and 83% of the sites sampled were within the medium (2.6 to 4.0 ppm) range of plant-available Zn based on the numerical concentration (Table 4). Mehlich-3 Zn at sites 6, 8, and 12 responded consistently to a change in sample depth and tended to numerically decrease as sampling depth increased to a 2-ft depth. While M3-Zn at sites 2, 4, and 7 also responded consistently to the change in sampling depth, Zn concentration at these sites tended to numerically increase as depth increased to an 18-in. depth.

PRACTICAL APPLICATIONS

Information regarding the fertility status of clayey soils can help guide fertilizer management decisions. Current protocols restrict soil sampling to near surface depths (0- to 4- or 0- to 6-in.) for immobile nutrients and therefore cannot take into consideration the contribution of nutrients located in the subsurface soil to plant nutrition during the growing season. In order to improve current soil-test methods it is necessary to identify the nutrient concentration and sampling depth that most accurately reflects the nutrient uptake pattern within the soil profile. This study will support the development of fertilizer N calibration curves using either DIF or DSD soil-test values by identifying how site and sampling depth influence AH-N concentration. Also, results from this study can aid the management of fertilizer inputs by serving as an index of the nutrient content of clayey soils used for rice production in Arkansas.

ACKNOWLEDGMENTS

This research was made possible through an allocation of Rice Check-off Program funds distributed by the Rice Research and Promotion Board.

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Table 1. Year, soil series, taxonomic classification, and previous crop for twelve sites sampled in Arkansas from 2009 to 2010.

Site	Year	Soil series	Classification	Previous crop
1	2009	Jackport	fine, smectitic, thermic, Chromic Epiaquerts	Soybean[a]
2	2009	Desha	very-fine, smectitic, thermic, Vertic Hapludolls	Soybean
3	2009	Jackport	fine, smectitic, thermic, Chromic Epiaquerts	Soybean
4	2009	Sharkey	very-fine, smectitic, thermic Chromic Epiaquerts	Rice
5	2009	Sharkey	very-fine, smectitic, thermic Chromic Epiaquerts	Soybean
6	2010	Sharkey	very-fine, smectitic, thermic Chromic Epiaquerts	Soybean
7	2010	Kobel	fine, smectitic, nonacid, thermic Vertic Endoaquepts	Soybean
8	2010	Jackport	fine, smectitic, thermic, Chromic Epiaquerts	Soybean
9	2010	Desha	very-fine, smectitic, thermic, Vertic Hapludolls	Soybean
10	2010	Jackport	fine, smectitic, thermic, Chromic Epiaquerts	Soybean
11	2010	Sharkey	very-fine, smectitic, thermic Chromic Epiaquerts	Rice
12	2010	Sharkey	very-fine, smectitic, thermic Chromic Epiaquerts	Soybean

[a] *Glycine max* L.

Table 2. Soil ammonium (NH_4-N) and nitrate (NO_3-N) concentrations as influenced by site, averaged across soil depths, or depth, averaged across sites, for clayey soils sampled in Arkansas from 2009 to 2010.

Site	NH_4-N	NO_3-N
	-------------(ppm)-------------	
1	2.2	0.5
2	0.1	1.4
3	1.1	0.6
4	1.9	2.8
5	2.4	0.7
6	5.1	1.8
7	4.1	8.4
8	1.7	4.6
9	2.4	7.6
10	3.9	4.0
11	0.5	1.5
12	1.0	2.5
LSD(0.05)	1.5	2.3
p-value	<0.0001	<0.0001

Depth	NH_4-N	NO_3-N
	-------------(ppm)-------------	
LSD(0.05)	1.5	2.3
0- to 6-in.	2.5	3.7
6- to 12-in.	2.4	3.2
12- to 18-in.	1.9	2.5
18- to 24-in.	1.9	2.6
LSD(0.05)	NS[a]	0.8
p-value	0.16	0.004

[a] NS, non-significant.

Table 3. Alkaline hydrolyzable-N (AH-N) concentration determined using diffusion (DIF) and direct steam distillation (DSD) soil-test methods for clayey soils sampled to 2 ft in Arkansas from 2009 to 2010.

	AH-N							
	DIF				DSD			
Site	0-6 in.	6- to 12-in.	12- to 18-in.	18- to 24-in.	0- to 6-in.	6- to 12-in.	12- to 18-in.	18- to 24-in.
	(ppm)							
1	133	88	67	38	140	106	75	52
2	107	83	65	55	121	100	76	67
3	121	65	58	55	131	75	74	62
4	141	130	121	113	155	149	129	127
5	142	154	138	127	151	158	140	133
6	100	80	68	61	127	109	80	90
7	140	138	131	107	163	146	147	128
8	93	73	63	53	99	76	67	54
9	134	105	86	57	142	121	87	73
10	123	79	66	60	149	93	76	70
11	129	126	125	124	130	140	127	134
12	147	131	110	101	164	132	123	106
LSD(0.05) within column for DIF	16				for DSD 26			
LSD(0.05) within row for DIF	19				for DSD 23			

Table 4. Soil pH (1:2 soil:water volume) and Mehlich-3 extractable phosphorus (M3-P), potassium (M3-K) and zinc (M3-Zn) of clayey soil samples removed in successive 6-in. increments (0- to 6-, 6- to 12-, 12- to 18-, and 18- to 24-in) to a 2-ft depth in Arkansas from 2009 to 2010.

	pH				M3-P				M3-K				M3-Zn			
Site	0-6	6-12	12-18	18-24	0-6	6-12	12-18	18-24	0-6	6-12	12-18	18-24	0-6	6-12	12-18	18-24
					(ppm)											
1	6.8	6.6	6.3	6.5	34	24	16	27	291	234	233	246	3.0	2.0	4.3	3.3
2	7.2	7.1	6.8	6.4	73	67	59	47	230	175	163	146	3.0	3.6	3.7	2.6
3	7.1	6.9	6.1	6.2	13	7	4	5	163	203	223	245	1.3	0.8	1.0	3.5
4	7.4	7.3	7.1	6.6	45	28	26	32	367	319	294	300	2.8	17.6	25.9	20.3
5	6.6	6.4	6.6	6.7	44	44	31	22	292	258	327	321	3.7	3.7	3.4	3.1
6	6.4	6.1	5.9	5.8	19	23	26	21	378	362	407	391	3.2	2.9	2.2	1.9
7	6.1	6.2	6.1	6.2	12	14	22	19	116	135	159	139	2.2	3.1	4.1	3.9
8	6.4	5.9	5.5	5.2	10	11	5	3	167	150	170	198	3.5	2.0	1.4	0.9
9	7.0	7.1	6.5	6.2	66	57	59	41	261	225	237	228	3.3	3.8	3.0	1.5
10	7.1	6.5	5.2	5.1	24	13	5	10	192	219	251	260	4.5	1.0	0.8	0.8
11	7.0	6.9	6.9	6.8	45	28	21	19	370	361	360	424	3.6	3.1	3.2	2.9
12	6.8	6.8	6.7	6.6	34	35	20	21	343	360	357	380	3.9	3.8	3.0	2.6

Winter Wheat Grain Yield and Ammonia Volatilization Response to Late-Winter Applied Nitrogen

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Soft red winter wheat (*Triticum aestivum* L.) requires adequate nitrogen (N) fertilization to produce maximal yields on most soils. Nitrogen fertilizer is usually applied to wheat in February just after tillering and prior to early spring growth. Typical recommendations include applying 90 lb N/acre in a single application on well-drained, silt-loam soils in mid-February to mid-March, however, higher N rates or poorly drained soils may require split applications. Urea is typically applied and is more susceptible to NH_3 volatilization than some other N fertilizers. Ammonia volatilization can cause economic loss to farmers applying urea fertilizer by reducing fertilizer use efficiency, as well as contribute to environmental problems (e.g., eutrophication). Ammonia loss occurs when surface-applied urea undergoes hydrolysis and is converted to NH_3 by the urease enzyme, and microsite pH near the urea prill is drastically increased thereby preventing conversion to NH_4. Despite a lower risk of volatilization losses in winter wheat compared to summer-grown crops, warm and wet conditions during early spring in Arkansas can be favorable for urea-N losses via volatilization. Engel et al. (2011) reported NH_3 losses on cold temperature soils were highly variable and could range from 3% to 44%. Other research reports NH_3 losses from surface-applied urea were highly variable based on soil texture, fertilizer application timing, cultural management, and environmental conditions and could range from negligible to over 50% (Sommer et al., 2004; Turner et al., 2010). Soil moisture was also implicated as a more influential climatic factor than warm temperatures. In an effort to increase producer profitability and improve fertilizer use efficiency on wheat, implementation of nutrient management practices that reduce the risk of N loss from surface-applied urea may be warranted.

One additive that can be used to reduce NH_3 volatilization loss from urea (e.g., under conditions that include high soil moisture, warm temperature, wind, etc.) is the urease inhibitor N-(n-butyl)-thiophosphoric triamide (NBPT) sold under the trade name Agrotain (Agrotain International, St. Loius, Mo.). Slaton et al. (2011) reported variability in the agronomic, and hence economic, benefits of applying Agrotain-treated urea to winter wheat due presumably to variable soil and weather conditions present when urea-N was applied. Their results indicated that additional research was needed to clarify the conditions under which NH_3 loss from urea occurs during February and March. Our research objectives were to examine differences, if any, in grain yield, total dry matter (TDM), and N uptake by soft red winter wheat fertilized with urea, urea+NBPT, or $(NH4)_2SO_4$ applied at three N rates (40, 80, or 120 lb N/acre) and to compare NH_3 volatilization from the three N sources applied at 120 lb N/acre.

PROCEDURES

A fertilization experiment was initiated during the fall 2010 to evaluate the effect of N fertilizer rate and source on wheat TDM, yield, and NH_3 volatilization. The trial was established on a Captina (Typic Fragiudult) silt loam following summer fallow at the Arkansas Agricultural Research and Extension Center located in Fayetteville, Ark. Five composite soil samples (0- to 4-in. depth) were taken from the site to determine soil chemical properties. Soil was oven-dried, crushed, and passed through a 2-mm sieve for measurement of Mehlich-3 extractable nutrients, total N and C, inorganic N (NO_3-N and NH_4-N), and soil water pH. The mean chemical values for this soil were 7.2 pH, 0.10% total N, 0.97% total C, 12.5 ppm NO_3-N, 9.9 ppm NH_4-N, 39 ppm P, 156 ppm K, 1317 ppm Ca, 52 ppm Mg, 12 ppm S, 98 ppm Fe, 232 ppm Mn, 3.0 ppm Zn, 3.5 ppm Cu, and 0.14 ppm B. AgriPro 'Beretta' wheat was drill-seeded (120 lb seed/acre) into a conventionally tilled seedbed on 15 October. Plots were 20-ft long by 8-ft wide allowing for twelve rows of wheat with a 7-in. row spacing.

Fertilizer treatments were broadcast by hand to each plot once on 22 February after wheat had begun to tiller (Feekes stage 3). Nitrogen sources included urea, urea treated with NBPT, and $(NH_4)_2SO_4$ (21-0-0-24S) sold under the trade name Honeywell Sulf-N® Ammonium Sulfate (Honeywell, Morristown, N.J.) with each source applied at 0, 40, 80, and 120 lb N/acre. Potassium (100 lb muriate of potash/acre) and phosphorus (100 lb triple superphosphate/acre) were broadcast applied to the area in late January to ensure these nutrients were not yield-limiting factors. Wheat was sampled for dry matter at heading (20 April, Feekes 10.5) by cutting three feet of an interior row. At maturity (13 June), grain yield was measured by harvesting eleven rows of wheat using a plot combine. Grain yield was adjusted to the uniform moisture of 13%.

The experiment was a three-by-three factorial design with three replicates for each treatment defined by three N sources by three N rates compared to a no N control. Analysis of variance was conducted using PROC GLM in SAS v9.2 (SAS Institute, Inc., Cary, N.C). Mean separations were evaluated using Fisher's Protected Least Significant Difference method at significance level 0.10.

A semi-open, static chamber system was used to measure NH_3 emissions from each fertilizer source applied at 120 lb N/acre as described by Griggs et al. (2007). Clear acrylic tubes measuring 5.5 in. (inside diameter) × 30 in. (height) were placed over actively growing wheat plants and driven 6 in. into the soil surface to prevent air flux or water infiltration. Plastic buckets were suspended 2 in. above each chamber with PVC pipe to allow air circulation, but prevent precipitation interference. Foam sorbers (1-in. thick) were form cut to fit inside each chamber, washed with phosphoric acid, rinsed with deionized water, dried, and stored in 1 gal plastic bags. Twenty mL of a 0.73 *M* H_3PO_4-33% glycerol (v:v) solution was added to each sorber to act as an acid trap for NH_3. The first sorber was placed approximately 6 in. below the top of the chamber to trap volatilized NH_3 from the fertilizer, and the second placed flush with the top of the chamber to limit interference from atmospheric NH_3. Air temperature within and outside the chamber was measured using Onset StowAway Tidbit temperature sensors (Onset Computer Corp., Bourne, Mass.), suspended approximately 5 in. above the growing point of the wheat. Temperature data was logged every half-hour for the duration of the experiment.

The NH_3 volatilization experiment was started 22 February. Sorbers were sampled 3, 6, 9, 12, 15, and 18 days after N fertilizer was applied. Upon removal with laboratory tongs, sorbers were placed into their original plastic bags and returned to the laboratory for extraction. Extraction was conducted by adding 100 mL of 2 *M* KCl to each plastic bag containing a foam sorber and hand squeezing to ensure the foam was adequately saturated. After sitting in solution overnight, sorbers were again hand squeezed to separate the KCl solution from the foam, and a portion of the solution was collected in a scintillation vial. The concentration of NH_4-N was determined by an autoanalyzer (Skalar), and expressed as a percent of the total fertilizer N applied.

The experiment was a randomized complete block design with four replicates per treatment defined by four N sources including an untreated control and six sampling times. The experiment was analyzed as a split-plot design with N source as the whole plot and sampling time as the subplot. Analysis of variance was conducted using the PROC GLM function in SAS v9.2 (SAS Institute, Inc., Cary, N.C). Means separations were evaluated using Fisher's Protected Least Significant Difference method at a significance level of 0.10.

RESULTS AND DISCUSSION

Climatic conditions for the duration of the wheat study were atypical of a normal Arkansas winter. In general, temperatures were below normal during December through February with record cold occurring in December and February. These months were marked by six significant snow events with snow in excess of 18 in. occurring 9 February and temperatures reaching -18 ºF. April and May were marked by above normal rain and catastrophic flooding in northwest Arkansas, with 13.5 in. of rain falling over 7 days in April and 10 in. in May. These rains events resulted in 300% to 500% the normal precipitation for these months.

The main effect of N rate was the only significant variable for TDM, yield, or N uptake (Table 1). All N sources behaved similarly for each parameter and were always greater than the no N control (Table 2). Winter wheat showed a strong positive response to N rate when fertilized with 40 to 120 lb N/acre (Table 1). Yields increased incrementally with each increase in N rate. Grain yields were maximized by 120 lb N/acre. Total dry matter followed a similar trend as grain yield with TDM increasing numerically as N rate increased. However, these differences were not significant between 40 and 80 lb N/acre or 80 and 120 lb N/acre. All N sources, averaged across N rates, produced greater TDM than wheat fertilized with no N. Nitrogen uptake followed the same trend as grain yield with N uptake increasing significantly with each N rate and was maximized at 63 lb N/acre by 120 lb N/acre. Fertilizer recovery, calculated by the difference method, ranged from 36% to 39% for all N rates, averaged across N sources and was significantly lower than fertilizer use efficiency (46.7%) for soft red winter wheat reported by Bashir et al. (1997) using ^{15}N-labeled urea.

The NH_3 volatilization experiment was conducted from 22 February to 13 March and temperature was recorded inside and outside of the volatilization chambers. Temperature inside the chamber ranged from 24 ºF to 117 ºF with an overall mean temperature of 54 ºF. Temperature and humidity data acquired from the National Climatic Data Center measured from Drake Field, Washington County, Ark., showed outside temperature ranged from 23 ºF to 72 ºF (mean 47 ºF) and humidity ranged from 22% to 100% (mean 72%). In general, mean temperature inside the chambers was 6.6 ºF warmer than the recorded outside air temperature.

