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ARKANSAS
SOIL FERTILITY STUDIES
• 2008 •

Nathan A. Slaton, Editor

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WAYNE E. SABBE
ARKANSAS
SOIL FERTILITY STUDIES
– 2008 –

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SUMMARY

Rapid technological changes in crop management and production require that the research efforts also 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 2008 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 2007. 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.

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

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

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Soil Test and Fertilizer Sales Data: Summary for the 2008 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 Soil Testing and Research Laboratory in Marianna between 1 January 2007 and 31 December 2007 were categorized according to geographic area (GA), county, soil association number (SAN), and selected cropping systems. The soil analysis procedure was changed to a 1:10 soil:Mehlich-3 extraction ratio for soil nutrient concentrations beginning 1 January 2006. The GA and SAN were derived from the General Soil Map, State of Arkansas (Base 4-R-38034, USDA, and University of Arkansas AES, 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, Zn, etc.) concentrations indicate the relative level of soil fertility.

RESULTS AND DISCUSSION

Crop Acreage and Soil Sampling Intensity

Between 1 January 2007 and 31 December 2007, 115,126 soil samples were analyzed by the University of Arkansas Soil Testing and Research Laboratory in Marianna. After removing standard and check soils measured for quality assurance (9,598), the total number of client samples was 105,528. A total of 76,385 soil samples, representing a total of 1,830,585 acres averaging 24 acres/sample, had complete data for total acres, soil pH, P, K, and Zn. The difference of 28,017 samples between the total samples and samples with reported acreage were designated as grid samples conducted on row crops (25,504) or special or research samples (2,513). Soil samples from the Bottom Lands and Terraces and Loessial Plains, primarily row-crop areas, represented 60% of the total samples and 78% of the total acreage (Table 1). The average number of acres represented by each soil sample ranged from 2 to 72 acres/sample (Table 2). Clients from Jackson (10,966); Clay (Corning and Piggott offices, 4,209); Arkansas (Stuttgart and De Witt offices, 4,081); Washington (3,781); Craighead (3,612); Lee (3,231); and Crittenden (3,063) counties submitted the most soil samples for analyses. Sample numbers from Jackson County increased by almost 300% this year due to one client submitting 9,000 samples. Sample numbers submitted by clients in Washington County have increased by more than 100% from previous years, which is likely due to regulations concerning P and its relation to water quality in northwest Arkansas.

Soil association numbers show that most samples were taken from row-crop and pasture production areas (Table 3). The soil associations having the most samples submitted were 22 (Foley-Jackport-Crowley), 44 (Calloway-Henry-Grenada-Calhoun), 25 (Dundee-Bosket-Dubbs), 4 (Captina-Nixa-Tonti), and 45 (Crowley-Stuttgart). However, the soil associations representing the largest acreage were 44, 24 (Sharkey-Alligator-Tunica), 45, 25, and 22, which represented 15, 15, 13, 9, and 8% of the total sampled acreage, respectively. Crop codes indicate that land used for i) row crop production accounted for 80% of the sampled acreage and 55% of submitted samples, ii) hay and pasture production accounted for 19% of the sampled acreage and 27% of submitted samples, and iii) home lawns and gardens accounted for 1% of sampled acreage and 14% of submitted samples (Table 4).

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 soil samples, respectively. The soil-test levels and median (Md) 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 thus is 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. For example, soils used for cotton production have a history of intensive fertilization. Similarly, rice is commonly grown on soils with low P and

K concentrations, which may be an artifact of the management practices (i.e., flooded soil conditions) used rather than routine fertilization practices. The pH of most soils in Arkansas ranges from 5.5 to 6.5; however, the predominant soil pH range varies among GA (Table 5), county (Table 6), and last crop produced (Table 7).

Table 7 contains soil-test concentration ranges and the median concentrations for each of the cropping system categories. Soil-test concentration ranges, from low to high concentrations, can be categorized into soil-test levels of 'Very Low' to 'Low', 'Medium', 'Optimum', 'High', 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 the highest median concentrations of P and K. The highest median concentrations of Zn occur in soils used for non-row-crops (i.e., grass and ornamental) excluding vegetable. 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. However, fertilizer tonnage does not account for the use of fresh animal manures or other by-products as a source of nutrients that may be applied to the land. Only processed manures or biosolids (e.g., pelleted poultry litter) are quantified in fertilizer tonnage data under the category of 'Organic'.

Table 1. Sample number and total acreage by geographic area for soil samples submitted to the University of Arkansas Soil Testing and Research Laboratory in Marianna from 1 January 2007 through 31 December 2007.

Geographic area	Acres sampled	No. of samples	Acres/ sample
Ozark Highlands - Cherty Limestone and Dolomite	161,233	10,592	15
Ozark Highlands - Sandstone and Limestone	6,759	313	22
Boston Mountains	36,199	3,142	12
Arkansas Valley and Ridges	61,255	4,635	13
Ouachita Mountains	36,844	3,246	11
Bottom Lands and Terraces	863,484	30,416	28
Coastal Plain	65,731	4,339	15
Loessial Plains	490,834	11,961	41
Loessial Hills	19,774	1,301	15
Blackland Prairie	4,603	295	16

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 2007, 86% of the samples and 99% of the represented acreage had commercial agricultural/farm crop codes. Likewise, 97% 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 fertilizers (57%), multi-nutrient fertilizer blends (27%), K fertilizers (7%), micronutrient fertilizers (6%), and P fertilizers (2%). Five counties in eastern Arkansas (Arkansas, Poinsett, Mississippi, St. Francis, and Phillips) accounted for 32% of the total fertilizer sold.

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Table 2. Sample number and total acreage by county for soil samples submitted to the University of Arkansas Soil Testing and Research Laboratory in Marianna from 1 January 2007 through 31 December 2007.

County	Acres sampled	No. of samples	Acres/ sample	County	Acres sampled	No. of samples	Acres/ sample
Arkansas, De Witt	135,943	2,563	53	Lee	231,025	3,231	72
Arkansas, Stuttgart	62,503	1,518	41	Lincoln	3,594	237	15
Ashley	10,610	547	19	Little River	8,409	230	37
Baxter	2,620	472	6	Logan, Booneville	856	138	6
Benton	13,167	1,668	8	Logan, Paris	7,447	433	17
Boone	28,584	1,310	22	Lonoke	85,488	2,130	40
Bradley	822	92	9	Madison	14,216	899	16
Calhoun	303	72	4	Marion	7,492	273	27
Carroll	42,301	1,640	26	Miller	6,602	426	16
Chicot	20,216	473	43	Mississippi	33,715	1,234	27
Clark	2,217	344	7	Monroe	69,586	1,370	51
Clay, Corning	22,158	2,793	8	Montgomery	4,674	317	15
Clay, Piggott	31,747	1,416	22	Nevada	877	54	16
Cleburne	4,165	291	14	Newton	5,638	248	23
Cleveland	8,621	298	29	Ouachita	1,697	272	6
Columbia	3,128	357	9	Perry	2,480	171	15
Conway	9,909	409	24	Phillips	10,039	419	24
Craighead	97,555	3,612	27	Pike	8,752	356	25
Crawford	5,509	390	14	Poinsett	51,488	1,341	38
Crittenden	118,777	3,063	39	Polk	7,321	449	16
Cross	122,977	2,258	55	Pope	13,075	800	16
Dallas	783	72	11	Prairie, Des Arc	19,273	491	39
Desha	13,552	915	15	Prairie, De Valls Bluff	13,000	282	46
Drew	1,434	184	8	Pulaski	3,336	1,256	3
Faulkner	5,243	592	9	Randolph	18,046	1,354	13
Franklin, Charleston	635	29	22	Saline	1,748	399	4
Franklin, Ozark	7,981	376	21	Scott	2,343	150	16
Fulton	5,651	290	20	Searcy	5,107	337	15
Garland	2,079	1,030	2	Sebastian	7,572	786	10
Grant	503	145	4	Sevier	10,635	370	29
Greene	27,335	1,180	23	Sharp	2,999	250	12
Hempstead	16,045	611	26	St. Francis	7,810	328	24
Hot Spring	4,844	462	11	Stone	3,583	350	10
Howard	11,610	473	25	Union	1,087	247	4
Independence	17,102	646	27	Van Buren	4,513	398	11
Izard	6,673	447	15	Washington	42,849	3,781	11
Jackson	69,679	10,966	6	White	15,728	1,694	9
Jefferson	43,531	1,352	32	Woodruff	24,101	353	68
Johnson	7,608	442	17	Yell, Danville	6,819	419	16
Lafayette	8,206	184	45	Yell, Dardanelle	5,997	226	27
Lawrence	65,242	1,904	34				

Table 3. Sample number, total acreage by soil association number (SAN), average acreage per sample, and median soil pH and Mehlich-3 extractable P and K values by soil association for soil samples submitted to the University of Arkansas Soil Testing and Research Laboratory in Marianna from 1 January 2007 through 31 December 2007.

		Acres	No. of	Acres/	Median		
SAN	Soil association	sampled	samples	sample	pH	P	K
1.	Clarksville-Nixa-Noark	33,196	1,523	22	6.0	90	158
2.	Gepp-Doniphan-Gassville-Agnos	13,354	1,074	12	6.1	47	144
3.	Arkana-Moko	51,765	2,198	24	5.8	106	166
4.	Captina-Nixa-Tonti	56,384	5,477	10	6.0	112	171
5.	Captina-Doniphan-Gepp	3,906	178	22	5.9	60	149
6.	Eden-Newnata-Moko	2,628	142	19	5.4	81	137
7.	Estate-Portia-Moko	3,701	78	48	6.3	139	161
8.	Brockwell-Boden-Portia	3,058	235	13	5.7	48	121
9.	Linker-Mountainburg-Sidon	8,651	612	14	5.8	72	137
10.	Enders-Nella-Mountainburg-Steprock	27,548	2,530	11	5.7	91	134
11.	Falkner-Wrightsville	779	47	17	5.3	29	105
12.	Leadvale-Taft	22,815	1,984	12	5.6	62	127
13.	Enders-Mountainburg-Nella-Steprock	3,234	252	13	5.5	51	107
14.	Spadra-Guthrie-Pickwick	3,974	203	20	5.5	109	136
15.	Linker-Mountainburg	30,453	2,149	14	5.5	67	130
16.	Carnasaw-Pirum-Clebit	15,466	1,589	10	5.5	77	115
17.	Kenn-Ceda-Avilla	8,430	478	18	5.4	77	102
18.	Carnasaw-Sherwood-Bismarck	8,804	920	10	5.6	113	118
19.	Carnasaw-Bismarck	255	30	9	5.3	78	134
20.	Leadvale-Taft	1,256	59	21	5.6	76	115
21.	Spadra-Pickwick	2,633	170	16	5.5	70	135
22.	Foley-Jackport-Crowley	135,896	12,919	11	5.8	34	111
23.	Kobel	77,340	1,291	60	6.3	34	121
24.	Sharkey-Alligator-Tunica	259,077	3,375	77	6.0	51	228
25.	Dundee-Bosket-Dubbs	159,182	5,592	29	6.1	61	179
26.	Amagon-Dundee	41,706	1,422	29	5.9	62	171
27.	Sharkey-Steele	15,000	452	33	6.3	41	250
28.	Commerce-Sharkey-Crevasse-Robinsonville	32,303	779	42	6.4	53	227
29.	Perry-Portland	38,237	1,127	34	6.0	53	160
30.	Crevasse-Bruno-Oklared	351	16	22	5.1	31	87
31.	Roxana-Dardanelle-Bruno-Roellen	9,193	329	28	5.8	60	150
32.	Rilla-Hebert	83,757	2,788	30	6.2	51	162
33.	Billyhaw-Perry	5,167	103	50	6.1	39	242
34.	Severn-Oklared	4,032	63	64	5.6	58	148
35.	Adaton	140	4	35	6.0	36	112
36.	Wrightsville-Louin-Acadia	1,747	104	17	5.4	21	106
37.	Muskogee-Wrightsville-McKamie	356	52	7	6.2	135	199
38.	Amy-Smithton-Pheba	2,655	215	12	5.3	46	95
39.	Darco-Briley-Smithdale	1,248	29	43	6.1	29	117
40.	Pheba-Amy-Savannah	2,921	323	13	5.3	71	84
41.	Smithdale-Sacul-Savannah-Saffell	23,375	1,643	14	5.4	88	106
42.	Sacul-Smithdale-Sawyer	24,266	1,694	14	5.5	80	116
43.	Guyton-Ouachita-Sardis	11,266	435	26	5.5	76	115
44.	Calloway-Henry-Grenada-Calhoun	261,031	7,219	36	6.4	34	107
45.	Crowley-Stuttgart	229,803	4,742	48	6.5	29	109
46.	Loring	3,327	156	21	5.6	33	106
47.	Loring-Memphis	16,250	1,123	15	5.9	35	124
48.	Brandon	197	22	9	5.9	16	127
49.	Oktibbeha-Sumter	4,603	295	16	5.6	74	138

Table 4. Sample number and total acreage by previous crop for soil samples submitted to the University of Arkansas Soil Testing and Research Laboratory in Marianna from 1 January 2007 through 31 December 2007.