Total NH_3 volatilization measured from 0 to 18 days after fertilization was relatively low with the maximum NH_3 evolved occurring for urea (2.6% of total N applied, Table 3). Urea+NBPT and $(NH_4)_2SO_4$ both produced NH_3-N loss of <1% of the total N applied. Cumulative NH_3 volatilization was significant for the source by day interaction. Across time, NH_3 volatilization from urea was always significantly greater than for urea+NBPT or $(NH_4)_2SO_4$. Ammonia volatilization from urea and urea+NBPT increased significantly from 0 to 9 days and 9 to 18 days with no significant NH_3 loss occurring after 12 days of the 18 day measurement period. Ammonia loss from $(NH_4)_2SO_4$ was never significant, reaching a maximum of only 0.16% of the applied N by 18 days after fertilization.

PRACTICAL APPLICATION

Nitrogen source had no significant effect on N uptake and grain yield by winter wheat, but both increased as N rate increased from 0 to 120 lb N/acre. Significant growth and yield differences among N sources were not measured and are consistent with relatively low NH_3 volatilization loss from urea (<3% of the applied N) and the other N sources applied to the soil surface in late February. Under the conditions of this study, NH_3 volatilization loss was not a major source of N loss and there was no benefit from using $(NH_4)_2SO_4$ or Agrotain-treated urea compared to urea. Plant uptake and NH_3 loss, as measured in the chambers, accounted for about 40% of the applied N suggesting the remaining 60% of the applied N resided in plant roots, was immobilized, remained in the soil as inorganic N, or was lost via leaching, runoff, or denitrification. Future studies investigating NH_3 loss from surface-applied urea and the potential benefits of urease inhibitors should perhaps examine specific situations (e.g., soil moisture, frozen soils, air temperature, etc.) to better identify under what circumstances a urease inhibitor might be beneficial.

ACKNOWLEDGMENTS

Research was funded by the University of Arkansas Division of Agriculture.

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Table 1. Winter wheat grain yield, total dry matter accumulation (TDM), and N uptake as affected by N fertilizer rate, averaged across N sources, at the Arkansas Agricultural Research and Extension Center during the 2010 to 2011 growing season.

N rate	Grain yield	TDM	N uptake	Fertilizer recovery
(lb N/acre)	(bu/acre)	(lb/acre)	(lb N/acre)	(% of applied)
0	23	3688	20	---
40	38	5520	35	38
80	48	6152	51	39
120	53	6731	63	36
LSD (0.10)	3	728	3	---
P-value	<0.0001	0.0306	<0.0001	---
CV %	8.1	16.3	9.0	---

Table 2. Winter wheat grain yield, total dry matter accumulation (TDM), and N uptake as affected by N source, averaged across N rates, at the Arkansas Agricultural Research and Extension Center during the 2010-2011 growing season.

N source	Grain yield	TDM	N uptake
	(bu/acre)	------------------ (lb/acre)-------------------	
Urea	47	5993	48
NBPT-treated Urea[a]	45	6300	51
$(NH_4)_2SO_4$	47	6111	50
UTC	23	3688	20
LSD (0.10)	NS	NS	NS
P-value	0.5951	0.4971	0.2006
CV %	8.1	16.3	9.0

[a] Agrotain was the urease inhibitor used for the NBPT-treated urea.

Table 3. Cumulative NH_3 volatilization as affected by the N fertilizer source and sampling time (Day) interaction at the Arkansas Agricultural Research and Extension Center at Fayetteville during the 2010 to 2011 growing season.

	N fertilizer source		
Day	$(NH_4)_2SO_4$	NBPT-treated urea[a]	Urea
	--------------------------------- (% Cumulative NH_3-N loss of total N applied) -----------------------		
3	0.082	0.033	0.815
6	0.118	0.128	1.736
9	0.148	0.424	2.325
12	0.154	0.605	2.507
15	0.157	0.676	2.584
18	0.159	0.718	2.619
P-value		<0.001	
LSD(0.10)		0.271 (compare days within same N source)	
LSD(0.10)		0.724 (compare two N sources)	

[a] Agrotain was the urease inhibitor used for the NBPT-treated urea.

Corn and Cotton Response to Urea and an Enhanced Efficiency Fertilizer

M. Mozaffari, N.A. Slaton, and M. Duren

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Supplemental nitrogen (N) fertilization usually increases cotton (*Gossypium hirsutumn* L.) and corn (*Zea mays* L.) yields in Arkansas. Soil and fertilizer N can be lost by processes such as denitrification and leaching. Reducing N fertilizer losses to the environment will increase the growers' profit margin and reduce potential environmental risks. A polymer-coated urea (44% N, Agrium Advanced Technologies, Loveland, Colo.) is currently being produced in Missouri and marketed in Arkansas under the trade name of Environmentally Smart Nitrogen or ESN. According to the manufacturer the polymer coating protects the urea-N against rapid loss to the environment with the N release rate controlled by temperature. The objective of this research was to evaluate cotton and corn response to ESN and urea in representative Arkansas soils.

PROCEDURES

Cotton Experiments

Two N fertilization experiments were conducted to evaluate cotton response to preplant application of urea, ESN, and their combination in 2011. One experiment was located at the Lon Mann Cotton Research Station in Marianna (LMCRS) on a Marvel fine sandy loam. The other trial was located at the Northeast Research and Extension Center (NEREC) in Keiser on a Sharkey silty clay. Before applying any fertilizer, soil samples were collected from the 0- to 6-in. depth and composited by replication. Soil samples were dried, crushed, and soil NO_3-N was measured with a specific ion electrode (Donahue, 1992). Other soil nutrients were measured with the Mehlich-3 soil-test (Table 1). Soil particle size analysis was performed by the hydrometer method (Arshad et al., 1996). Agronomically important information for all experiments is presented in Table 2.

Each cotton experiment was a randomized complete block design with a factorial arrangement of four urea-ESN combinations each applied at five rates ranging from 30 to 150 lb N/acre and a no N control. The four urea- and ESN-N combinations were: 100% urea-N; 50% urea-N plus 50% ESN-N; 25% urea-N plus 75% ESN-N, and 100% ESN-N. Each treatment was replicated six times. We blanket applied muriate of potash to supply 60 and 80 lb K_2O/acre at LMCRS and NEREC, respectively. Triple superphosphate was blanket applied to supply 50 and 30 lb P_2O_5/acre at LMCRS and NEREC, respectively. All fertilizers were hand applied onto the soil surface and incorporated immediately with a Do-all cultivator. We pulled the beds with a hipper and planted the cotton on top of the beds after fertilizers were incorporated. 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 University of Arkansas Cooperative Extension Service cultural recommendations for irrigated cotton production. The two center rows of cotton in each plot were harvested with a spindle-type picker equipped with an electronic weight measuring and recording system.

Corn Experiments

Corn N fertilization trials were conducted at the LMCRS on a Loring silt loam and NEREC on a Steele loamy sand. The experimental treatments and design for the corn experiments were similar to the cotton experiments. However, the N rates for the corn experiments ranged from 60 to 300 lb N/acre applied in 60-lb increments. Each treatment was replicated six times. At LMCRS, blanket applications of muriate of potash, triple superphosphate, and $ZnSO_4$ were made to supply 80 lb K_2O, 80 lb P_2O_5, ~ 6.0 lb Zn, and 3.0 lb S/acre. At NEREC, we applied 60 lb K_2O, 30 lb P_2O_5, ~ 6.0 lb Zn, and ~ 3.0 lb S/acre. All fertilizers were hand applied onto the soil surface and incorporated immediately with a Do-all cultivator. We pulled the beds with a hipper and planted the corn on top of the beds after fertilizers were incorporated. Corn was furrow irrigated as needed and the University of Arkansas Cooperative Extension Service recommended cultural practices were closely followed. Plots for both corn studies were 25-ft long and 12.6-ft wide allowing for four rows of corn planted in 38-in. wide rows. Corn plants in the center 2-rows of each plot were harvested with a plot combine and grain yields were adjusted to 15.5% moisture content.

We obtained monthly precipitation data from weather stations at LMCRS and NEREC and long-term average precipitation data from the Arkansas Variety Testing website (http://www.arkansasvarietytesting.com/crop/data/2). Analysis of variance (ANOVA) was performed using the GLM procedure of SAS (SAS Institute, Cary, N.C.). Data were analyzed by crop and site. The data from the control (0 lb N/acre) were not included in the ANOVA. When appropriate, means were separated by the least significant difference (LSD) method and interpreted as significant when $P \leq 0.10$.

RESULTS AND DISCUSSION

The 2011 growing season was slightly drier than normal. In these experiments, corn and cotton were planted in May or June (Table 2) following above normal precipitation in April and early May, which caused widespread flooding and delayed planting. At LMCRS, total precipitation during the growing season, was 16.3 in. relative to the long-term average (1960 to 2007) of 19.7 in. (Table 3). At LMCRS, monthly rainfall was lower than normal early in the season. At NEREC, total growing season and long-term average precipitation were 11.0 and 14.2 in., respectively, and monthly rainfall was consistently lower than the long-term average. Thus, the weather conditions were not conducive for significant N loss by leaching and denitrification.

Neither N source nor the N source by rate interaction significantly influenced seedcotton yield at either site ($P \geq 0.37$). Seedcotton yields at both sites were significantly ($P < 0.0001$) increased by N fertilization (Table 4). Seedcotton yield of cotton that did not receive any N fertilizer averaged 1237 and 1731 lb/acre at the NEREC and LMCRS, respectively. At both sites application of 30 lb N/acre resulted in the lowest yield of the N-fertilized cotton. At LMCRS, seedcotton yield was maximized by application of 90 to 150 lb N/acre. At NEREC, the yield of cotton fertilized with 120 lb N/acre was significantly higher than cotton fertilized with 30 lb N/acre, but was not higher than cotton fertilized with 150 or 90 lb N/acre. The yield means for various urea-ESN combinations and rates are listed in Table 4. The low yields at NEREC are perhaps a reflection of the late planting date of June 6.

Corn grain yields were not significantly influenced by the interaction of N source and N rate at either site ($P \geq 0.37$, Tables 5 and 6). Corn grain yields at both sites were significantly influenced by N rate ($P < 0.0001$) and N source. Corn that did not receive any N fertilizer produced 46 and 29 bu/acre at LMCRS and NEREC, respectively. Averaged across all N sources, the yields of the N-fertilized corn ranged from 95 to 157 bu/acre at LMCRS (Table 5) and 67 to 139 bu/acre at NEREC (Table 6). Generally, grain yields increased as the N application rates increased, with maximal yields at both sites produced with 240 lb N/acre. Averaged across all N rates and at both sites, corn fertilized with 100% ESN-N produced higher yields than corn fertilized with 100% urea-N (Tables 5 and 6). Yield data showed a consistent trend at each site to increase numerically and sometimes statistically as the proportion of ESN-N increased from 0 to 100%. The results suggest that under the conditions of these two experiments corn uptake of N from ESN was more efficient than that of urea-N, even though weather conditions were not conducive for significant N losses from urea.

PRACTICAL APPLICATION

The summer of 2011 was drier than normal which created a field environment where minimal N loss from preplant incorporated urea was expected, especially compared to years with above average rainfall. Averaged across N sources, seedcotton yields were not different among the various combinations of urea and ESN fertilizers. However, at both sites, the yields of corn fertilized with 100% ESN-N were 7% to 10% greater than corn fertilized with 100% urea-N. Additional research on a wide range of soils and weather conditions, particularly under higher than normal rainfall, is needed to gain a better understanding of the agronomic and environmental performance of ESN in Arkansas. These results suggest that ESN is a viable N fertilizer that can be preplant incorporated for irrigated corn and cotton production in Arkansas.

ACKNOWLEDGMENTS

This research was funded by a grant from USDA CS-REES, support of Agrium Advanced Technologies, and Cotton Incorporated. We appreciate the assistance of the University of Arkansas Soil Testing and Research Laboratory staff with soil analyses.

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Table 1. Selected soil property means (0- to 6-in. depth) of samples taken before applying fertilizers to cotton and corn fertilization trials at the Lon Mann Cotton Research Station (LMCRS) and Northeast Research and Extension center (NEREC) in 2011.

			Mehlich-3-extractable nutrients						Soil physical properties			
Site ID	Soil pH[a]	Soil NO_3-N[b]	P	K	Ca	Mg	Cu	Zn	Sand	Silt	Clay	Texture
		(ppm)							(%)			
LMCRS-cotton	6.6	25	39	95	1183	205	1.0	1.0	20	60	20	silt loam
NEREC-cotton	7.0	18	62	286	3316	630	4.3	4.9	27	25	48	clay
LMCRS-corn	7.1	18	50	131	1462	330	1.7	3.0	2	70	29	silty clay loam
NEREC-corn	6.7	14	46	169	2303	467	3.1	4.7	44	20	36	clay loam

[a] Soil pH was measured in a 1:2 (weight:volume) soil-water mixture.
[b] NO_3-N measured by ion-specific electrode.

Table 2. Selected agronomically important information for corn and cotton N fertilization trials established at the Lon Mann Cotton Research Station (LMCRS) and Northeast Research and Extension Center (NEREC) during 2011.

Site ID	Previous crop	Cultivar	Planting date	N application date	Harvest date
LMCRS-cotton	fallow	Stoneville 4288	26 May	25 May	11 Oct
NEREC-cotton	soybean	Stoneville 5458	6 June	6 June	12 Oct
LMCRS-corn	soybean	Pioneer 31P42	12 May	10 May	4 Oct
NEREC-corn	soybean	Pioneer 31P52	3 June	19 May	26 Sep

Table 3. Average rainfall by month in 2011 and the long-term monthly mean rainfall (1960-2007, average) at the Lon Mann Cotton Research Station (LMCRS) and Northeast Research and Extension Center (NEREC).

		Precipitation					
Site ID	Precipitation	May	June	July	August	September	Total
		(in.)					
LMCRS[a]	2011	3.0	3.3	4.4	3.4	2.2	16.3
LMCRS	Average[b]	5.9	3.9	3.9	2.8	3.2	19.7
NEREC[c]	2011	-	3.6	3.4	1.2	2.2	11.0
NEREC	Average	-	3.9	3.7	2.9	3.7	14.2

[a] At LMCRS, cotton and corn were planted on 25 May and 12 May, respectively.
[b] Long-term average for 1960 to 2007.
[c] At NEREC, cotton and corn were planted on 6 June and 3 June, respectively.

Table 4. Seedcotton yield as affected by the non-significant (*P* > 0.10 N) N source and N source by rate interaction and significant (*P* < 0.0001) N rate effect, averaged across N sources, for two cotton N fertility experiments conducted at the Lon Mann Cotton Research Station and Northeast Research and Extension Center in 2011.

	Seedcotton yield									
	Lon Mann Cotton Research Station					Northeast Research and Extension Center				
	N fertilizer combination (%)					N fertilizer combination (%)				
N rate	100% Urea-N	50%Urea-N 50%ESN-N[a]	25% Urea-N 75% ESN-N	100% ESN-N	N rate mean	100%-N Urea-N	50%Urea-N 50%ESN-N	25% Urea-N 75% ESN-N	100% ESN-N	N rate mean
(lb N/acre)	(lb/acre)									
0	1731[b]					1237[b]				
30	2175	2187	2024	2059	2118	1438	1387	1341	1322	1372
60	2774	2529	2824	2283	2602	1488	1447	1468	1400	1451
90	3094	2990	2999	2974	3014	1353	1609	1501	1568	1515
120	2906	3050	3008	2993	2989	1528	1544	1607	1566	1561
150	2558	2846	2943	3221	2907	1549	1679	1589	1687	1619
LSD 0.10	NS[c]				172[b]	NS				69[b]
P-value	0.3760				<0.0001	0.6927				<0.0001

[a] ESN, Environmentally Smart N, polymer coated urea.
[b] The LSD value to compare means among N rates from 30 to 150 lb N/acre. The 0 lb N/acre treatment was not included in the statistical analysis.
[c] NS, not significant (*P* > 0.10).