Crop	Acres sampled	No. of samples	Acres/ sample
Corn	100,689	2,057	49
Cotton	284,081	8,089	35
Grain sorghum, non-irrigated	9,682	217	45
Grain sorghum, irrigated	39,504	494	80
Rice	156,051	3,835	41
Soybean	701,330	15,080	47
Wheat	26,362	747	35
Cool-season grass hay	43,079	2,150	20
Native Warm-season grass hay	7,876	464	17
Warm-season grass hay	73,311	3,427	21
Pasture, all categories	191,528	8,549	22
Home garden	4,029	3,424	1
Home lawn	5,447	4,200	1
Small fruit	642	491	1
Ornamental	2,944	1,843	2

Table 5. Soil test data (% of sampled acres) and median (Md) values by geographic area for soil samples submitted to the University of Arkansas Soil Testing and Research Laboratory in Marianna from 1 January 2007 through 31 December 2007.

	Soil pH[z]						Mehlich-3 soil Zn[y] (ppm)						Mehlich-3 soil P[y] (ppm)						Mehlich-3 soil K[y] (ppm)					
Geographic area	<5.4	5.4-5.7	5.8-6.2	6.3-6.9	>6.9	Md[x]	<1.6	1.6-3.0	3.1-4.0	4.1-8.0	>8.0	Md	<16	16-25	26-35	36-50	>50	Md	<61	61-90	91-130	131-175	>175	Md
	---(% of sampled acreage) ---						--(% of sampled acreage) --					(ppm)	-- (% of sampled acreage)---					(ppm)	---- (% of sampled acreage) ----					(ppm)
Ozark Highlands - Cherty Limestone and Dolomite	21	20	24	21	14	5.9	2	10	8	28	52	8.5	4	7	7	10	72	98	6	13	18	18	45	163
Ozark Highlands - Sandstone and Limestone	21	23	22	24	10	5.9	4	23	10	27	36	5.3	11	13	11	11	54	63	7	20	23	21	29	132
Boston Mountains	31	22	23	17	7	5.7	2	13	10	29	46	7.3	4	7	7	10	72	87	10	17	21	17	35	134
Arkansas Valley and Ridges	40	21	18	13	8	5.5	4	15	11	29	41	6.5	10	11	10	11	58	65	10	19	23	17	31	127
Ouachita Mountains	42	22	18	13	5	5.5	3	13	11	29	44	7.0	7	7	7	11	68	84	16	20	22	15	27	115
Bottom Lands and Terraces	21	19	26	26	8	6.0	4	22	18	41	15	4.4	7	14	16	21	42	45	5	14	26	21	34	141
Coastal Plain	45	21	16	11	7	5.4	4	17	11	26	42	6.5	10	10	8	10	62	79	20	20	20	14	26	109
Loessial Plains	12	11	19	28	30	6.4	5	26	16	35	18	4.3	13	24	21	19	23	31	7	27	33	16	17	108
Loessial Hills	28	17	22	21	12	5.8	5	27	16	29	23	4.2	17	18	16	17	32	35	8	18	28	20	26	122
Blackland Prairie	40	19	23	10	8	5.6	3	18	7	28	44	6.5	10	9	8	9	64	74	9	16	21	18	36	138
Average	30	20	21	18	11	5.8	4	18	12	30	36	6.1	9	12	11	13	55	66	10	18	24	18	30	129

[z] Analysis by electrode in 1:2 soil weight:deionized water volume.

[y] Analysis by ICAP in 1:10 soil weight:Mehlich-3 volume.

[x] Md = median.

Table 6. Soil test data (% of sampled acres) and median (Md) values by county for soil samples submitted to the University of Arkansas Soil Testing and Research Laboratory in Marianna from 1 January 2007 through 31 December 2007.

	Soil pH^z						Mehlich-3 soil P^y (ppm)						Mehlich-3 soil K^y (ppm)						Mehlich-3 soil Zn^y (ppm)					
County	<5.4	5.4-5.7	5.8-6.2	6.3-6.9	>6.9	Md^x	<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	7	8	14	26	45	6.8	16	30	25	18	11	27	5	32	37	15	11	101	4	19	16	45	16	4.8
Arkansas, Stuttgart	15	16	22	26	21	6.2	12	22	21	22	23	33	3	17	34	17	29	125	6	25	15	40	14	4.3
Ashley	22	12	16	29	21	6.2	10	14	13	20	43	46	7	13	26	23	31	140	16	33	13	25	13	3.2
Baxter	11	9	16	19	45	6.8	5	10	10	15	60	76	4	8	24	23	41	156	1	7	7	24	61	10.0
Benton	21	18	20	27	14	6.0	3	5	7	10	75	93	4	9	15	20	52	179	1	7	7	34	51	8.2
Boone	14	18	27	23	18	6.1	2	5	9	10	74	104	6	11	15	17	51	183	2	11	8	27	52	8.7
Bradley	34	23	12	13	18	5.6	14	8	6	4	68	112	9	19	23	17	32	117	4	16	5	21	54	8.9
Calhoun	42	15	26	10	7	5.6	6	6	4	21	63	65	15	36	22	10	17	87	1	19	25	17	38	4.1
Carroll	20	25	29	18	8	5.8	1	4	4	7	84	128	4	10	15	17	54	189	1	6	5	24	64	10.7
Chicot	10	16	26	36	12	6.2	8	11	12	18	51	53	7	11	14	14	54	199	3	18	15	32	32	5.2
Clark	50	13	19	12	6	5.4	8	7	6	7	72	101	13	22	24	16	25	118	4	15	10	30	41	6.3
Clay, Corning	12	20	31	29	8	6.0	12	21	23	23	21	33	10	31	40	13	6	98	4	16	15	49	16	5.0
Clay, Piggott	11	16	32	35	6	6.1	3	7	10	18	62	59	2	11	27	29	31	145	3	23	20	41	13	4.3
Cleburne	43	20	16	16	5	5.5	6	9	6	11	68	88	9	18	25	14	34	130	19	14	12	27	28	7.1
Cleveland	27	20	18	23	12	5.8	7	16	14	19	44	45	8	15	14	17	46	163	8	36	15	19	22	3.4
Columbia	47	26	15	8	4	5.3	8	4	6	10	72	88	18	22	22	14	24	94	4	16	9	22	49	6.2
Conway	39	25	18	12	6	5.5	11	9	8	10	62	84	12	16	17	19	36	139	6	14	12	24	44	6.6
Craighead	14	16	23	28	19	6.2	14	20	18	20	28	34	12	24	27	16	21	109	5	21	15	35	24	4.7
Crawford	30	23	20	17	10	5.7	6	10	8	14	62	65	11	19	19	17	34	134	2	11	9	37	41	7.0
Crittenden	15	18	25	31	11	6.1	1	6	16	28	49	50	0	3	13	21	63	209	1	17	18	52	12	4.7
Cross	7	6	16	32	39	6.7	10	23	21	24	22	34	6	25	30	14	25	112	5	26	17	36	16	4.2
Dallas	58	19	14	7	2	5.2	13	15	8	25	39	41	31	29	21	10	9	77	6	25	13	33	23	4.4
Desha	11	14	31	31	13	6.2	2	6	10	22	60	58	1	6	19	19	55	189	8	28	17	36	11	3.9
Drew	63	9	12	11	5	4.9	47	10	5	6	32	17	29	21	19	10	21	90	4	18	11	25	42	6.1
Faulkner	42	17	16	18	7	5.5	20	15	11	12	42	40	15	24	22	16	23	106	6	24	15	30	25	4.5
Franklin, Charleston	55	28	4	4	9	5.3	4	14	31	7	44	41	7	28	24	10	31	101	4	17	0	35	44	5.9
Franklin, Ozark	42	22	21	12	3	5.4	8	8	6	11	67	96	5	17	24	16	38	137	1	10	10	29	50	7.8
Fulton	31	29	19	13	8	5.6	15	20	15	14	36	35	8	20	24	20	28	125	10	32	15	24	19	3.5
Garland	35	19	21	18	7	5.6	5	6	5	12	72	89	9	20	26	16	29	123	2	11	12	29	46	7.3
Grant	47	12	20	14	7	5.4	10	14	15	19	42	43	12	27	28	21	12	100	6	23	17	20	34	4.8
Greene	18	16	27	28	11	6.1	15	24	22	17	22	31	6	22	29	22	21	121	3	32	24	29	12	3.6
Hempstead	37	25	21	12	5	5.5	6	6	6	8	56	101	15	17	17	14	37	137	2	12	8	25	53	9.1
Hot Spring	43	21	17	14	5	5.5	8	14	9	9	60	68	21	20	20	12	27	104	2	16	14	37	31	5.5
Howard	40	24	12	11	13	5.5	8	9	4	5	74	150	9	12	12	15	52	181	3	7	9	24	57	10.3
Independence	20	21	25	21	13	5.9	10	13	12	14	51	52	9	14	27	24	26	130	3	17	12	33	35	5.8
Izard	34	22	25	15	4	5.7	12	14	13	14	47	48	16	32	23	12	17	93	8	32	15	27	18	3.7
Jackson	31	22	23	19	5	5.7	10	20	20	20	30	35	7	21	37	22	13	113	4	26	19	39	12	4.1
Jefferson	17	14	24	31	14	6.2	5	7	14	26	48	49	5	13	26	19	37	142	9	27	20	28	16	3.8
Johnson	34	20	22	16	8	5.7	10	12	10	11	57	74	9	16	20	15	40	148	4	14	10	31	41	6.8
Lafayette	38	25	19	9	9	5.6	5	3	7	9	76	98	4	9	22	23	42	154	9	20	11	20	40	5.7
Lawrence	14	18	29	28	11	6.1	19	28	19	17	17	27	11	22	30	19	18	111	5	27	19	38	11	4.0
Lee	21	19	25	25	10	5.9	1	6	13	27	53	52	2	8	21	22	47	168	8	35	16	33	8	3.5
Lincoln	30	19	22	23	6	5.8	9	7	8	16	60	72	8	11	14	12	55	183	0	13	14	35	38	6.3
Little River	48	17	13	9	13	5.4	26	21	10	11	32	28	20	19	23	14	24	103	10	29	14	31	16	3.8

continued

Table 6. Continued.