Table 5. Corn grain yield as affected by the non-significant (*P* > 0.10 N) N source by rate interaction and significant N source (*P* = 0.09) and (*P* < 0.0001) N rate effects for a corn N fertility experiment conducted at the Lon Mann Cotton Research Station in Marianna during 2011.

	Corn grain yield						
	N fertilizer combination						
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 combination	N Source mean
(lb N/acre)	(bu/acre)						
0	46					None	46
60	98	79	102	102	95	100% Urea-N	127
120	115	122	128	128	123	50%Urea-N, 50%ESN-N	132
180	135	148	144	152	144	25% Urea-N,75% ESN-N	137
240	131	160	145	159	148	100% ESN-N	140
300	150	154	165	159	157		
LSD 0.10	NS[b]				11[c]	LSD 0.10	10[c]
P-value	0.6617				<0.0001	*P*-value	0.0938

[a] ESN, Environmentally Smart N, polymer coated urea.
[b] NS, not significant (*P* > 0.10).
[c] LSD value compares the yield of treatments that received N.

Table 6. Corn grain yield as affected by the non-significant ($P > 0.10$ N) N source by rate interaction and significant N source ($P = 0.0483$) and ($P < 0.0001$) N rate effects for a corn N fertility experiment conducted at the Northeast Research and Extension Center in 2011.

	Corn grain yield						
	N fertilizer combination						
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 combination	N Source mean
(lb N/acre)	(bu/acre)						
0	29					None	29
60	67	68	64	71	67	100% Urea-N	113
120	105	103	117	117	110	50%Urea-N, 50%ESN-N	111
180	123	126	123	137	127	25% Urea-N,75% ESN-N	118
240	139	122	132	140	134	100% ESN-N	121
300	129	136	145	145	139		
LSD 0.10	NS[b]				8[c]	LSD 0.10	7[c]
P-value	0.6334				<0.0001	*P*-value	0.0483

[a] ESN, Environmentally Smart N, polymer coated urea.
[b] NS, not significant ($P > 0.10$).
[c] LSD value compares the yields of treatments that received N.

Corn Response to Soil Applied Phosphorus and Potassium Fertilizer in Arkansas

M. Mozaffari, N.A. Slaton, S. Hayes and B. Griffin

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Corn (*Zea mays* L.) has become an important crop in Arkansas in the past decade. In 2010, approximately 390,000 acres of corn were harvested in Arkansas. Phosphorus (P) and potassium (K) both play important roles in many plant physiological processes. Corn yield in many agricultural soils may be limited by P and/or K deficiency. Applying the right rate of P or K fertilizer to corn will enable the growers to maximize net returns from fertilization. Unfortunately, very little information is available describing corn response to P and K fertilization under current Arkansas production practices and the limited data that is available is based on a modified (1:7) Mehlich-3 test which is no longer in use. In 2010, we initiated replicated field experiments to evaluate corn response to P and K fertilization under current Arkansas crop production practices. The reliability and applicability of such information will increase if the studies are conducted on a range of soils with various levels of Mehlich-3 extractable nutrients (e.g., P and/or K), pH and other properties. Thus, the specific objectives of this research were to evaluate the effect of soil-applied P or K fertilizer rates on corn ear-leaf P or K concentration at silking and grain yield.

PROCEDURES

Phosphorus Experiments

Five replicated P fertilization trials were conducted at the Lon Mann Cotton Research Station in Lee County (LEZ11), Rohwer Research Station in Desha County (DEZ11), and three commercial fields in Clay County (CLZ11), Chicot County (CHZ11), and Prairie County (PRZ11) on soils typically used for corn production in Arkansas. Prior to P application, soil samples were taken from the 0- to 6-in. depths and composited by replication. 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 (weight: volume) soil-water mixture and particle size analysis was performed by the hydrometer method (Arshad et al., 1996).

Selected agronomically important information is listed in Table 1. Phosphorus application rates ranged from 0 to 160 lb P_2O_5/acre in 40 lb/acre increments as triple superphosphate. The experimental design was a randomized complete block where each treatment was replicated five to six times. Phosphorus treatments were applied onto the soil surface in a single application either before planting (PRZ11) or shortly after crop emergence (CHZ11, ClZ11, DEZ11, and LEZ11). At PRZ1, the P fertilizer was mechanically incorporated, beds were pulled and then corn was planted on slightly raised beds. Blanket applications of muriate of potash, urea, and $ZnSO_4$ were made to supply 80 to 100 lb K_2O, 280 to 310 lb N/acre, ~5 lb S, and ~10 lb Zn/acre, respectively. All experiments were fertilized with a total of 280 to 310 lb N/acre as urea or urea ammonium nitrate (28% or 32% N) in two or three split applications (at preplant, 4- to 6-leaf stage, and pre-tassel) depending on the location. Corn was grown on beds and furrow irrigated as needed by the cooperating grower or research station staff. Experimental plots were 25-ft long and 10- to 12.6-ft wide allowing for four rows of corn spaced 30 or 38 in. apart, depending on the location. Corn management closely followed University of Arkansas Cooperative Extension Service recommendations for irrigated corn.

When corn was at the early- to mid-silk stage, corn ear-leaf samples were collected from 8 to 10 plants/plot, dried in an oven at 70 ºC to a constant weight, and ground to pass through a 60-mesh sieve and P concentration in the leaf was measured following digestion (Jones and Case, 1990). The middle two rows of each plot were harvested either with a plot combine or by hand with harvested ears placed through a combine later. The calculated grain yields were adjusted to a uniform moisture content of 15.5% for statistical analysis.

Potassium Experiments

Four replicated field experiments were conducted in Chicot (CHZ14), Clay (CLZ12), Desha (DEZ12), and Prairie (PRZ12) counties adjacent to the P studies described above. The agronomic information for K trials is the same as described for the P trials (Table 1). Prior to K application, soil samples were taken from the 0- to 6- and 6- to 12-in. depths and processed similar to P experiments.

Potassium application rates ranged from 0 to 200 lb K_2O/acre in 40 lb K_2O/acre increments applied as muriate of potash using the same procedures outlined for the P experiments. Triple superphosphate and $ZnSO_4$ were broadcast to supply 80 lb P_2O_5, ~10 lb Zn, and ~5 lb S/acre. At DEZ12, 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 three locations, plots were 25-ft long and either 10- or 12.6-ft wide allowing for four rows of corn planted in 38- or 30-in. wide rows. All experiments were randomized complete block designs and each treatment was replicated six times.

Analysis of variance was performed using the GLM procedure of SAS (SAS Institute, Cary, N.C.). Each experiment was analyzed separately. When appropriate, significant differences among means were separated by the least significant difference method (LSD) with significance interpreted at the 0.10 level. If corn responded positively to a nutrient application, we investigated the relation between the nutrient application rate and grain yield or compared the mean of control (0 fertilizer) to the mean of all of the fertilized treatments.

RESULTS AND DISCUSSION

Phosphorus Experiments

For the P trials, the soil pH ranged from 6.3 to 7.4 and Mehlich-3 extractable P ranged from 20 to 51 ppm (Table 2). According to the current University of Arkansas Cooperative Extension Service fertilizer recommendations the soil-test P level was Above Optimum (>50 ppm) at CHZ13, Optimum (36 to 50 ppm) at CLZ11 and PRZ1, Medium (26 to 35 ppm) at DEZ11 and Low (16 to 25 ppm) at LEZ11. Soils with 'Low', 'Medium', and 'Optimum' soil-test P levels receive a recommendation for 100, 75, and 0 lb P_2O_5/acre, respectively.

Phosphorus fertilization significantly (P = 0.084) increased corn ear-leaf P concentration at LEZ11 and DEZ11 (Table 3), which had Low or Medium soil-test P levels, respectively (Table 2). At these sites, leaf P concentration in corn fertilized with 160 lb of P_2O_5/acre was significantly higher than corn fertilized with ≤40 lb of P_2O_5/acre. Leaf P concentration in corn fertilized with no P ranged from 0.27% to 0.36% and in corn treated with 160 lb P_2O_5/acre, ranged from 0.30% to 0.38% relative to a critical P concentration of 0.25% (Campbell and Plank, 2000). Corn grain yields were not significantly influenced by P fertilization at any of the sites (Table 3). Grain yield of the corn fertilized with 0 and 160 lb P_2O_5/acre ranged from 147 to 179 and 149 to 186 bu/acre, respectively. Lack of response to P fertilization at CHZ13, CLZ11, and PRZ11, which had Medium or Above Optimum soil-test P levels, is consistent with the current University of Arkansas Cooperative Extension Service corn fertilization recommendations and interpretations. We expected a significant yield response to P application at LEZ11 where the corn yields in P-treated plots were numerically higher than corn that received no P. Additional tests on soils with similar soil-test P values are needed to ascertain if the lack of response to P fertilization at LEZ11 was an anomaly or our interpretation of soil-test P needs to be changed.

Potassium Experiments

Soil pH in the 0- to 6- and 6-to 12-in. depths ranged from 6.6 to 7.5 (Table 4). The Mehlich-3 extractable K in the 0- to 6-in. depth ranged from 83 to 120 ppm (Table 4). According to the University of Arkansas soil-test interpretation, soil-test K was 'Low' (61 to 90 ppm) at CLZ12 and 'Medium' (91 to 130 ppm) at the other three sites. Current fertilization guidelines recommended 110 and 75 lb K_2O/acre for 'Low' and 'Medium' soil-test K levels, respectively, for corn with a yield goal of 175 bu/acre. Soil-test K in the 6- to 12-in. depth ranged from 38 to 97 ppm, and was numerically lower than in the 0- to 6-in. depth at each site. This was expected since K leaching in these soils is expected to be very minimal.

Corn ear-leaf K concentration was significantly increased by K application at CLZ12 and DEZ12 (Table 5), the two sites with the lowest surface and subsoil K concentrations (Table 4). Potassium application did not significantly increase the ear-leaf K concentration at CHZ12 and PRZ12, the two sites with highest Mehlich-3 extractable K (Table 5). Ear-leaf K concentration in corn fertilized with no K ranged from 1.12% to 1.79% K and in corn fertilized with 200 lb K_2O/acre ranged from 1.60% to 2.17% K. Corn ear-leaf concentrations < 1.80% K indicate possible K deficiency (Campbell and Plank, 2000). Based on this suggested critical K concentration, positive yield increases from K fertilization would have been expected at all sites except PRZ12 and perhaps CLZ12. Application of 40 and 160 lb K_2O/acre increased the ear-leaf K concentrations to the sufficiency level at CLZ12 and DEZ12, respectively.

Grain yield of corn that did not receive any K ranged from 124 to 184 bu/acre. Potassium fertilization significantly affected corn grain yield at CLZ12 (Table 5), the site with lowest level of Mehlich-3 extractable K (Table 4), but the increase was not consistent among K fertilizer rates. There was no significant linear or quadratic trends between the K application rates and corn grain yield (P > 0.1). The mean yield of the corn from the control plot (0 lb K_2O/acre) was not significantly different (P > 0.1) than the mean yield of all of the fertilized treatments (40 to -200 lb K_2O/acre). The lack of a positive grain yield response to K fertilization at sites CHZ14 and PRZ12, which had a Medium soil-test K level, was not unexpected and is consistent with the current University of Arkansas Cooperative Extension Service interpretation of Mehlich-3 extractable K for corn production.

PRACTICAL APPLICATIONS

The 2010 and 2011 results have shown that corn yield has not responded positively to P fertilization when Mehlich-3 extractable P was 'Above Optimum' (>50 ppm, four sites), 'Optimum' (36 to 50 ppm, two sites), 'Medium' (26 to 35 ppm, two sites), or 'Low' (16 to 25 ppm, one site). In the K fertilization trials, corn has responded positively to K fertilization in four of eight trials. Corn did not respond to K fertilization at three sites with 'Medium' soil-test K and one site with 'Low' soil-test K. Positive responses have occurred on soils with Very Low (1), Low (2), and 'Optimum' soil-test K values. In general, our results suggest that current University of Arkansas Cooperative Extension Service soil-test-based P and K fertilizer recommendations are able to predict soils that need no P accurately, but sites with lower soil-test P need to be evaluated. Potassium recommendations for corn, need further evaluation, as there appears to be some variability in the measured responses.

ACKNOWLEDGMENTS

We appreciate the financial support of the Arkansas Corn and Grain Sorghum Promotion Board. Many thanks to Davis Bell, Bruce Bond, and Keith Woolverton for allowing us to conduct experiments on their farms. The assistance of the staff of the University of Arkansas Soil Testing and Research Laboratory in Marianna with laboratory analyses is greatly appreciated.

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Table 1. Soil series, previous crop, corn hybrid, and planting, fertilizer application, leaf sampling and harvest dates for P and K fertilization trials conducted in Chicot (CHZ13), Clay (CLZ11), Desha (DEZ11), Lee (LEZ11), and Prairie (PRZ11) counties during 2011.

Site ID	Soil series	Previous crop	Hybrid	Planting date	Fertilizer application date	Ear-leaf sampling date	Harvest date
CHZ13	Gallion silt loam	soybean	Pioneer 1656	18 April	4 April	17 June	29 July
CLZ11	Falaya silt loam	soybean	DeKalb 6696	15 May	2 June	18 July	26 Aug
DEZ11	Sharkley and Desha clay	sorghum	Pioneer 1615HR	13 April	5 May	7 July	2 Sep
LEZ11	Calloway silt loam	soybean	Pioneer 31P42	9 May	26 May	13 July	23 Aug
PRZ11	Calloway silt loam	soybean	DeKalb 6482	9 April	8 April	6 June	8 Aug

Table 2. Selected mean properties of soil collected from the 0- to 6-in. depth, before P-fertilizer application, for five P fertilization trials established in Chicot (CHZ13), Clay (CLZ11), Desha (DEZ11), Lee (LEZ11), and Prairie (PRZ11) counties during 2011.

		Mehlich-3-extractable nutrients							Soil physical properties			
Site ID	Soil pH[a]	P[b]	K	Ca	Mg	Mn	Cu	Zn	Sand	Silt	Clay	Texture
		(ppm)							(%)			
CHZ13	7.3	51	147	3174	679	70	2.4	2.7	24	34	42	clay
CLZ11	7.0	48	98	1114	313	235	1.4	5.6	12	67	21	silt loam
DEZ11	6.6	31	187	2391	689	106	2.2	2.0	6	50	44	silty clay
LEZ11	6.3	20	69	971	223	173	1.1	5.1	5	80	15	silt loam
PRZ11	7.4	37	121	1803	219	230	1.6	5.0	18	58	24	silt loam

[a] Soil pH was measured in a 1:2 (weight:volume) soil-water mixture.
[b] Standard deviation of soil-test P means: 6 ppm for CHZ13, 3 ppm for CLZ11, 6 ppm for DEZ11, 5 ppm for LEZ11, and 9 ppm for PRZ11.

Table 3. Effect of P fertilization rate on ear-leaf P concentration at the silking stage and corn grain yield in five P fertilization trials conducted in Chicot (CHZ13), Clay (CLZ11), Desha (DEZ11), Lee (LEZ11), and Prairie (PRZ11) counties during 2011.

	CHZ13		CLZ11		DEZ11		LEZ11		PRZ11	
P rate	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)	(%)	(bu/acre)	(%)	(bu/acre)	(%)	(bu/acre)	(%)	(bu/acre)	(%)	(bu/acre)
0	0.27	147	0.36	168	0.27	148	0.31	179	0.32	174
40	0.29	159	0.35	187	0.27	153	0.33	188	0.31	186
80	0.28	152	0.37	171	0.28	152	0.37	186	0.33	184
120	0.29	141	0.37	174	0.28	150	0.37	181	0.30	176
160	0.30	149	0.37	183	0.30	150	0.38	186	0.30	182
CV[a]	9	15	6	10	6	9	12	6	11	9
P value	0.4065	0.7733	0.4754	0.6637	0.0849	0.9775	0.0842	0.7175	0.6827	0.6136
LSD 0.10[b]	NS[c]	NS	NS	NS	0.02	NS	0.04	NS	NS	NS

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

Table 4. Selected properties of soil taken from the 0- to 6- and 6- to12-in. depths before K-fertilizer application for four K fertilization trials conducted in Chicot (CHZ14), Clay (CLZ12), Desha (DEZ12), and Prairie (PRZ12) counties during 2011.

Site	Sampling	Soil	Mehlich-3-extractable nutrients							Soil physical properties			
ID	depth	pH[a]	P	K[b]	Ca	Mg	Mn	Cu	Zn	Sand	Silt	Clay	Texture
	(in.)		(ppm)							(%)			
CHZ14	0-6	7.3	57	112	2366	533	69	2.2	3.1	34	35	32	clay loam
CHZ14	6-12	7.3	52	97	2387	501	59	2.3	2.9	33	37	31	clay loam
CLZ12	0-6	6.7	33	83	1132	310	267	1.4	5.3	4	73	23	silt loam
CLZ12	6-12	6.6	15	38	798	265	159	1.2	2.2	1	76	23	silt loam
DEZ12	0-6	6.6	38	95	960	144	142	1.1	0.3	6	50	44	silty clay
DEZ12	6-12	6.7	17	58	1321	188	97	1.1	1.1	-	-	-	-
PRZ12	0-6	7.5	43	120	1835	210	213	1.6	5.4	17	61	21	silt loam
PRZ12	6-12	7.5	13	52	1599	155	266	1.1	2.5	15	60	24	silt loam

[a] Soil pH was measured in a 1:2 (weight:volume) soil-water mixture.
[b] Standard deviation of soil-test K in the 0- to 6- and 6- to 12-in. depths: 11 and 12 ppm for CHZ14; 17 and 3 ppm for CLZ12; 20 and 9 ppm for DEZ12; and 10 and 7 ppm for PRZ12, respectively.

Table 5. Effect of K fertilization rate on corn ear-leaf K concentration at the silk stage and grain yield in four K fertilization trials conducted in Chicot (CHZ14), Clay (CLZ12), Desha (DEZ12), and Prairie (PRZ12) counties during 2011.

	Chicot County (CHZ14)		Clay County (CLZ12)		Desha County (DEZ12)		Prairie County (PRZ12)	
K rate	Leaf K	Grain yield	Leaf K	Grain yield	Leaf K	Grain yield	Leaf K	Grain yield
(lb K_2O/acre)	(%)	(bu/acre)	(%)	(bu/acre)	(%)	(bu/acre)	(%)	(bu/acre)
0	1.48	137	1.70	124	1.12	171	1.79	184
40	1.59	134	1.94	136	1.42	172	1.67	167
80	1.65	145	2.05	127	1.47	177	1.79	165
120	1.56	147	2.05	123	1.67	167	1.90	180
160	1.63	141	2.09	119	1.79	166	1.87	171
200	1.60	135	2.17	136	1.82	175	1.96	184
CV[a]	8	13	7	5	8	9	14	12
P value	0.3184	0.8717	<0.0001	0.0023	<0.0001	0.8353	0.4179	0.6338
LSD 0.10[b]	NS[c]	NS	0.14	6.9	0.12	NS	NS	NS

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

Utilization of the Dark Green Color Index to Determine Cotton Nitrogen Status

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Inadequate or excessive applications of fertilizer N in cotton (*Gossypium hirsutum* L.) are financially and environmentally costly. Timely in-season determination of the N nutritional status of cotton can help producers combat these negative effects; however, current methods of N determination are often time consuming and/or expensive. More instantaneous, accurate methods of determining N status, which utilize equipment already in the possession of the producer, are needed. Recent work utilizing an inexpensive digital camera and image processing software to calculate the dark green color index (DGCI) has resulted in successful determination of corn and turf N status (Karcher and Richardson, 2003; Rorie et al., 2011). The objective of this research was to examine the effectiveness of the DGCI derived from standard digital photographs and image-analysis software to determine the N status of cotton and to compare sensitivities of calculated DGCI from laboratory, field nadir, and field off-nadir photographs to measurements of leaf N concentrations from laboratory and chlorophyll meter determinations.

PROCEDURES

Sampling was conducted on the field trial described by Mozaffari et al. (2012). The trial was planted with Stoneville 4288 on 27 May 2011 at the Lon Mann Cotton Research Station near Marianna, Ark. Fertilizer N rates included 0, 30, 60, 90, 120, and 150 lb N/acre as urea applied in a single preplant application and incorporated to create a wide range of plant N status. For a full description of the trial, refer to Mozaffari et al. (2012). Leaf sampling, chlorophyll meter readings and digital pictures were taken at the third week of flowering. Field nadir and field off-nadir (approximately 60° from nadir) pictures were taken of the canopy with an inexpensive digital camera (Canon PowerShot SD450, Lake Success, N.Y.) against a neutral pink color board that included yellow and green disks which served as interval color standards (Fig. 1). Two most recently matured, fully expanded leaves 4 to 6 nodes from the terminal were sampled and placed on ice. Chlorophyll meter (Minolta SPAD-502, Konica Minolta Sensing, Inc., Tokyo, Japan) measurements and pictures of the leaf samples were taken indoors under fluorescent lighting against a standardized color board (referred to as laboratory DGCI) within 2 hours of sampling (Fig. 2). Leaf samples were dried and ground to pass a 20-mesh sieve and leaf N concentration of the ground sample was determined by dry combustion (ELEMENTAR Rapid N, ELEMENTAR Analysensysteme, Hanau, Germany) by the Agricultural Diagnostic Laboratory at the University of Arkansas in Fayetteville, Ark.

Images were processed using SigmaScan Pro v. 5.0 (Systat Software, Inc., Chicago, Ill.). This software normalized each image using internal color standards prior to the calculation of DGCI. A full description of the DGCI calculation used can be found by Rorie et al. (2011). Images were manually cropped and cleaned to eliminate noise in analysis. Linear regressions of the replicate data examining the relationships between DGCI measurements (field nadir, field off-nadir, and laboratory), SPAD readings, and leaf N concentrations were performed in JMP 9 (SAS Institute Inc., Cary, N.C.).

RESULTS AND DISCUSSION

Visible differences in N status due to treatment were noted at sampling; cotton receiving 0 lb N/acre appeared stunted and yellow in color, while cotton receiving 150 lb N/acre appeared much larger and dark green in color (Fig. 1). The regressed replicate data indicated the response of leaf N concentration to fertilizer N rate was significant, positive and linear (r^2 = 0.55, data not shown) and measured leaf N values reached and exceeded published critical values (Bell et al., 2003).

Field nadir and off-nadir DGCI readings did not correlate as strongly to leaf N as laboratory DGCI readings (Fig. 2). The laboratory DGCI readings were also slightly more sensitive to leaf N (r^2 = 0.603) than SPAD readings were to leaf N (r^2 = 0.561, not shown). Coefficients of determination with leaf N ranged from 0.44 for the nadir DGCI readings to 0.603 for the laboratory DGCI readings. Stronger relationships between laboratory DGCI readings and leaf N than between all other methods may be due to the laboratory method's inclusion of all plant material used to determine leaf N concentration. In contrast, the SPAD meter measured only a portion of each leaf and the field nadir and off-nadir methods included upper canopy plant material which was not in the leaf N measurement.

The relationship between nadir laboratory DGCI readings and SPAD readings was strong (Fig. 2). This strong relationship is logical, as both measurements are conducted on the same tissue. Failure of the field nadir and off-nadir DGCI readings to correlate as strongly with SPAD readings is again most likely due to the inclusion of tissue in the field images that was not actually sampled by the SPAD meter. However, the relationship between SPAD readings and field off-nadir DGCI readings was also quite strong ($r^2 = 0.818$). These results suggest that field off-nadir images may be the most practical method for in-field determination of cotton N status since the relationship between laboratory DGCI readings and SPAD readings was only slightly higher but consisted of leaf sampling, storing, transportation, and more required time than other methods.

PRACTICAL APPLICATIONS

The objective of this research was to examine the effectiveness of DGCI derived from standard digital photographs and image-analysis software to determine cotton N status, and to compare sensitivities of calculated DGCI from laboratory, field nadir, and field off-nadir photographs to changes in leaf N and SPAD readings. Initial results indicate digital image analysis as a practical and inexpensive method sensitive to cotton N status which could possibly replace chlorophyll meters. Although laboratory images are the most sensitive to changes in leaf N and SPAD readings, field off-nadir images seem to be the most practical method of cotton N status determination for the producer since it requires no destructive sampling and much less time. Further research across years and sites is necessary to establish critical DGCI values for cotton and streamline the image processing. An effective extension program could be easily set up to allow producers to email or picture message off-nadir images of the crop of interest with a standardized color board for instantaneous determination of cotton N status.

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Fig. 1. Field off-nadir images of plots recieving 150 lb N/acre (LEFT) and 0 lb N/acre (RIGHT) with standardized color board in the background. Standardized color board consists of a dark green and yellow color chip on a neutral pink background to allow the normalization of each image during analysis. The high N rate treatment was taller and visibly darker green than 0 lb N/acre treatment.

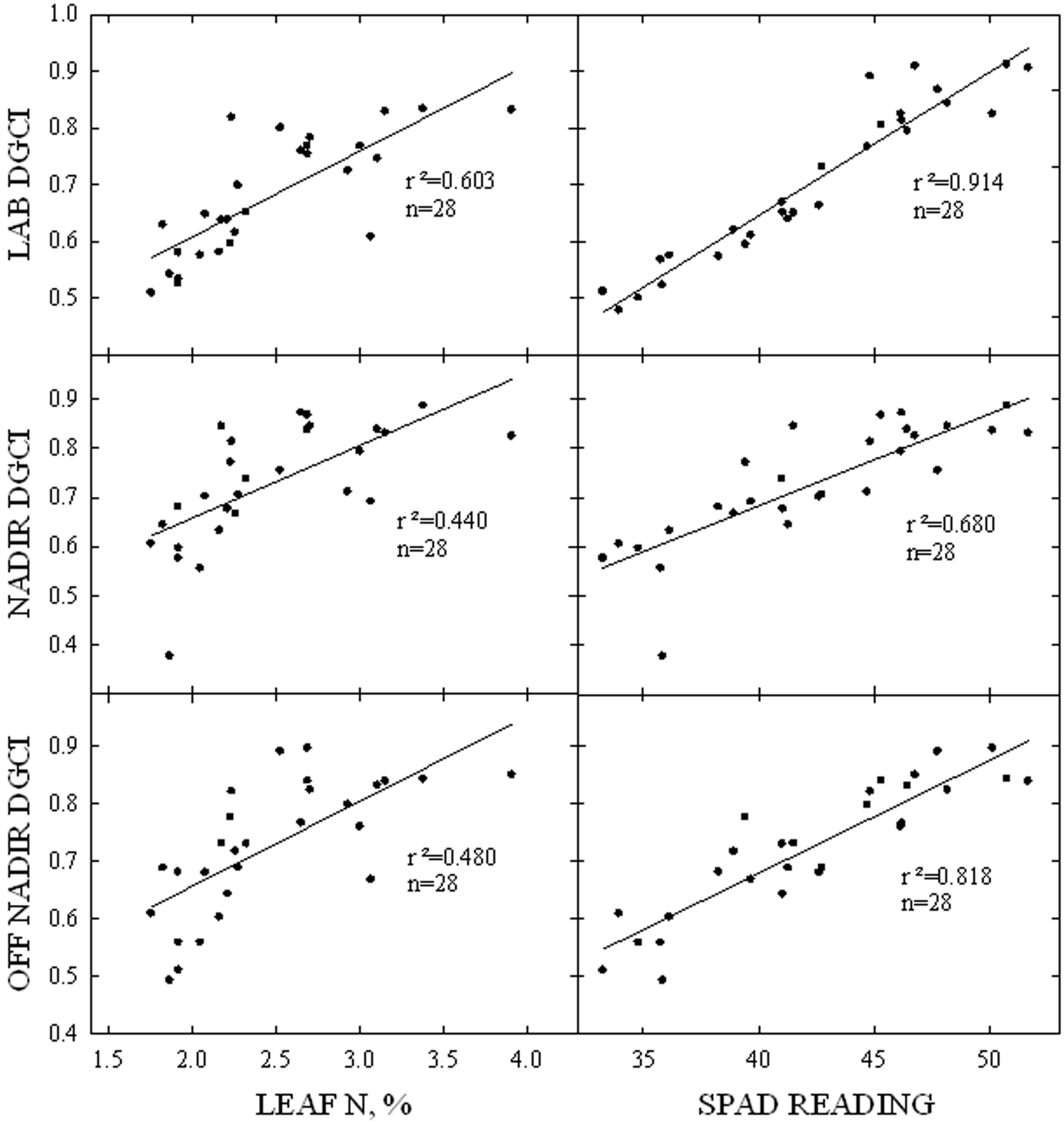

Fig. 2. Simple linear regression and coefficients of determination between laboratory DGCI, field nadir DGCI, field off-nadir DGCI, and leaf N or SPAD readings during 2011 at the third week of flower near Marianna, Ark.

Wheat and Double-Crop Soybean Yield Response to Phosphorus and Potassium Fertilization

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Soft red winter wheat (*Triticum aestivum* L.) is grown in rotation with soybean [*Glycine max* (L.) Merr.] and grain crops in Arkansas. Farmers often examine crop and production input prices when deciding whether to grow wheat and follow with double-cropped soybean or grow full-season soybean. The most recent statistics including double-crop soybean production show 610,000 to 750,000 acres were harvested in 2007 and 2008, respectively, with average yields of 33 to 34 bu/acre (USDA-NASS, 2008). Double-crop soybean accounted for about 22% of the Arkansas soybean acres and 75% to 87% of the harvested wheat acres.

The influence that wheat has on the phosphorus (P) and potassium (K) nutritional requirements and yield potential of the following soybean crop are of interest since fertilizer costs and yield potential are important components of farm profitability. Our primary objectives were to determine wheat grain yield response to P and K fertilization rate, evaluate how nutrient uptake and removal of wheat grown for grain influences soybean response to P and K fertilization, evaluate soybean response to fall and spring fertilizer application, and compare soil-test P and K values from samples collected at three different times.

PROCEDURES

In fall 2010, trials were established at the Lon Mann Cotton Research Station (LMCRS) on a Convent silt loam following irrigated soybean and the Pine Tree Research Station (PTRS) on a Calhoun silt loam following dryland soybean, which were not harvested. Each site had two adjacent plot areas designated for the P or K trial. Each experiment contained three factors including fertilizer rate (0, 50, 100, and 150 lb K_2O/acre or 0, 40, 80, and 120 lb P_2O_5/acre), P and K application time (fall, before planting wheat; or spring, after wheat harvest) and wheat management (cover crop or grain). Wheat grown as a cover crop received no N fertilizer and was killed with glyphosate, applied with a rolling applicator, in March 2011. Each trial contained 16 treatments arranged as a randomized complete block (RCB) design with a 4 (rate) by 2 (time) by 2 (wheat) factorial arrangement in each of five blocks.

Two composite soil samples (0- to 4-in. depth) were taken in each block from the plots designated to receive no fertilizer with different wheat management practices (cover crop or wheat for grain) to determine mean soil chemical properties. Soil samples were collected from these plots in the fall when wheat was planted, in March, and in June, following wheat harvest. For the June sampling, composite samples were also collected from two additional plots in each block which included plots that received 80 lb P_2O_5 or 100 lb K_2O/acre from each of the wheat management treatments. Soil was oven-dried at 130 °F, crushed, and passed through a 2-mm sieve for measurement of Mehlich-3 extractable nutrients, organic matter by weight loss on ignition, and soil water pH. Mean values of selected soil chemical properties are listed in Table 1.