County	Soil pH^z						Mehlich-3 soil P^y (ppm)						Mehlich-3 soil K^y (ppm)						Mehlich-3 soil Zn^y (ppm)					
	<5.4	5.4-5.7	5.8-6.2	6.3-6.9	>6.9	Md	<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	44	25	15	13	3	5.4	12	13	9	19	47	45	9	15	30	14	32	122	3	15	11	29	42	6.5
Logan, Paris	44	31	15	8	2	5.4	13	10	9	13	55	63	19	23	19	16	23	106	2	13	11	37	37	6.6
Lonoke	19	18	29	27	7	6.0	10	20	19	20	31	36	6	18	33	20	23	121	9	35	18	27	11	3.3
Madison	30	28	26	14	2	5.7	2	4	5	7	82	133	8	14	16	16	46	162	1	6	10	27	56	9.1
Marion	22	17	21	24	16	6.0	3	12	8	11	66	72	4	14	19	23	40	154	2	14	13	31	40	6.1
Miller	45	18	14	12	11	5.5	9	8	11	12	60	66	18	17	21	18	26	117	4	18	12	25	41	6.1
Mississippi	16	18	31	29	6	6.0	0	1	3	12	84	74	0	1	4	16	79	241	0	6	14	66	14	5.4
Monroe	9	7	17	35	32	6.6	20	23	19	22	16	29	6	26	36	18	14	108	6	33	17	33	11	3.6
Montgomery	50	23	14	9	4	5.4	2	4	12	12	70	86	24	20	20	10	26	106	2	10	14	32	42	6.6
Nevada	44	16	25	12	3	5.5	17	9	7	7	60	65	13	16	31	14	26	112	6	21	13	20	40	5.8
Newton	21	21	22	22	14	6.0	2	6	10	11	71	78	6	16	17	18	43	160	2	18	12	37	31	5.6
Ouachita	60	12	12	11	5	5.2	18	9	12	7	54	61	31	26	18	13	12	82	9	24	12	25	30	4.7
Perry	44	21	22	8	5	5.4	16	9	10	9	56	62	9	17	22	16	36	135	5	24	11	25	35	4.9
Phillips	16	12	26	36	10	6.2	1	4	12	27	56	53	2	11	19	35	33	153	4	30	23	26	17	3.8
Pike	54	22	12	10	2	5.3	6	7	10	11	66	84	37	22	18	10	13	77	7	16	11	27	39	6.4
Poinsett	5	9	18	24	44	6.7	12	25	20	18	25	31	13	32	24	12	19	96	2	12	12	40	34	6.2
Polk	53	21	13	9	4	5.3	5	6	8	14	67	82	25	22	20	12	21	98	5	16	11	27	41	6.2
Pope	34	22	19	16	9	5.6	8	10	9	10	63	75	12	17	22	16	33	129	6	12	10	29	43	7.0
Prairie, Des Arc	22	17	23	26	12	5.9	15	26	23	20	16	29	6	34	38	13	9	98	9	32	18	24	17	3.5
Prairie, De Valls Bluff	13	7	15	38	27	6.6	14	40	26	14	6	24	5	35	41	11	8	98	4	32	21	33	10	3.6
Pulaski	36	16	14	20	14	5.7	8	7	8	11	66	84	8	17	29	20	26	124	2	9	7	29	53	8.5
Randolph	15	14	23	34	14	6.2	13	20	20	20	27	34	6	22	28	19	25	122	4	23	18	37	18	4.4
Saline	41	18	17	15	9	5.5	16	13	8	9	54	60	27	17	19	17	20	101	4	24	11	27	34	5.1
Scott	42	21	24	11	2	5.5	17	12	9	7	55	59	13	24	17	17	29	121	4	19	17	28	32	5.4
Searcy	43	19	21	13	4	5.5	5	8	7	10	70	77	5	15	24	22	34	142	5	22	17	30	26	4.6
Sebastian	36	18	17	15	14	5.7	11	14	10	9	56	61	8	17	28	22	25	127	1	10	8	29	52	8.6
Sevier	40	27	22	4	7	5.5	9	10	9	10	62	93	25	13	17	12	33	115	3	15	8	26	48	7.7
Sharp	14	16	26	22	22	6.1	13	14	13	12	48	46	6	13	20	27	34	148	5	24	12	25	34	4.7
St. Francis	23	17	23	28	9	6.0	3	13	19	26	39	44	2	17	20	18	43	164	3	20	21	30	26	4.4
Stone	41	21	19	12	7	5.5	6	7	7	9	71	85	6	18	26	22	28	129	5	16	12	33	34	5.6
Union	46	17	15	17	5	5.4	11	13	7	8	61	66	19	28	22	18	13	97	7	11	9	27	46	7.3
Van Buren	34	23	20	16	7	5.6	6	10	10	11	63	67	14	20	23	14	29	121	9	26	11	26	28	4.4
Washington	19	19	25	21	16	6.0	4	6	5	8	77	125	7	12	17	17	47	167	2	7	6	25	60	10.6
White	31	17	22	20	10	5.8	6	10	11	11	62	67	12	21	23	16	28	117	3	15	11	28	43	6.9
Woodruff	17	17	28	27	11	6.0	10	22	21	20	27	34	7	24	36	20	13	110	4	30	21	34	11	3.8
Yell, Danville	42	32	18	7	1	5.4	7	5	4	6	78	128	12	16	18	19	35	141	1	6	4	25	64	10.3
Yell, Dardanelle	45	25	14	8	8	5.4	7	10	4	15	64	66	15	17	21	14	33	123	8	25	9	26	32	5.0
Average	31	19	20	19	11	5.8	10	12	12	14	52	64	11	19	23	17	30	130	5	19	13	30	33	5.8

[z] Analysis by electrode in 1:2 soil weight:deionized water volume.

[y] Analysis by ICAP in 1:10 soil weight:Mehlich-3 volume.

[x] Md = median.

Table 7. Soil test data (% of sampled acres) and median (Md) values by previous crop for soil samples submitted to the University of Arkansas Soil Testing and Research Laboratory in Marianna from 1 January 2007 through 31 December 2007.

	Soil pH[z]						Mehlich-3 soil Zn[y] (ppm)						Mehlich-3 soil P[y] (ppm)						Mehlich-3 soil K[y] (ppm)					
Geographic area	<5.4	5.4-5.7	5.8-6.2	6.3-6.9	>6.9	Md[x]	<1.6	1.6-3.0	3.1-4.0	4.1-8.0	>8.0	Md	<16	16-25	26-35	36-50	>50	Md	<61	61-90	91-130	131-175	>175	Md
	---(% of sampled acreage) ---						--(% of sampled acreage) --					(ppm)	-- (% of sampled acreage)---					(ppm)	---- (% of sampled acreage) ----					(ppm)
Corn	17	19	27	26	11	6.0	5	23	17	40	15	4.4	4	10	15	29	42	47	3	12	28	25	32	141
Cotton	11	18	31	32	8	6.1	6	23	19	41	11	4.2	0	2	7	19	72	64	1	3	13	27	56	186
Grain sorghum, non-irrigated	42	18	17	15	8	5.5	1	21	17	46	15	4.7	3	10	11	26	50	51	3	16	28	17	36	140
Grain sorghum, irrigated	42	25	15	12	6	5.5	3	21	17	50	9	4.5	3	5	14	30	48	50	2	8	13	14	63	230
Rice	11	12	23	32	22	6.3	4	25	18	38	15	4.3	20	26	22	19	13	27	8	21	26	15	30	121
Soybean	9	12	22	31	26	6.4	4	23	17	41	15	4.4	10	23	23	23	21	33	6	24	32	16	22	113
Wheat	41	21	19	11	8	5.5	6	29	17	37	11	4.0	6	12	14	26	42	45	4	11	23	22	40	154
Cool-season grass hay	25	23	30	18	4	5.8	2	16	12	29	41	6.5	5	7	7	9	72	85	11	15	19	16	39	143
Native Warm-season grass hay	48	22	15	11	4	5.4	8	24	15	28	25	4.2	20	20	12	12	36	34	24	22	24	14	16	96
Warm-season grass hay	36	23	23	15	3	5.6	3	16	9	27	45	6.9	7	8	9	10	66	91	16	20	21	16	27	115
Pasture, all categories	36	26	23	12	3	5.6	3	14	11	28	44	6.8	9	9	8	9	65	80	11	16	19	16	38	141
Home garden	15	10	16	27	32	6.5	1	7	5	19	68	13.7	3	4	4	5	84	173	3	9	15	15	58	194
Home lawn	37	17	17	18	11	5.7	2	11	11	37	39	6.7	6	8	9	13	64	67	6	15	26	24	29	137
Small fruit	47	16	14	16	7	5.5	4	17	14	32	33	5.3	5	8	7	12	68	83	6	24	24	17	29	124
Ornamental	21	10	15	26	28	6.4	1	6	5	20	68	12.9	6	6	5	8	75	109	7	14	21	19	39	148
Average	29	18	21	20	12	5.8	4	18	14	34	30	6.2	7	11	11	17	54	69	7	15	22	18	38	146