'AgriPro Beretta' wheat was drill-seeded (100 to 120 lb seed/acre) into conventionally tilled seedbeds on 18 October at PTRS and 1 November at LMCRS. Individual plots were 20-ft long and 13-ft wide at the PTRS and 22-ft long by 12.7-ft wide at LMCRS with 7.5- and 7.0-in. wide rows, respectively.

Fertilizer treatments were broadcast by hand to the soil surface of each plot within 1 to 3 days after planting wheat for fall applications and on 8 June for spring applications following wheat harvest on 7 June. Each P rate trial included the rates of 0, 40, 80, and 120 lb P_2O_5/acre applied as triple superphosphate. Potassium fertilizer (100 lb muriate of potash/acre) was broadcast-applied to P trials on the same date as fall and spring treatments were applied to ensure that K was not yield limiting. A total of 140 lb N/acre was applied as urea in two equal splits made on 22 and 23 February and 22 and 23 March. At maturity, grain yields were measured by harvesting all 16 rows of each plot with a small-plot combine at PTRS and 8 rows at LMCRS. Grain yields were adjusted to a uniform moisture content of 13%.

Soil-test data were subjected to two analysis of variance (ANOVA) procedures. First, data collected at three different times from plots receiving no fertilizer and subjected to different wheat stand management practices (cover or grain) were analyzed as a RCB with a split-plot structure where sample time was the subplot. The objective of this analysis was to determine how wheat management influenced soil-test parameters across time. The second ANOVA was to evaluate how wheat management and nutrient rate influenced soil-test parameters from samples collected in June 2011.

Wheat yield data was analyzed as a RCB design of four nutrient rates with each trial having five blocks. Wheat growing in plots that were to receive P or K fertilizer after wheat harvest were considered as extra observations (n = 20) of 0 lb P_2O_5 or K_2O/acre. Thus, mean yields were based on either five (50, 100, and 150 lb lb K_2O or 40, 80, or 120 lb P_2O_5/acre) or 25 (0 lb P_2O_5 or K_2O/acre) observations. All ANOVA was performed with the Proc Mixed procedure in SAS v9.1 (SAS Institute, Inc., Cary, N.C.). When appropriate, mean separations were performed using Fisher's Protected Least Significant Difference method at a significance level of 0.10.

Soybean (Armor 48-R40) was seeded in 15- or 38-in. wide rows on 8 June at the PTRS and LMCRS, respectively, into untilled seedbeds following wheat harvest. At LMCRS, soybean was planted in twin rows on top of the existing beds. At PTRS, the research areas were flush irrigated immediately after planting and then received 1.1 in. of rain (total for 11 and 13 June rainfall) resulting in poor stand establishment in some plots and requiring that soybean be replanted on 23 June. The post-wheat-harvest P and K fertilizer applications were made following wheat harvest and soil sample collection as described previously. Soybean was irrigated and treated for pests as needed during the season. Recently matured trifoliate leaf samples were collected (15/plot) at the R2 stage, dried, ground, digested, and analyzed for nutrient concentrations. Tissue analysis results are not complete and will not be summarized in this report. The treatment structure of the soybean trials was a split-split plot where nutrient rate was the whole plot, fertilizer application time was the subplot, and wheat management was the sub-subplot. Soybean receiving no P or K fertilizer (control) was not included in the ANOVA, which was performed by site using the same procedures and interpretation parameters as described for soil and wheat. Single-degree-of-freedom contrasts were used to compare the yield of soybean receiving no fertilizer against the average yields produced by the two highest fertilizer rates to assess whether P or K fertilization had any overall benefit to yield.

RESULTS AND DISCUSSION

Site Descriptions

The soil-test P level associated with the average Mehlich-3 extractable P at each site was classified as 'Very Low' (<16 ppm) at PTRS-P and 'Medium' (26 to35 ppm) at LMCRS-P (Table 1). Based on the University of Arkansas Cooperative Extension Service fertilizer guidelines for winter wheat, 100 and 50 lb P_2O_5/acre would have been recommended for the Very Low and Medium soil-test P levels with little or no yield increase expected at LMCRS-P. For the K trials, both sites had 'Medium' (91 to 130 ppm K) soil-test K levels and 60 lb K_2O/acre would have been recommended for wheat. A limited amount of previous research has shown little or no yield increase from K fertilization of wheat grown on soils having Medium K availability, but soybean grown following wheat is usually responsive to K fertilization.

Soil Responses to Fertilization Time, Rate, or Wheat Management

Soil response to the selected treatment variables differed between sites. For soil receiving no P fertilizer, soil-test P was not affected by sample month or wheat management at the LMCRS-P trial, but the 2-way interaction was significant at PTRS-P (Table 2). In general, mean soil-test P was similar between wheat management systems in October and March, but differed in June following wheat harvest with wheat for grain having lower soil-test P than the cover crop. This suggests that plant uptake of P reduced soil-test P. For soil-test K, the 2-way interaction was significant at both K trial sites (Table 2).

At LMCRS-K and PTRS-K, soil-test K was similar among wheat management systems for samples collected in October and March, but in June soil K was lower where wheat was grown for grain harvest suggesting significant crop uptake of K (Table 2). The general trend among all treatments was for soil-test K to be greatest in October 2010, intermediate in March 2011, and slightly lower in June 2011. The exception to this generalization occurred for the June 2011 sample for grain at LMCRS-K, which was similar to the October 2010 soil K. At PTRS-K, June soil-test K was lowest showing a decline from K uptake by wheat produced for grain and some environmental effect (e.g., soil moisture) that resulted in lower (approximately one-half the value measured in October) overall soil-test K. Soil pH (data not shown) sometimes fluctuated among sample times and wheat management systems, but the numerical differences within a trial differed by only 0.1 to 0.3 pH units.

For soil samples collected in June 2011, soil-test P and K were significantly affected by treatments only at the PTRS (Table 3). At PTRS-P, the main effect of P fertilizer rate, averaged across wheat management practices, was significant (p-value = 0.0210) with soil-test P being greater in soil amended with 80 lb P_2O_5/acre (17 ppm) compared to soil receiving no P fertilizer (10 ppm). The two-way interaction significantly influenced soil-test K at PTRS-K. Overall, the results indicate that fertilization increased soil-test K and wheat production for grain lowered soil-test K.

Wheat Response to Fertilization

Single-degree-of-freedom contrasts showed that there was no yield benefit from P or K fertilization at LMCRS or PTRS (Table 4). At LMCRS-P, the model showed a significant effect of P rate on yield, but the yields among P rates followed no consistent pattern suggesting the measured yield differences were due to some source of variability within the trial. The lack of positive yield increases from fertilization on soils having Medium soil-test P and K was not surprising, but the absence of a yield increase from P fertilization at the PTRS soil was unexpected as soil-test P was Very Low (Table 1).

Soybean Response to Fertilization

Single-degree-of-freedom contrasts showed no benefit from P (P = 0.2482) or K (P = 0.8887) fertilization, averaged across all other variables, at LMCRS, but both nutrients increased ($P < 0.05$) yields by 2 to 3 bu/acre at the PTRS. The ANOVA showed similar responses for each nutrient within each location. In all four trials, the main effect of wheat management influenced soybean yield with greater yields produced following wheat produced for grain (Table 5). We expect that this was from better soybean stands where wheat was harvested for grain because the planting equipment used at each site had a deeper and more uniform seeding depth in the harvested wheat stubble. The soil where wheat was grown as cover crop and killed was too dry and hard for good seed-to-soil contact.

Yields of the soybean receiving no P or K are included in Table 6 as a reference but were not included in the ANOVA. Other than wheat management (Table 5), soybean yields in the P and K trails at LMCRS were not affected by treatments or treatment combinations involving P or K fertilization rate or application time. At the PTRS, the fertilizer application rate by time interaction was significant in both nutrient trials (Table 6). No clear pattern could be distinguished among the treatments, but there was a tendency for yields to be more consistent and slightly higher across the low and moderate fertilizer rates when fertilizer was applied in the spring after wheat harvest. The exception was that yields were greatest overall when the highest P or K fertilizer rates were applied in the fall. Sites that show greater overall response to P and K fertilization would aid in differentiating the best times to apply fertilizer.

PRACTICAL APPLICATION

The first year of research on this project showed that wheat growth and time of soil sampling can both have a significant influence on soil-test P and K, with the greatest changes in soil-test K. However, the effects of time and wheat management on soil-test P and K were not consistent across soils suggesting that other factors (e.g., clay type, soil-test level, replenishment among soil nutrient pools) influence how soil-test values change in response to nutrient removal and environmental conditions (e.g., moisture and temperature). These results reinforce the need for growers and consultants to develop sound soil sampling protocols to monitor changes across time and ensure that accurate fertilizer recommendations are generated.

Soybean growth was affected by wheat management at all sites, but the influence was associated with stand establishment more than nutrient availability. Soybean planted into an undisturbed seedbed (no-till) following wheat grown and managed for grain production produced greater yields than following wheat grown as a cover crop. No conclusion concerning the influence of wheat management on soybean P and K requirement can be finalized after the first year of research.

ACKNOWLEDGMENTS

Research was funded by grants from the Arkansas Soybean and Wheat Check-off Programs administered by the Arkansas Soybean and Wheat Research and Promotion Boards and the University of Arkansas System Division of Agriculture.

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Table 1. Selected soil chemical property means (n = 10) from soil samples collected in October 2010 in P and K fertilization trials with winter wheat and double-cropped soybean conducted at the Lon Mann Cotton Research Station (LMCRS) and the Pine Tree Research Station (PTRS) during the 2010-2011 growing season.

Site	SOM	Soil pH	P[a]	K[a]	Ca	Mg	S	Na	Fe	Mn	Cu	Zn
			Mehlich-3 extractable nutrients									
	(%)		(ppm)									
LMCRS-P	2.2	7.2	34	114	1167	260	8	38	159	99	1.5	1.7
PTRS-P	2.8	8.0	13	101	2699	301	14	39	277	146	0.9	1.5
LMCRS-K	2.3	7.1	31	107	1185	255	9	41	178	117	1.6	1.8
PTRS-K	2.7	7.9	15	112	2569	292	15	40	246	176	1.0	1.5

[a] Standard deviation of soil-test P in P trials was 4.4 ppm for LMCRS-P and 1.6 ppm for PTRS-P, and soil-test K in K trials was 7 ppm for LMCRS-K and 17 ppm for PTRS-K.

Table 2. Soil-test P and K means (for soil receiving no fertilizer) as affected by soil sample time, wheat management or their interaction at the Pine Tree Experiment Station (PTRS) and Lon Mann Cotton research Station (LMCRS) during the 2010 to 2011 growing season. Soil-test P data is from the P trials and soil-test K data is from the K trials.

		Wheat management*			
Site	Sample time	Cover crop	Grain	Cover crop	Grain
		(ppm P)		(ppm K)	
PTRS	October 2010	13.8 Aa	12.8 Aab	109 Aa	116 Aa
	March 2011	12.4 Ab	11.8 Ab	87 Ab	79 Abc
	June 2011	12.2 Ab	9.0 Bc	67 Ac	53 Bd
	p-value	0.0130		0.0303	
LMCRS	October 2010	33.0	34.2	108 Aa	106 Aa
	March 2011	32.2	33.0	94 Ab	92 Ab
	June 2011	33.0	36.8	86 Bb	106 Aa
	p-value	0.2507		0.0710	

* For data with a significant 2-way interaction, lowercase letters compare two means among soil sample times and uppercase letters compare means between wheat management systems within each sample time.

Table 3. Soil-test P and K means as affected by fertilizer rate and wheat management for soil samples collected in June 2011 at the Lon Mann Cotton Research Station (LMCRS) and Pine Tree Research Station (PTRS). Soil-test P data is from the P trials and soil-test K data is from the K trials.

		Wheat management*			
Site	Nutrient rate*	Cover crop	Grain	Cover crop	Grain
	(lb P_2O_5 or K_2O/acre)	(ppm P)		(ppm K¶)	
PTRS	0	12	9	67 A b	53 B c
	80 or 100	18	16	98 A a	69 B b
	p-value	0.8311		0.0033	
LMCRS	0	31	37	86	106
	80 or 100	34	35	86	90
	p-value	0.3583		0.3092	

* Phosphorus applied at 80 lb P_2O_5/acre and potassium applied at 100 lb K_2O/acre.
¶ For data with a significant 2-way interaction, lowercase letters compare two means among fertilizer rates and uppercase letters compare means between wheat management systems within each fertilizer rate.

Table 4. Wheat grain yield as affected by P or K fertilizer rate at the Lon Mann Cotton Research Station (LMCRS) and the Pine Tree Research Station (PTRS) during the 2010 to 2011 growing season.

	Phosphorus trials			Potassium trials	
Nutrient rate	LMCRS	PTRS	Nutrient rate	LMCRS	PTRS
(lb P_2O_5/acre)	(bu/acre)		(lb K_2O/acre)	(bu/acre)	
0	87	96	0	83	99
40	95	99	50	85	100
80	81	100	100	83	101
120	92	95	150	88	102
LSD0.10	8	NS	LSD0.10	NS	NS
p-value	0.0236	0.3238	p-value	0.8306	0.4290
C.V., %	8.6	5.3	C.V., %	11.4	4.6
SDF* contrast	0.4041	0.2314	SDF contrast	0.5556	0.1163

* SDF, single-degree-of-freedom contrast comparing the yield wheat fertilized with P (40, 80, and 120 lb P_2O_5/acre) against wheat receiving no P.

Table 5. Double-crop soybean yield as affected by the main effect of wheat management, averaged across nutrient rates and fertilizer application times, in four nutrient trials conducted at the Lon Mann Cotton Research Station (LMCRS) and Pine Tree Research Station (PTRS) in 2011.

Wheat management	LMCRS		PTRS	
	P trial	K trial	P trial	K trial
	(bu/acre*)			
Cover crop	68 b	68 b	56 b	58 b
Grain	72 a	74 a	58 a	60 a
p-value	0.0923	0.0027	0.0038	0.0699

* Means within a column followed by the same lowercase letter are different at the 0.10 level.

Table 6. Double-crop soybean yield as affected by the interaction between fertilizer rate and application time, averaged across wheat management, in P and K fertilization trials conducted at Pine Tree Research Station in 2011.

Wheat management	Potassium trial (lb K_2O/acre)				Phosphorus trial (lb P_2O_5/acre)			
	0	50	100	150	0	40	80	120
	(bu/acre)							
Fall	57*	57	56	63	56*	56	55	62
Spring		59	60	60		55	58	57
LSD0.10¶	3.5				3.5			
LSD0.10†	2.0				2.7			
p-value	0.0008				0.0174			

* Control (no P or K) plot mean yields are listed as reference values, not included in the statistical analysis.
¶ Compare two means from two different fertilizer rates.
† Compare two means between application times within the same fertilizer rate.

Soybean Response to Fertilization with Phosphorus or Potassium

N.A. Slaton, R.E. DeLong, C.G. Massey, J. Shafer, and J. Branson

BACKGROUND INFORMATION AND RESEARCH PROBLEM

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

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

PROCEDURES

Phosphorus and K fertilization trials with soybean were established at the Pine Tree Branch Station (PTRS) and Rice Research and Extension Center (RREC) during 2011. Specific soil and agronomic information for each site is listed in Table 1. Each location will be referred to by the site name listed in Table 1. Management with respect to seeding rate, irrigation, and pest control at all sites closely followed recommendations from the University of Arkansas Cooperative Extension Service. In each trial, soybean was flood irrigated as needed.

At each site, individual plots were 16- to 25-ft long by 6.5- to 24-ft wide. Before fertilizer was applied to the research tests, a composite soil sample was collected from the 0- to 4-in. depth from each replicate (n = 6-8). Soil samples were oven-dried at 130 °F, crushed, and passed through a 2-mm sieve. Soil water pH was determined in a 1:2 soil 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. More specific details of each trial are provided in the following sections.

Long-term Potassium Trial (PTRS-LT)

In 2000, a long-term K fertilization trial was established and cropped to rice at the PTRS (PTRS-LT) on a Calhoun silt loam. Soybean was grown following rice in 2011, the 12th year of the study. The annual application of muriate of potash rates from 0 to 160 lb K_2O/acre was performed on 10 May. Soil samples (0- to 4-in. depth) were collected from each plot on 22 March 2011 and processed as described previously. Boron (1 lb B/acre as granubor) and triple superphosphate (50 lb P_2O_5/acre) were broadcast applied to the research area before planting.

Rice Research and Extension Center P and K Trials

Four adjacent research areas were established at the RREC in 2007 and cropped with a rice-soybean or soybean-rice rotation in 2007 and 2008. This report contains information on plots planted to soybean in 2011 (Table 1). Soil samples were collected from each plot on 23 March 2011, processed, and analyzed as described previously. Phosphorus (triple superphosphate) or K (muriate of potash) fertilizer has been applied annually since 2007 at rates of 0, 40, 80, 120, and 160 lb P_2O_5 or K_2O/acre. Blanket applications of triple superphosphate and muriate or potash were applied to the K and P trials, respectively, to maintain sufficient soil availability of the nutrient not being studied. The trial is a randomized complete block design with six blocks of each nutrient rate. The soil-test and yield data included in this report is specific for 2011, but represents the cumulative effect of fertilization and cropping since 2007.

Phosphorus Rate Trials

Short-term P fertilizer rate trials were conducted at two sites (Table 1) including PTRS-C4 and PTRS-24W. Soil samples (0- to 4-in. depth) were collected in May before fertilizer applications were made. Triple superphosphate was hand broadcast to the soil surface at rates equivalent to 0, 40, 80, 120, and 160 lb P_2O_5/acre on 19 May, 12 days before soybean was planted. Muriate of potash (80 lb K_2O/acre) and a granular B fertilizer (1 lb B/acre) was broadcast to the soil surface to ensure these nutrients were not yield limiting. Each trial was a randomized complete block design with six replications.

In all trials, trifoliate leaves (15) were collected at the R2 growth stage, dried to a constant moisture, ground to pass a 1-mm sieve, digested, and analyzed for elemental concentrations by ICPS. A 12- to 20-ft long section of the middle of each plot was harvested with a plot combine. Soybean moisture was adjusted to 13% for final yield calculations. For all studies, analysis of variance was conducted by site with the PROC GLM procedure in SAS v9.1 (SAS Institute, Inc., Cary, N.C.). When appropriate, mean separations were performed using Fisher's Protected Least Significant Difference method at a significance level of 0.10. Single-degree-of-freedom contrasts were used to compare selected treatments with significant differences identified when $P < 0.10$.

RESULTS AND DISCUSSION

Soil-test P and K have both changed significantly due to the application of different P or K rates in trials conducted at the RREC for four years or the PTRS for 9 years (Table 3). Linear regression of the cumulative amount of applied nutrient and the listed soil-test P and K means can be used to determine how much P and K are required to build soil-test concentrations. After 4 years of cropping and fertilization with the same annual rates, the Dewitt silt loam at the RREC requires 21 lb P_2O_5/acre to increase soil-test P by 1 ppm and 13 lb K_2O/acre to increase soil-test K by 1 ppm. On the alkaline Calhoun soil at the PTRS, 45 lb K_2O/acre is needed to increase soil-test K by 1 ppm after 11 years of cropping fertilization. The RREC data show how annual fertilization has changed soil-test, but does not show whether soil from each fertilizer rate treatment has changed from its initial concentration. The initial soil-test P and K concentrations were uniform among plots in 2007 and averaged 150 ppm K and 18 ppm P suggesting that the annual mean soil-test K of soil receiving no K has declined (150, 139, 144, 87, and 113 ppm) and soil-test P (18, 16, 22, 18, and 16 ppm) has remained relatively constant across time.

Trifoliate leaf P concentrations in the RREC P trial were not different among treatments, but soybean yield was benefited by P fertilization (Table 4). The single-degree-of-freedom contrast comparing soybean receiving no P against soybean fertilized with 80, 120, and 160 lb P_2O_5/acre showed a significant increase of 3.1 bu/acre. Multiple means comparison also showed a significant yield increase from annual P rates ≥80 lb P_2O_5/acre/year.

Soybean leaf K concentration and seed yields were significantly affected by K fertilization rate in long-term trials at RREC-K and PTRS-LTK (Table 4). The single-degree-of-freedom contrast comparing soybean receiving no K against soybean fertilized with 80, 120, and 160 lb K_2O/acre showed a significant 3.2 bu/acre increase at RREC-K. This represents the first significant yield difference observed among the annual K fertilization rates in the RREC-K experiment. Despite the significant differences in trifoliate leaf K concentrations, leaf K would not have been considered low or deficient (<1.5 to 1.8% K). The significant difference measured in soybean yield (Table 4) due to K fertilization is in agreement with the recent decline in soil-test K (Table 3).

At PTRS-LTK, trifoliate leaf K and grain yield were dramatically affected by annual K rate. Leaf K concentrations in soybean receiving no K would have been considered deficient (Table 4). Annual application of 40 to 160 lb K_2O/acre resulted in yield increases of 24% to 34% compared to the no K control, but the greatest yields were produced in soil receiving 120 and 160 lb K_2O/acre/year.

Soil in the two short-term P rate trials, PTRS-24W and -C4, would have been categorized as having Very Low (< 16 ppm) or Low (16 to 25 ppm) soil-test P levels and received a recommendation for 80 or 60 lb P_2O_5/acre, respectively. Soybean yield and trifoliate leaf P concentration were not affected by P fertilization at either site (Table 5).

PRACTICAL APPLICATION

After five years of cropping and application of different P and K fertilizer rates, significant yield differences were observed for the first time at the RREC. At the PTRS, after 11 years of fertilization with different K rates, soybean yields ranged from 55 to 74 bu/acre and clearly highlighted the benefits of applying moderate K fertilizer rates. The long-term trials highlight the need to monitor soil-test K across time in individual fields because soil-test K may fluctuate from one year to the next with the magnitude being great enough to influence recommendations.

To date we have accumulated 45 site-years of information for our soybean response to P fertilization database. A linear plateau model describing the relationship between soil-test P (ppm) and the percent relative yield of soybean receiving no P fertilizer was significant ($P = 0.0006$) and estimated the critical soil-test P as 20 ppm, but the 95% confidence interval for the predicted critical soil-test P ranged from 13 and 28 ppm. Results from the long-term trials suggest that soil-test P and K plus knowledge of the recent P and K fertilization history and previous soil-test results are important components of a fertilization program. The results of these short- and long-term trials highlight the need to continue conducting research focused on correlating and calibrating soil-test based fertilizer recommendations.

ACKNOWLEDGMENTS

Research was funded by a grant from the Soybean Check-off Program administered by the Arkansas Soybean Research and Promotion Board and the University of Arkansas System Division of Agriculture.

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Table 1. Selected soil and agronomic management information for P and K fertilization trials conducted in 2011.

Site (Nutrient)	Soil series	Cultivar	Previous crop	Tillage	Row width	Plant date
					(in.)	
PTRS-C4 (P)	Calhoun	Armor 53-R15	Milo	Conv.	15	30 May
PTRS-24W (P)	Calhoun	Armor 48-R40	Soybean	Conv	15	30 May
PTRS-KLT (K)	Calhoun	Armor 48-R40	Rice	No-till	15	30 May
RREC-K (K)	Dewitt	Armor 48-R40	Rice	No-till	7	16 May
RREC-P (P)	Dewitt	Armor 48-R40	Rice	No-till	7	16 May

Table 2. Selected soil chemical property means (n = 4-8) of P or K of soil from the unfertilized control in P and K fertilization trials conducted at multiple sites during 2011.

	Soil	Soil	Mehlich-3 soil nutrients								
Site (Nutrient)	OM	pH	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
	(%)		---- (ppm) ----								
PTRS-C4 (P)	2.7	7.3	15[a]	106	1428	224	15	202	328	1.3	1.0
PTRS-24W (P)	2.6	8.0	16[b]	90	2187	306	7	361	248	1.8	1.1
PTRS-LTK (K)	2.9	7.5	18	–[c]	1918	377	28	440	160	8.7	0.6
RREC-K (K)	2.5	6.1	25	–[c]	1086	147	11	627	80	7.3	0.6
RREC-P (P)	2.2	5.7	–[c]	122	952	115	9	550	111	9.5	0.6

[a] Standard deviation of soil-test P mean is 4 ppm.
[b] Standard deviation of soil-test P mean is 1.7 ppm.
[c] Soil-test P and or K means for each annual P or K rate are listed in Table 3.

Table 3. Mehlich-3 extractable soil P or K means as affected by annual P or K fertilization rate for three multi-year trials from samples collected in March 2011 at the Pine Tree Research Station (PTRS-LTK) or the Rice Research and Extension Center (RREC) in 2011.

	RREC[a]		PTRS-LTK[b]
Annual nutrient rate	P rate trial	K rate trial	K rate trial
(lb K_2O or P_2O_5/acre)	(ppm P)	----(ppm K)----	
0	16	113	57
40	23	120	63
80	31	126	72
120	37	143	83
160	48	164	89
LSD0.10	3	10	6
p-value	<0.0001	<0.0001	<0.0001

[a] Fertilization of trials at the RREC was initiated in 2007. Cumulative fertilizer rates can be calculated by multiplying the annual rate shown by 4.
[b] Fertilization of the PTRS trial was initiated in 2000, but annual rates were changed after 2006. Cumulative rates after the 2010 season were 0, 380, 760, 1140, and 1520 lb K_2O/acre.

Table 4. Trifoliate leaf P or K concentration and seed yield of soybean as affected by annual P or K fertilization rate for three multi-year trials conducted at the Pine Tree Research Station (PTRS-LTK) or the Rice Research and Extension Center (RREC) in 2011.

Annual nutrient	RREC-P Trial		RREC-K Trial		PTRS-LTK Trial	
rate	Leaf P	Yield	Leaf K	Yield	Leaf K	Yield
(lb K_2O or P_2O_5/acre)	(% P)	(bu/acre)	(% K)	(bu/acre)	(% K)	(bu/acre)
0	0.387	55	1.96	52	1.16	55
40	0.377	54	2.07	57	1.65	68
80	0.392	61	2.10	58	1.77	71
120	0.387	57	2.10	55	1.99	73
160	0.393	57	2.20	54	2.02	74
LSD0.10	NS[a]	3	0.09	NS	0.10	4
p-value	0.4228	0.0353	0.0020	0.1469	<0.0001	<0.0001
SDF[b]	0.6071	0.0801	0.0003	0.0940	<0.0001	<0.0001

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

Table 5. Trifoliate leaf P concentration and seed yield of soybean as affected by P fertilization rate at two sites at the Pine Tree Research Station (PTRS) during 2011.

P-fertilizer	PTRS-24W		PTRS-C4	
Rate	Leaf P	Yield	Leaf P	Yield
(lb P_2O_5/acre)	(% P)	(bu/acre)	(% P)	(bu/acre)
0	0.410	75	0.400	74
40	0.412	74	0.423	74
80	0.417	75	0.418	74
120	0.438	75	0.413	72
160	0.433	74	0.415	76
LSD0.10	NS[a]	NS	NS	2
p-value	0.2281	0.9181	0.6736	0.0876
SDF[b]	0.2140	0.7981	0.1826	0.8155

[a] NS, not significant ($P > 0.10$).
[b] SDF, single-degree-of-freedom contrast comparing the yield of soybean receiving no P fertilizer against the mean yield of soybean fertilized with 80, 120, and 160 lb P_2O_5.

'Midland 99' Bermudagrass Forage Yield Response to Phosphorus and Potassium Fertilization

N.A. Slaton, C.G. Massey, R.E. DeLong, B. Haller, and B. Gordon

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Warm- and cool-season forages produced for hay were grown on 1.48 million acres in Arkansas during 2010 making hay forage one of the most widely cultivated crops in Arkansas (USDA-NASS, 2011). Soil-test summaries since 2006 for warm- and cool-season grasses provide strong evidence that farmers are not fertilizing these forages sufficiently with the end-result of declining median soil-test phosphorus (P) and potassium (K) values. These trends call for research and education programs to ensure that sufficient soil fertility is maintained to prevent bermudagrass stand decline, soil erosion, and reduced water quality. We have previously reported on a project examining selected soil chemical property and common bermudagrass responses to annual P and K fertilizer management during a 5-year period (Slaton et al., 2011). This report summarizes similar P and K research that was initiated in 2011 on a new site having suboptimal soil P and K availability. Our research objective was to evaluate soil-test P and K and Midland 99 bermudagrass yield and nutrient uptake as affected by annual P and K fertilization. The overall goal of this forage research effort is to develop and/or verify current soil-test based fertilizer recommendations for bermudagrass forage grown for hay.

PROCEDURES

Forage fertilization trials were initiated (year 1) in April 2011 on a Barling silt loam with an established stand of Midland 99 bermudagrass on a commercial farm located in El Paso, Ark. The field had been leveled and sprigged in 2009. Forage growth and yield was poor in 2010. Visual inspection of the research area in spring 2011 showed that the Bermudagrass stand was uniform in the P trial and non-uniform in the K rate trial. The research plots for each trial were outlined with flags in April 2011 and composite soil samples (five 1-in.-wide cores/composite) were collected from each plot to a depth of 4 in. to monitor changes in soil-test P and K following fertilization. Soils were dried at 130 °F, crushed to pass a 2-mm diameter sieve, analyzed for water pH (1:2 soil weight:water volume ratio), and extracted for plant-available nutrients using the Mehlich-3 method (Table 1).

In the K rate trial, muriate of potash was applied in two or three applications for cumulative season-total rates equaling 0, 90 (45 × 2), 180 (60 × 2), 270 (90 × 3), 360 (120 × 3), and 450 (150 × 3) lb K_2O/acre. Potassium fertilizer treatments were applied on 19 April (green-up), 22 June following the second harvest, and 26 July following the third harvest. Phosphorus (150 lb 12-40-0-10S-1Zn/acre, sold as MESZ) and N fertilizers (260 lb urea/acre) were broadcast applied to the K rate trial at greenup. After subsequent harvests, the area received 80 to 100 lb urea-N plus 100 lb MESZ or ammonium sulfate/acre.

In the P rate trial, triple superphosphate was applied in one to three split applications for cumulative rates equivalent to 0, 30 (× 1), 60 (30 × 2), 90 (30 × 3), 120 (40 × 3), and 150 (50 × 3) lb P_2O_5/acre. Fertilizer application dates were the same as given for K. The P research area received 150 lb muriate of potash/acre, 200 lb 0-0-22-11S-11Mg/acre (sold as K-MAG), and 260 lb urea/acre at greenup. Following each harvest the area received 150 lb muriate of potash and 80 to 100 lb urea-N/acre.

In each trial, forage was harvested by cutting an 18-ft long by 3.8-ft wide swath with a self-propelled, cycle-bar mower at a height of 2.0 to 2.5 in. Forage was harvested on 18 May, 22 June, 26 July, and 31 August. Hay harvests were scheduled for every 30 days, but were adjusted according to growth and weather conditions. The biomass from each plot was weighed and adjusted to a total dry weight expressed as lb dry forage/acre. A subsample of forage from each plot was dried to determine moisture content, ground to pass a 1-mm sieve, and digested in concentrated HNO_3 and 30% H_2O_2 to determine forage P and K concentrations and total nutrient uptake and removal.

Each experiment was a randomized complete block design with each fertilizer rate replicated five times. Analysis of variance procedures were performed with the PROC MIXED procedure in SAS (SAS Institute, Inc., Cary, N.C.). Forage yield, nutrient concentration, and nutrient uptake data were analyzed by harvest time and for the season total production (sum of each harvest). Initial soil-test data were analyzed as a randomized complete block design. When appropriate, mean separations were performed using Fisher's Protected Least Significant Difference method at a significance level of 0.05.