[z] Analysis by electrode in 1:2 soil weight:deionized water volume.

[y] Analysis by ICAP in 1:10 soil weight:Mehlich-3 volume.

[x] Md = median.

Table 8. Fertilizer tonnage sold in each Arkansas county from 1 July 2007 through 30 June 2008[z].

County	Fertilizer sold	County	Fertilizer sold
	(tons)		(tons)
Arkansas	92,858	Lee	18,579
Ashley	17,612	Lincoln	13,703
Baxter	1,693	Little River	4,168
Benton	13,215	Logan	1,566
Boone	2,049	Lonoke	48,825
Bradley	1,055	Madison	3,366
Calhoun	188	Marion	712
Carroll	1,235	Miller	7,871
Chicot	32,518	Mississippi	64,319
Clark	893	Monroe	31,074
Clay	44,243	Montgomery	204
Cleburne	1,065	Nevada	527
Cleveland	8	Newton	520
Columbia	217	Ouachita	221
Conway	6,044	Perry	480
Craighead	49,010	Phillips	50,771
Crawford	2,999	Pike	2,866
Crittenden	19,939	Poinsett	67,376
Cross	34,477	Polk	941
Dallas	2,625	Pope	1,667
Desha	36,694	Prairie	28,390
Drew	9,103	Pulaski	9,100
Faulkner	2,941	Randolph	16,807
Franklin	910	Saline	1,674
Fulton	763	Scott	193
Garland	1,567	Searcy	871
Grant	719	Sebastian	1,604
Greene	32,488	Sevier	502
Hempstead	2,411	Sharp	783
Hot Spring	1,935	St. Francis	51,278
Howard	633	Stone	1,052
Independence	7,424	Union	3,062
Izard	1,467	Van Buren	5,342
Jackson	24,618	Washington	3,014
Jefferson	38,062	White	22,402
Johnson	786	Woodruff	33,905
Lafayette	6,375	Yell	531
Lawrence	22,624		

[z] Arkansas Distribution of Fertilizer Sales by County July 1, 2007 to June 30, 2008, Arkansas State Plant Board, Division of Feed and Fertilizer, Little Rock, Ark., and University of Arkansas AES, Fayetteville, Ark.

Table 9. Fertilizer nutrient, formulation, and use category sold in Arkansas from 1 July 2007 through 30 June 2008[z].

	Container			Use		
Fertilizer	Bag	Bulk	Liquid	Farm	Non-farm	Totals
	--- (tons) ---					
Multi-nutrient	24,857	242,673	15,741	267,507	15,764	283,271
Nitrogen	8,585	456,559	93,678	557,784	1,038	558,822
Phosphate	138	19,219	566	19,886	36	19,923
Potash	473	69,799	800	70,725	347	71,072
Organic	34	175	0	175	34	209
Micronutrient	1,823	53,202	2,523	56,687	861	57,548
Lime	374	8,092	0	8,428	36	8,466
Miscellaneous	13,353	880	190	1,239	13,184	14,423
Totals	49,637	850,599	113,498	982,431	31,300	1,013,734

[z] Arkansas Distribution of Fertilizer Sales By Counties 1 July 2007-30 June 2008, Arkansas State Plant Board, Division of Feed and Fertilizer, Little Rock, Ark., and University of Arkansas Agricultural Experiment Station, Fayetteville, Ark.

Phosphorus Fertilization Increases Seedcotton Yield In Arkansas

M. Mozaffari, N.A. Slaton, J. Long, J. Osborn, and M. Hamilton

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Phosphorus (P) is important for balanced plant nutrition and producing optimal cotton (*Gossypium hirsutum* L.) yield. Improved P-fertilizer recommendations will enable cotton growers to get a sound return on their fertilizer investment and reduce the risk of potential environmental concerns over eutrophication of water supplies. Advances in production practices have increased cotton yields in Arkansas during the last three decades. Consequently, the optimal P-fertilizer rates or critical soil-test P values may have changed. Therefore, a need exists for updated information on cotton response to P fertilization with the soil conditions and cropping practices common to eastern Arkansas. The objective of this study was to evaluate the effect of P-fertilizer rate on seedcotton yield and soil-test P concentration on a soil commonly used for cotton production in Arkansas.

PROCEDURES

A replicated field experiment was conducted on a Commerce silt loam on a commercial farm in Crittenden County, Ark., in 2008. This field has been in continuous cotton for the last three years. Before application of any soil amendments, a composite (8 to 10 cores) soil sample was collected from the 0- to 6-inch depth of each replication (n=4). Soil samples were oven dried at 65°C, crushed, extracted with Mehlich-3 solution, and the elemental concentrations were measured by inductively coupled plasma atomic emission spectroscopy. Soil particle size was determined on composite samples collected from the first and second replications using the hydrometer method (Arshad et al., 1996). Soil pH was measured in a 1:2 (volume:volume) soil-water mixture. Composite soil samples were also collected from 0- to 6-inch depth of each plot after cotton harvest and processed as described before.