RESULTS AND DISCUSSION

The summer of 2011 was characterized by rainfall and temperature extremes. Monthly precipitation was above normal in April and May and below normal from June through August. In addition, 2011 was one of the hottest summers on record. The initial soil chemical properties at this site can be characterized as having near optimal soil pH, 'Very Low' soil-test P (< 16 ppm) and 'Low' soil-test K (61 to-90 ppm, Table 1). The mean soil-test P and K values were uniform among the randomized plots designated to receive each annual P and K rate (Table 2). Although the soil chemical properties were statistically uniform throughout each research area, the stand of Midland 99 bermudagrass was not uniform and resulted in high coefficients of variation for yield.

Fertilization with P or K had no significant ($P < 0.10$) effect on season total dry matter accumulation by bermudagrass (Tables 3 and 4). However, forage receiving no P or K produced the lowest numerical season total dry matter yields that were 4% to 9% lower than the second lowest yielding P and K treatments, respectively. Single-degree-of-freedom contrasts support the lack of significant differences, but also provide some evidence that yields will become significantly different in the near future if P and K continue to be omitted from the fertilization program. Based on single-degree-of-freedom contrasts, yields from the first two and the fourth individual harvest events were unaffected by K fertilization (Table 3), but K fertilization increased yield during the third harvest (Table 3). The density of bermudagrass was not very uniform in the K research area and resulted in larger than desired coefficients of variation for yield data. Hopefully, aggressive P and N fertilization during 2011 will improve the uniformity of stand density. Phosphorus fertilization resulted in similar numerical and statistical yield results as described for K (Table 4). Forage receiving no P produced the lowest numerical yield at three of the four individual harvests, but the differences were never significant.

Tissue P and K concentrations were consistently and numerically lowest in forage receiving no K or P (Tables 5 and 6), but the differences were not always significantly different from forage fertilized with K or P. Tissue P concentrations in forage receiving no P would be considered deficient (≤ 0.20%; Plank and Campbell, 2011) for the first two harvests, but not the two final harvests. Likewise, forage K concentrations were considered deficient (< 1.50% K) for forage on the second and third harvests but not the first and fourth harvests. Within each harvest, total P and K uptake generally increased numerically and sometimes statistically as P or K rate increased. However, when the season total (cumulative amount) of P or K uptake was summed across the four harvests, uptake was significantly increased by fertilization with the unfertilized controls having the lowest P or K removals and the highest fertilization rates removing the greatest P and K. In contrast, cumulative recovery or plant uptake of the applied fertilizer (e.g., calculated by the difference method) tended to decrease as P or K fertilizer rate increased with ranges of 41% to 22% and 27% to 4% of the applied K and P fertilizers, respectively. On average, each ton of forage produced contained from 36 to 51 lb K_2O and 10 to 11 lb P_2O_5. The K content of each ton of harvested forage increased numerically as K rate increased but remained relatively constant across P rates (data not shown).

PRACTICAL APPLICATION

A new forage research site was established in 2011 on a soil with low to very low P and K fertility. The stand of Midland 99 bermudagrass was not uniform across all plots and resulted in a high C.V. for the collected data. Despite the suboptimal soil fertility levels and variable stand, forage yield was not affected by different levels of P or K fertilization, but forage uptake and removal of soil and/or applied fertilizer P and K tended to increase as fertilization rate increased. We intend to continue to manage the forage at this site to improve its stand density and uniformity as the site's initial low soil fertility offers a unique opportunity to learn about soil P and K availability and fertilization.

ACKNOWLEDGMENTS

Funding provided by the University of Arkansas System Division of Agriculture. Special thanks to Oakley Farms and Mr. Roddy Watson for their assistance in establishing and maintaining this research.

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Table 1. Selected soil chemical property means (*n* = 30; 0- to 4-in. depth) for bermudagrass P and K fertilization trials conducted on a Barling silt loam in El Paso, Ark.

Nutrient	Soil organic matter	Soil pH	Mehlich-3 extractable nutrients P	K	Ca	Mg	S	Na	Fe	Mn	Zn	Cu
	(%)		[mean (standard deviation) in ppm]									
Potassium	1.8[a]	6.2	14 (5)	82 (12)	804	50	13	12	116	153	0.6	0.3
Phosphorus	2.0	5.7	11 (3)	73 (10)	751	71	13	16	128	182	0.6	0.3

[a] n = 5 for soil organic matter (analyzed from the plots receiving no P or K fertilizer).

Table 2. Mehlich-3 extractable soil P and K before fertilization with P and K in 2011.

Annual K rate	Potassium trial	Annual P rate	Phosphorus trial
(lb K_2O/acre)	(Mehlich-3 K, ppm)	(lb P_2O_5/acre)	(Mehlich-3 P, ppm)
0	87	0	11
90	73	30	13
180	81	60	11
270	79	90	12
360	82	120	10
450	87	150	12
LSD0.05	NS	LSD0.05	NS
p-value	0.3946 (C.V., 14%)	*p*-value	0.5608 (C.V., 25%)

Table 3. Forage dry matter yield during 2011 as affected by K fertilization rate for a trial conducted on a Barling silt loam in El Paso, Ark.

Season total K_2O rate[a]	Season total	Harvest 1 (May)	Harvest 2 (June)	Harvest 3 (July)	Harvest 4 (August)
(lb K_2O/acre)	(lb forage/acre)				
0	9651	1527	2420	2785	2929
90[×2]	10823	1783	2939	3455	2645
180[×3]	10577	1457	2756	3144	3219
270[×3]	11145	1844	2850	3408	3044
360[×3]	10884	1578	2778	3368	3160
450[×3]	11286	1579	2643	3147	3918
LSD(0.10)	NS[b]	NS	NS	NS	657
p-value	0.6900	0.8919	0.9441	0.5085	0.0636
C.V., %	15.5	36.5	30.8	18.5	19.1
SDF[c]	0.1277	0.6810	0.3770	0.0895	0.3584

[a] The superscripted value indicates the number of split applications needed to apply the season-total K rate. Potassium fertilizer treatments applied at greenup and after the June and July harvests.

[b] NS = not significant.

[c] SDF = single-degree-of-freedom contrast comparing the no K control against the mean yield of bermudagrass fertilized with 180 to 450 lb K_2O/acre.

Table 4. Forage dry matter yields by harvest during 2011 as affected by P fertilization rate for a trial conducted on a Barling silt loam in El Paso, Ark.

Season total K_2O rate[a]	Season total	Harvest 1 (May)	Harvest 2 (June)	Harvest 3 (July)	Harvest 4 (August)
(lb P_2O_5/acre)	(lb forage/acre)				
0	10966	1198	3022	3970	2777
30$^{\times1}$	12018	1529	3861	3805	2823
60$^{\times2}$	11618	1275	3541	3834	2969
90$^{\times3}$	11934	1593	3665	3663	3011
120$^{\times3}$	11798	1601	3587	3665	2944
150$^{\times3}$	11475	1309	3431	3695	3040
LSD(0.10)	NS[b]	NS	NS	NS	NS
p-value	0.7282	0.5980	0.4547	0.8083	0.7902
C.V., %	9.8	32.4	18.1	10.7	11.6
SDF[c]	0.2106	0.2957	0.1095	0.2200	0.2235

[a] The superscripted value indicates the number of split applications needed to apply the season-total P rate. Phosphorus fertilizer treatments applied at greenup and after the June and July harvests.
[b] NS = not significant.
[c] SDF, single-degree-of-freedom contrast comparing the no P control against the mean yield of bermudagrass fertilized with 60 to 150 lb lb P_2O_5/acre.

Table 5. Forage K concentrations and aboveground K uptake by harvest during 2011 as affected by K fertilization rate for a trial conducted on a Barling silt loam in El Paso, Ark.

	Forage K concentration				Aboveground potassium uptake				
Season total K_2O rate[a]	Harvest 1 (May)	Harvest 2 (June)	Harvest 3 (July)	Harvest 4 (August)	Season total	Harvest 1 (May)	Harvest 2 (June)	Harvest 3 (July)	Harvest 4 (August)
(lb K_2O/acre)	(% K)				(lb K_2O/acre)				
0	1.68	1.41	1.40	1.69	175	30	40	44	61
90$^{\times2}$	1.77	1.44	1.52	1.94	212	39	50	62	61
180$^{\times3}$	1.87	1.54	1.77	2.25	238	33	51	67	87
270$^{\times3}$	1.71	1.59	1.79	2.38	252	38	53	72	90
360$^{\times3}$	1.81	1.74	1.77	2.45	254	34	57	71	91
450$^{\times3}$	1.91	1.84	1.99	2.63	290	36	54	74	126
LSD(0.10)	NS[b]	0.23	0.28	0.30	29	NS	NS	13	24
p-value	0.2251	0.0268	0.0215	0.0003	<0.0001	0.8391	0.3659	0.0103	0.0013
C.V., %	9.0	13.2	15.1	12.2	11.1	33.7	24.0	18.6	25.1
SDF[c]	0.0783	0.0196	0.0032	<0.0001	<0.0001	0.3507	0.0366	0.0003	0.0023

[a] The superscripted value indicates the number of split applications needed to apply the season-total K rate. Potassium fertilizer treatments applied at greenup and after the June and July harvests.
[b] NS = not significant.
[c] SDF = single-degree-of-freedom contrast comparing the no K control against the mean yield of bermudagrass fertilized with 180 to 450 lb K_2O/acre.

Table 6. Forage P concentrations and aboveground P uptake by harvest during 2011 as affected by P fertilization rate for a trial conducted on a Barling silt loam in El Paso, Ark.

	Forage P concentration				Aboveground phosphorus uptake				
Season total P_2O_5 rate[a]	Harvest 1 (May)	Harvest 2 (June)	Harvest 3 (July)	Harvest 4 (August)	Season total	Harvest 1 (May)	Harvest 2 (June)	Harvest 3 (July)	Harvest 4 (August)
(lb P_2O_5/acre)	(% P)				(lb P_2O_5/acre)				
0	0.196	0.180	0.252	0.250	56.4	5.2	12.5	22.9	15.7
30$^{\times1}$	0.236	0.184	0.250	0.274	64.4	8.3	16.3	22.0	17.8
60$^{\times2}$	0.216	0.188	0.254	0.268	62.2	6.3	15.4	22.2	18.3
90$^{\times3}$	0.214	0.182	0.238	0.266	61.0	7.6	15.4	19.7	18.1
120$^{\times3}$	0.234	0.186	0.252	0.288	64.6	8.6	15.2	21.3	19.5
150$^{\times3}$	0.232	0.190	0.262	0.274	62.6	6.9	14.7	22.1	18.9
LSD(0.10)	0.020	NS[b]	NS	0.019	5.9	NS	NS	NS	2.1
p-value	0.0200	0.7768	0.1674	0.0675	0.2152	0.3579	0.4070	0.5267	0.0923
C.V., %	8.4	6.4	5.2	6.6	8.7	36.4	18.6	12.1	10.6
SDF[c]	0.0071	0.2877	0.9399	0.0136	0.0318	0.1197	0.0712	0.2511	0.0057

[a] The superscripted value indicates the number of split applications needed to apply the season-total P rate. Phosphorus fertilizer treatments applied at greenup and after the June and July harvests.
[b] NS = not significant.
[c] SDF = single-degree-of-freedom contrast compare mean forage yields of the no P control against the yield fertilized with 60 to 150 lb P_2O_5/acre.

Corn Yield Response to Nitrogen Source, Rate, and Application Strategy

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

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Urea is the primary nitrogen (N) fertilizer used for corn production in Arkansas making proper urea-N management critical to producing high yields. For corn grown in loamy soils, the University of Arkansas Cooperative Extension Service recommends 250 lb N/acre, which is usually applied in two or three split applications to help increase N fertilizer use efficiency. Growers typically preplant incorporate a portion of the N fertilizer and apply additional N at the V6 to V8 and tasseling growth stages. Efficient uptake of fertilizer N is critical for producing high corn yields and reducing N losses via leaching, runoff, ammonia volatilization, and/or denitrification.

A controlled-release N fertilizer called Environmentally Smart N (ESN, http://www.smartnitrogen.com/) is being manufactured by Agrium Advanced Technologies and marketed as a N source for corn production. The ESN fertilizer is urea encased in a thin, permeable polymer-coating, which should help minimize N losses under some field conditions. The rate of N release from ESN is most influenced by temperature with the N release rate increasing as temperature increases. The ESN is now being produced at a fertilizer plant in New Madrid, Mo., and will likely be commercially available to Arkansas growers. Although ESN has been used successfully in Midwest corn-producing states for several years, limited research has been conducted in the Midsouth. Thus, our research objective was to compare corn yield response to urea and ESN fertilizers.

PROCEDURES

In 2011, experiments were established in a commercial production field in Prairie County (near Hazen, Ark.) and at the Pine Tree Research Station. Both sites were in fields mapped as a Calloway silt loam and cropped to soybean in 2010. A composite soil sample (0- to 6-in.) was collected from the plot designated to receive no N fertilizer in each of four blocks. Each composite soil sample consisted of five soil cores collected from a flat soil surface before beds were formed. Soil was dried, crushed to pass through a 2-mm-diameter sieve, and analyzed for soil water pH, Mehlich-3 extractable nutrients, inorganic N, and total N content (Table 1). Triple superphosphate and muriate of potash rates equivalent to 60 lb P_2O_5 and 80 lb K_2O/acre, respectively, were broadcast to each site before beds were pulled.

Each experiment contained the same treatments which were arranged in a randomized complete block (n = 4) design. Each plot was 4 rows (30-in. wide rows) wide and 30 ft long. The primary treatments (10) included three N rates 70, 140, and 210 lb N/acre applied as preplant urea (no Agrotain), preplant ESN, and urea applied in split applications [preplant and V6 to V7 (with Agrotain)] compared to a no N control. Two additional N treatments that included 95 and 165 lb N/acre applied preplant as ESN plus another 45 lb N/acre as Agrotain-treated urea at tasseling were included in each experiment. The rates and times of each fertilizer application are summarized in Table 2. Preplant N (plus P, K, and Zn fertilizers) was broadcast by hand onto the tilled (flat) soil surface on 8 April and incorporated on 9 April when the beds were formed before corn (DeKalb 64-82 at Prairie County and 67-88 at PTRS) was planted. At the V7 stage (26 May), urea was hand broadcast to a dry soil surface to the designated plots and followed by irrigation (e.g., furrow irrigation) to incorporate the urea. The tasseling application was made on 21 June at both sites.

Corn was furrow-irrigated as needed at each site. Each replicate was 32-corn rows wide (6 plots) and 60 or 70-ft deep (2 plots), which allowed for irrigation water to pass through each replicate before entering into the next replicate. At maturity, the middle 20 ft of the two center rows in each plot at Prairie County was marked, the total number of plants were counted, corn was hand harvested and placed into labeled burlap bags, and transported to the PTRS where it was shelled in a small-plot combine. At the PTRS, border area between plots was mowed, each plot was measured (29- to 30-ft length harvested), plants were counted, and plots were harvested with a small plot combine. Grain weight and moisture content were determined and yields were adjusted to a uniform moisture content of 15.5% and expressed as bu/acre. Plant population values are defined as ear-bearing stalks in the harvested area.

Each experiment was a randomized complete block design (RCB) with five blocks. Two statistical analyses were performed including one that included all 12 treatments (RCB) and a second that included only the three N rates (70, 140, and 210 lb N/acre) receiving preplant ESN, preplant urea, or a portion of the urea applied preplant with the balance of N sidedressed at the V7 stage (factorial treatment structure). Analysis of variance was performed with the Proc Mixed procedure of SAS v9.1 (SAS Institute, Cary, N.C.). When appropriate, Fisher's Protected Least Significant Difference method was used to separate means at a significance level of 0.10.

RESULTS AND DISCUSSION

The total amount of precipitation recorded at the PTRS totaled 9.0 in. from 9 to 30 April, 9.5 in. in May, 2.6 in. in June, and 0.4 in. in July. Between 20 April and 3 May, a two-week period, 12.3 in. of rain was measured during which time soils were saturated or too wet for fieldwork and historic flooding occurred across Arkansas. Similar amounts of rainfall occurred at the Prairie County site. The Rice Research Extension Center near Stuttgart, Ark. (approximately 30 miles southeast from the Prairie County field) measured 20.5 in. of precipitation from 9 April through 31 May and 15.1 in. during the 20 April to 3 May period. Based on weather and field traits (e.g., poor soil drainage) conditions were favorable for early season N losses via runoff, leaching and/or denitrification.