Cotton cultivar Stoneville 5590 was planted by the cooperating grower on 24 May 2008 into a conventionally tilled seedbed. Triple superphosphate (0-46-0) was applied to the soil surface at rates of 0, 30, 60, 90 and 120 lb P_2O_5/acre on 5 June. A blanket application of 80 lb K_2O/acre (as 0-0-60) was applied to the research area on the same date. Urea was applied by the grower to supply 100 lb N/acre in mid-June. Individual plots were 40-ft long and 10-ft wide allowing for four rows of cotton with 30-inch-wide row spacings. Cultural management practices closely followed the University of Arkansas recommendations for irrigated-cotton production. Irrigation timing was managed by the cooperating grower. Plants in a 10-ft-long section of one center row were hand-picked on 20 October and used to calculate seedcotton yield.

The experiment was a randomized complete block design with four replications. Analysis of variance was performed using the GLM procedure of SAS to determine the effect of P-fertilizer rate on seedcotton yield and post-harvest, Mehlich-3-extractable P. Mean separations were performed using the Waller-Duncan minimum significant difference (MSD) test at significance level of 0.10.

RESULTS AND DISCUSSION

Soil at the research site contained 33% sand, 42% silt, 25% clay, and had an average soil pH of 7.9 (Table 1). Mehlich-3-extractable P was 20 ppm, which is interpreted as 'Low' with a corresponding recommendation for cotton of 70 lb P_2O_5/acre to build soil-test P and maximize cotton yields. Cotton plants grown in soil receiving no P fertilizer appeared stunted and, by harvest, were visibly shorter than plants receiving P, suggesting that a positive yield response to P fertilization would occur. In 2007, we also observed that cotton grown in another location in this field responded positively to P-fertilization (Mozaffari et al., 2008).

Yields ranged from 1889 to 3275 lb seedcotton/acre and, compared to the no P control, seedcotton yield was significantly increased by all rates of P fertilization (Table 2). Cotton receiving the greatest P rate produced the highest cotton yield, which was significantly greater than yields of cotton receiving $\leq$60 lb P_2O_5/acre. Application of 90-120 lb P_2O_5/acre produced maximal seedcotton yields, which were about 70% higher than cotton receiving no P.

Phosphorus-fertilizer rate also significantly increased post-harvest soil-test P (Table 2). Post-harvest, soil-test P in soil receiving no P was 17 ppm compared to the average of 20 ppm before planting. Soil-test P in soil receiving P fertilizer increased as P rate increased and ranged from 22 to 46 ppm. Application of 120 lb P_2O_5/acre increased the soil-test P level from 'Low' to 'Optimum.'

PRACTICAL APPLICATION

Application of P fertilizer significantly increased seedcotton yield in a Commerce silt loam having ‘Low’ Mehlich-3-extractable soil P. Current soil-test-based P-fertilizer recommendations would have recommended 70 lb P_2O_5/acre and although seedcotton yields would have been increased by this application rate, yields would not have been maximized. The maximum P fertilizer rate currently recommended is 90 lb P_2O_5/acre for soils having ‘Very Low’ soil-test P (<16 ppm). For the past two years, trials conducted in this field suggest that cotton grown in soils with ‘Low’ soil-test P should respond positively to P fertilization. Additional research is needed to properly correlate and calibrate the soil-test-based, P-fertilizer recommendations for cotton. Results from this experiment will be added to a database on cotton response to P fertilization so that recommendations can be verified and/or revised once sufficient data have been collected.

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Table 1. Selected soil chemical and particle size property means (0- to 6-inch depth) for soil samples taken before adding any fertilizer to a cotton P-fertilization trial conducted on a commercial farm in Crittenden County, Ark., during 2008.

Location	Soil	Soil	Mehlich-3 extractable nutrients							Particle size analysis			
	pH^z	NO_3-N^y	P	K	Ca	Mg	Mn	Cu	Zn	Sand	Silt	Clay	Texture
		(ppm)								(%)			
CRIG71	7.9	30	20	110	2294	474	125	2.9	3.8	33	42	25	loam

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

[y] NO_3-N measured by ion-specific electrode.

Table 2. Effect of soil-applied P-fertilizer rate on seedcotton yield and post-harvest, soil-test P for a trial established in Crittenden County, Ark., during 2008.

P-fertilizer rate	Seedcotton yield	Post-harvest soil-test P
(lb P_2O_5/acre)	(lb/acre)	(ppm)
0	1899	17
30	2491	22
60	2753	24
90	2805	37
120	3275	46
P value	0.0026	0.0009
MSD at 0.10[z]	407	9

[z] Minimum significant difference at P=0.10 as determined by Waller-Duncan Test.

Potassium Fertilization Increases Seedcotton Yield in a Silt Loam

M. Mozaffari, N.A. Slaton, and J.R. Long

BACKGROUND INFORMATION AND RESEARCH PROBLEM

A high-quality and -yielding cotton crop (*Gossypium hirsutumn* L.) requires more potassium (K) than any other nutrient with the exception of nitrogen (N). Plant demand for K is particularly high during fruit development and K deficiency can seriously limit cotton yield potential (Oosterhuis et al., 2003). Modern cotton cultivars mature faster and have higher yield potential than obsolete cultivars. Information on cotton response to K fertilization under current production practices will aid in developing agronomically sound K-fertilizer recommendations. The objective of this experiment was to evaluate the effect of K-application rate on seedcotton yield and Mehlich-3-extractable soil K for a modern cotton cultivar grown using production practices common to Arkansas.

PROCEDURES

The 2008 growing season was the fifth year of a replicated, continuous-cotton K-fertilization experiment on a Convent silt loam at the University of Arkansas Lon Mann Cotton Research Station in Marianna, Ark. Prior to 2008, the experimental design was a randomized complete block arranged in a split-plot structure where cotton cultivar was the main-plot factor and K rate (0, 30, 60, 90, 120 and 150 lb K_2O/acre) was the sub-plot factor. During the first four years of study, the cultivar-by-K-fertilizer rate interaction never significantly affected seedcotton yield or post-harvest, soil-test K. Therefore, in 2008, cultivar was removed as an experimental treatment, resulting in a simple randomized complete block design of six K-rates with each K rate replicated eight times. The same K-rates were applied to the same plots, a practice established and followed since 2004. Each individual plot was 43-ft long and 12.5-ft wide allowing for four rows of cotton with 38-inch-wide row spacings.