Significant corn yield differences existed among the 12 N fertilizer treatments (Table 2). Corn receiving no N produced the lowest yields. Regardless of N application method, corn yields increased as N rate increased significantly from 70 to 140 lb N/acre (Table 2). However, within each N application strategy, application of 210 lb N/acre produced yields that were similar compared to the yield with 140 lb N/acre (Tables 2 and 3). Yields were numerically higher for corn fertilized with 210 lb N/acre when ESN (preplant) and split applications of urea were made, but yield decreased numerically when urea was applied preplant at 210 lb N/acre. Preplant application of 210 lb urea-N/acre stunted corn and seedlings showed symptoms of P deficiency at both sites, which had similar soil properties. Thus, the numerically lower yield may have been a 'side-effect' of urea hydrolysis and waterlogged conditions (e.g., high rhizosphere pH, P precipitation, NH_3 injury to the root system, and/or HCO_3-toxicity) rather than N deficiency. These symptoms were not present on corn receiving the highest rates of ESN.

The statistical analysis shown in Table 3, provides a more appropriate statistical analysis of the N sources that were applied at all three N rates. When averaged across N sources, corn yield increased as N rate increased from 70 to 140 lb N/acre, but the yield increase from 140 to 210 lb N/acre was not significant. At both sites, averaged across N rates, corn fertilized with urea-preplant produced the lowest overall yield and ESN-preplant produced yields that were greater than urea-preplant. Corn receiving split applications of urea produced yields that were similar to corn fertilized with ESN-preplant, but the response differed slightly between sites. At Prairie County, the split applied urea produced a yield that was numerically intermediate between ESN-preplant and urea-preplant. At PTRS, the yields for split applied urea and ESN-preplant were nearly identical.

PRACTICAL APPLICATION

Based on results from two experiments conducted in 2011, corn fertilized with ESN-preplant produced better yields than corn fertilized with urea-preplant. Although N loss was not measured, the yield results, which were consistent across the two sites, provide indirect evidence that less N was lost from ESN than urea. As a general rule, we expect split applications of urea to provide more efficient recovery of fertilizer N by corn than when urea is applied only before planting, especially in years when when large amounts of rainfall occur between the dates that preplant N is applied and corn receives sidedress N. Likewise, as shown by results from a similar trial conducted in 2010 (Slaton et al., 2011), urea and ESN applied preplant will often produce similar results when soil and environmental conditions conducive for N loss are low. These results suggest that ESN should be considered as a preplant N source when large amounts of N are to be applied preplant, especially on soils where denitrification and/or leaching is likely.

ACKNOWLEDGMENT

Research was funded by the Arkansas Corn and Grain Sorghum Check-off program administered by the Arkansas Corn and Grain Sorghum Research and Promotion Board, Agrium Inc., and the University of Arkansas System Division of Agriculture.

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Slaton, N.A., R.E. DeLong, C.G. Massey, J. Shafer, and S. Clark. 2011. Corn yield response to nitrogen source, rate, and application strategy. *In*: N.A. Slaton (ed.). Wayne E. Sabbe Arkansas Soil Fertility Studies 2010. University of Arkansas Agricultural Experiment Station Research Series 588:50-52. Fayetteville, Ark.

Table 1. Selected soil properties (0- to 6-in. depth) for corn N-fertilization trials located in Prairie County and the Pine Tree Research Station (PTRS) in 2011.

Site	pH	Total C	Total N	Inorganic N NH_4-N	Inorganic N NO_3-N	Mehlich-3 P	K	Ca	Mg	S	Zn
		------- (%) ------		---------- (ppm) ----------							
Prairie	7.6	0.72	0.074	9	7	18	97	1367	200	13	2.7
PTRS	7.6	0.84	0.079	5	12	25	83	1602	231	6	2.6

Table 2. The effect of N-fertilizer source and N rate on corn grain yield (15.5% moisture) and harvested plant population for trials located in Prairie County and the Pine Tree Research Station (PTRS).

N source[a]	N rate Total N	Preplant N	V6-7 N	Tassel N	Prairie County Yield	Prairie County Population[b]	PTRS Yield	PTRS Population[b]
	---------- (lb N/acre) ----------				(bu/acre)	(plant/acre)	(bu/acre)	(plant/acre)
No N	0	0	0	0	113	34,412	47	27,732
ESN	70	70	0	0	160	35,393	141	28,870
Urea-PP	70	70	0	0	153	35,284	131	30,052
Urea-SPL	70	0	70	0	159	35,937	141	29,061
ESN	140	140	0	0	198	34,799	187	30,727
Urea-PP	140	140	0	0	187	35,284	178	28,648
Urea-SPL	140	45	95	0	185	34,848	182	27,894
ESN + Tas	140	95	0	45	189	34,848	190	29,450
ESN	210	210	0	0	213	34,739	199	30,186
Urea-PP	210	210	0	0	177	34,086	168	28,543
Urea-SPL	210	70	140	0	197	35,502	199	30,311
ESN + Tas	210	165	0	45	215	33,868	203	30,309
				LSD0.10	24	NS	14	NS
				P-value	<0.0001	0.9050	<0.0001	0.1676
				C.V., %	10.7	5.0	7.1	7.0

[a] ESN, Environmentally Smart N applied preplant; Urea-PP, urea applied preplant; Urea-SPL, urea split applied between preplant and V7 stage (Agrotain-treated urea); & ESN + Tas, ESN applied preplant followed by urea applied at tassel emergence.

[b] Harvested plants is the total number of plants in the harvested area expressed on a per acre basis, which consisted of a 20 or 30 ft length in each of the two middle corn rows (40 to 60 row-ft total).

Table 3. Comparison of selected N-fertilizer treatments that received a total of 70, 140, and 210 lb N/acre for trials located in Prairie County and the Pine Tree Research Station (PTRS). The interaction between N source and rate was not significant for either site, but the main effects were significant. Refer to Table 2 for the exact times and rates that each N source and rate were applied.

N source	Yield Prairie County	Yield PTRS	N rate	Yield Prairie County	Yield PTRS
	------ (bu/acre) ------			------ (bu/acre) ------	
Urea - Preplant	172 b[a]	159 b	70	157 b	138 b
ESN - Preplant	196 a	176 a	140	195 a	182 a
Urea- Split Applied (preplant fb V7)	180 ab	174 a	210	196 a	189 a
p-value	0.0526	0.0023		0.0004	<0.0001

[a] Mean yield values within a column followed by the same letter are not statistically different.

Wheat Grain Yield Response to Phosphorus Fertilization Rate

N.A. Slaton, T.L. Roberts, R.E. DeLong, C.G. Massey, J. Shafer, S.D. Clark, and J. Branson

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Soft red winter wheat (*Triticum aestivum* L.) is one of the most phosphorus (P)-responsive crops grown in Arkansas. Based on our research experiences, positive yield responses to P fertilization are more common for wheat than for rice (*Oryza sativa* L.) and soybean (*Glycine max* (L.) Merr.). The more frequent positive response rate to P fertilization may be attributed partially to the cool and often wet soil conditions during the late winter months, previous crop residue (immobilization of inorganic P), and P fixation in soils that were flooded during the summer for rice production. A better understanding of the P fertilizer requirements of wheat grown on soils with a range of P availability would aid in developing accurate fertilizer recommendations. The fundamental concepts of soil-test based fertilizer recommendations are that the probability and magnitude of a positive response to fertilizer is greatest for soils with low nutrient availability and both diminish as soil nutrient availability increases. Thus, confidence in soil-test based fertilizer recommendations are greatest when a large number research trials are conducted on soils having a range of nutrient availability index values.

The ultimate goals of this fertilization project are to i) identify the critical soil P availability index (Mehlich-3) values that require P fertilizer to maximize yield and ii) calibrate the appropriate P fertilizer rates that should be recommended for each soil-test level. Our short-term objective was to determine wheat grain yield response to P fertilization rate on silt loam soils.

PROCEDURES

Field studies were established during the fall of 2010 to evaluate the effect of P fertilization rate on wheat yield. Trials were located at the Lon Mann Cotton Research Station (LMCRS) on a Loring silt loam following summer fallow, a Dexter silt loam following soybean at the Newport Research Station (NRS), the Pine Tree Research Station (PTRS) on a Loring silt loam (PTRS-Rice) following rice and a Calloway (PTRS-Milo) silt loam following grain sorghum (*Sorghum bicolor* L.). Trials were also established at the Rice Research Extension Center (RREC) and the Vegetable Research Station, but results will not be reported due to glyphosate drift and extensive bird damage, respectively. A composite soil sample (0- to 4-in. depth) was taken from each replicate at each site to determine soil chemical properties. Soil was oven-dried at 130 °F, crushed, and passed through a 2-mm sieve for measurement of Mehlich-3 extractable nutrients, organic matter by weight loss on ignition, and soil water pH. Mean values of selected soil chemical properties are listed in Table 1.

'AgriPro Beretta' wheat was drill-seeded (100 to 120 lb seed/acre) into conventionally tilled seedbeds on 18 October at PTRS-L and PTRS-C, 28 October at NRS, and 9 November at LMCRS. Individual plots were 20-ft long and 6.5-ft wide allowing for 8 rows of wheat with 7.0-to 7.5-in. wide row spacings.

Fertilizer treatments were broadcast by hand to the soil surface of each plot 1 to 3 days after planting. Each P rate trial included 0, 30, 60, 90, 120, and 150 lb P_2O_5/acre as triple superphosphate. Potassium (K) fertilizer (100 lb muriate of potash/acre) was broadcast applied to P trials on the same date as treatments were applied to ensure K was not yield limiting. A total of 140 lb N/acre was applied as urea in two equal splits made on 22 and 23 February and 22 and 23 March. At maturity, grain yields were measured by harvesting all eight rows of each plot with a small-plot combine. Grain yields were adjusted to a uniform moisture content of 13%.

For each experiment, fertilizer rates were arranged in a randomized complete block design with five replicates per treatment. Data from each experiment was analyzed separately. Analysis of variance procedures were conducted with the PROC GLM procedure in SAS v9.1 (SAS Institute, Inc., Cary, N.C.). When appropriate mean separations were performed using Fisher's Protected least significant difference method at a significance level of 0.10. Each site was also classified as responsive ($P < 0.10$) or non-responsive to P fertilization using a single-degree-of-freedom contrast that compared the no P control yield against the mean yield of wheat fertilized with 60 to 150 lb P_2O_5/acre.

RESULTS AND DISCUSSION

Site Descriptions

The soil-test level associated with the average Mehlich-3 extractable P at each site was classified as 'Very Low' (<16 ppm) at the PTRS-Milo, 'Medium' (26 to 35 ppm) at the PTRS-Rice, and 'Optimum' (36 to 50 ppm) at LMCRS and NRS (Table 1). Based on the University of Arkansas Cooperative Extension Service fertilizer guidelines for winter wheat, 100, 50, and 0 lb P_2O_5/acre would have been recommended for the Very Low, Medium, and Optimum soil-test P levels.

Wheat Response to P-Fertilizer Rate

The grain yield of wheat receiving no P fertilizer was increased significantly by P fertilization only at PTRS-Milo (Table 2), which was also the soil with the lowest soil P availability index (Table 1). At PTRS-Milo, wheat yield was increased by an average of 9 bu/acre by application of 30 to 120 lb P_2O_5/acre with the highest numerical yields produced by 90 lb P_2O_5/acre. Although statistically significant differences were defined by the multiple means comparison (LSD) at PTRS-Rice, wheat receiving no P produced a yield that was statistically similar to all other P rates.

Table 3 summarizes the results of 34 P fertilization trials with wheat conducted since 2002. Wheat yields are most likely to be increased by P fertilization when soil-test P is < 11 ppm and only one significant yield response to P fertilization has been measured when soil-test P is > 30 ppm. The overall relationship between relative yield of wheat receiving no P fertilizer and soil-test P, as predicted with a linear plateau model, was significant ($P = 0.0062$), albeit weak ($r^2 = 0.28$) and predicted a critical soil-test P of 41 ppm with a large standard error (± 11). Previously, we estimated that the critical soil-test P for wheat following rice in the rotation was 32 ppm (Slaton et al., 2005). Having an equal number of site-years in each soil-test category will likely improve the overall relationship. The soil-test categories with the greatest number of test sites also have the greatest amount of uncertainty concerning yield response to P fertilization.

PRACTICAL APPLICATION

Current soil-test P recommendations accurately predicted the need for P fertilization of wheat at all four test sites. The one site that had a Medium soil-test P level did not respond significantly to P fertilization, but, by definition, the Medium soil-test level is one of uncertainty. The current University of Arkansas Cooperative Extension Service recommendations for P fertilization would have accurately predicted wheat response to P fertilization in 71% (24 of the 34) of the wheat P research sites. Future research should continue to examine wheat response to P fertilization in the soil-test P categories that need additional site-years to equalize observations among the categories.

ACKNOWLEDGMENTS

Research was funded by a grant from the Wheat Check-off Program administered by the Arkansas Wheat Research and Promotion Board and the University of Arkansas System Division of Agriculture.

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Table 1. Selected soil chemical property means (*n* = 5) of P fertilization trials with soft red winter wheat conducted at the Lon Mann Cotton Research Station (LMCRS), Newport Research Station, and two trials at the Pine Tree Research Station (PTRS) during the 2010-2011 growing season.

		Soil	Mehlich-3 extractable nutrients									
Site	SOM	pH	P[a]	K	Ca	Mg	S	Na	Fe	Mn	Cu	Zn
	(%)		(ppm)									
LMCRS	2.0	7.3	42	162	1296	381	13	20	167	90	1.6	4.3
Newport	3.5	5.4	49	142	1089	127	14	9	198	119	1.2	3.7
PTRS-Milo	2.6	7.2	10	176	1618	273	12	44	135	140	1.2	0.4
PTRS-Rice	2.4	7.7	26	122	2308	399	21	88	188	200	2.5	1.2

[a] Standard deviation (*n* = 5) of soil-test P in P trials was 3.2 ppm for LMCRS, 11.6 ppm for Newport, 0.7 ppm for PTRS-Milo, and 1.7 ppm for PTRS-Rice.

Table 2. Winter wheat grain yield as affected by P fertilizer rate at the Lon Mann Cotton Research Station (LMCRS), Newport, and two trials at the Pine Tree Research Station (PTRS), during the 2010-2011 growing season.

	Grain yield			
P rate	LMCRS	Newport	PTRS-Milo	PTRS-Rice
(lb P_2O_5/acre)	(bu/acre)			
0	67	92	66	88
30	67	90	74	88
60	69	86	74	91
90	68	86	77	89
120	71	94	75	90
150	69	94	71	87
LSD0.10	NS[a]	5	NS	NS
P-value	0.9802	0.0361	0.1370	0.8429
SDF contrast[b]	0.6414	0.1674	0.0087	0.4278

[a] NS = not significant ($P > 0.10$).
[b] SDF = single-degree-of-freedom contrast compares yields of wheat receiving no P against the yield of wheat receiving 60 to 120 lb P_2O_5/acre.

Table 3. Summary of wheat grain yield responses to P fertilization based on soil-test (Mehlich-3) P increments in the 0- to 4-in. depth.

Mehlich-3 soil P	Total sites	Responsive sites	Response frequency	No P avg. yield	No P yield averages[a] % Yield	Increase
(ppm)	(No.)	(% of sites)		(bu/acre)	(% of max)	(bu/acre)
≤10	4	4	100	49	79	12
11-20	8	4	50	69	90	6
21-30	10	5	50	57	87	8
31-40	4	1	25	76	94	5
41-50	5	0	0	63	94	4
>50	3	0	0	66	97	2

[a] % relative yield indicates the mean yield of wheat receiving no P compared to the maximum yield of wheat receiving P. 'Increase' indicates the yield difference between wheat receiving no P and the maximum yield of wheat receiving P.

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