Prior to application of any soil amendments, six soil cores were collected from the 0- to 6-inch depth of each plot and composited. The same procedure was followed in the fall after cotton harvest. Soil samples from each plot were oven dried at 65°C, crushed, and extracted with Mehlich-3 solution and the elemental concentrations were measured by inductively coupled plasma atomic emission spectroscopy. Soil pH was measured in a 1:2 (volume:volume) soil-water mixture. Soil particle size analysis was determined by the hydrometer method (Arshad et al., 1996).

On 12 May 2008, urea (46-0-0) and triple superphosphate (0-46-0) were broadcast-applied to supply 60 lb N and 46 lb P_2O_5/acre, respectively. All K-fertilizer treatments were broadcast on the same day and incorporated with a Do-All. An additional 50 lb N/acre as urea were broadcast onto all plots on 8 July. Cotton ('Stoneville 4554B2RF') was seeded into a conventionally tilled seedbed on 22 May, emerged on 1 June, and pests were managed using recommended practices. Cotton was irrigated as needed and managed using the University of Arkansas Cooperative Extension Service Irrigation Scheduler program. Cotton was harvested with a spindle-type mechanical picker on 4 November. Analysis of variance was performed to evaluate the effect of annual K application rate on seedcotton yield and soil-test K using the PROC GLM procedure of SAS. Significant treatment means were separated by the Waller-Duncan minimum significant difference (MSD) test when appropriate ($P < 0.10$).

RESULTS AND DISCUSSION

Averaged across soil samples collected before seeding, the average soil pH was 6.8 and Mehlich-3-extractable P was 60 ppm (Above Optimum, Table 1). Previous annual K-fertilizer application rate had significantly influenced preplant soil-test K, producing mean soil-test K values ranging from 93 to 143 ppm K (Table 2). Soil-test K increased as annual K-fertilizer rate increased with the annual K rates of 0 to 120 lb K_2O/acre being interpreted as Medium and the highest K rate (150 lb K_2O/acre) having an Optimum soil-test K level. Post-harvest, soil-test K was also significantly influenced by annual K-fertilizer rate with mean values ranging from 82 to 125 ppm (Table 2). Annual K-fertilizer application rate significantly increased seedcotton yield in 2008 (Table 2). Potassium application rates >30 lb K_2O/acre significantly increased seedcotton yields compared to the no K control. The greatest yield was produced with the highest annual K-fertilizer rate.

PRACTICAL APPLICATION

Annual K-fertilization rate significantly increased seedcotton yield in 2008. Current soil-test-based recommendations would have recommended 60 lb K_2O/acre be applied to soil from all annual K rates except the highest annual rate (150 lb K_2O/acre), which would have received a recommendation for 40 lb K_2O/acre to aid in maintaining an Optimum soil-test K level. The highest annual K rate also produced the greatest seedcotton yield, suggesting that more short- and long-term research is needed to better define soil-test-based, K-fertilizer recommendations for cotton. Data collected during the past five years suggest that K-fertilization is an important component of cotton fertilization and is essential for maximizing cotton yield potential.

ACKNOWLEDGMENTS

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Table 1. Selected soil chemical and physical property means (0- to 6-inch depth) for soil samples taken before adding any fertilizer to a K-fertilization trial conducted with cotton during 2008 on a Convent silt loam at the Lon Mann Cotton Research Station in Marianna, Ark.

	Soil	Soil	Mehlich-3 extractable nutrients							Particle size analysis			
Location	pH[z]	NO_3-N[y]	P	K	Ca	Mg	Mn	Cu	Zn	Sand	Silt	Clay	Texture
		(ppm)								(%)			
LEG87	6.8	15	60	115	2169	314	165	1.3	2.1	14	63	23	silt loam

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

[y] NO_3-N measured by ion-specific electrode.

Table 2. Mean Mehlich-3 soil-test K concentrations in spring (preplant) and fall (post-harvest) 2008 and seedcotton yield as affected by annual K-fertilizer rate during the 5th year (2008) of a continuous-cotton, K-fertilization trial conducted on a Convent silt loam at the Lon Mann Cotton Research Station in Marianna, Ark.

Annual	Mehlich-3 soil-test K		
K-fertilizer rate	Preplant	Post-harvest	Seedcotton yield
(lb K_2O/acre)	--------------------------(ppm)	----------------------------	(lb/acre)
0	93	82	2973
30	100	87	3244
60	110	96	3457
90	114	104	3696
120	126	108	3937
150	143	125	4317
MSD[z] 0.10	9	8	283
P value	<0.0001	<0.0001	<0.0001

[z] Minimum significant difference at P=0.10 as determined by Waller-Duncan Test.

Seedcotton Yield Response to Biosolids, Poultry Manure, and Urea in Two Soils

M. Mozaffari, N.A. Slaton, J.R. Long, L.A. Fowler, and F.M. Bourland

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Cotton (*Gossypium hirsutum* L.) yield in Arkansas is usually increased by nitrogen (N) fertilization. In recent years, record high synthetic-fertilizer prices coupled with desire for improving soil quality and recycling nutrients have rekindled interest in using various byproducts as alternative fertilizer sources. Fresh (FPL) and pelleted poultry litter (PPL) are two examples of alternative fertilizers available to Arkansas cotton producers. A heat-dried, pelleted biosolid is now being sold as a low-grade, high-organic matter fertilizer under the trade name Top Choice Organic (TCO)[1] by some fertilizer dealers in Arkansas. Unfortunately, there is very little information on crop and soil response to biosolid, FPL, or PPL under the production systems common to eastern Arkansas. Replicated field studies to evaluate cotton and soil response to FPL, PPL, and TCO are needed to provide information to cotton producers who might be interested in incorporating these products into their crop fertilization programs. The specific objective of this project was to evaluate cotton yield response to FPL, PPL, TCO, and urea-N fertilizer on two soils commonly used for cotton production in the Mississippi River Delta Region of Arkansas.

PROCEDURES

Replicated field experiments were conducted at two locations on soils representing those commonly used for cotton production in Arkansas (Table 1). The experimental sites included a Sharkey clay at the University of Arkansas Northeast Research and Extension Center in Mississippi County (MSG82) and a Dundee silt loam at the Judd Hill Plantation Cooperative Research Farm in Poinsett County (POG82). Prior to application of any soil amendment, a composite soil sample (8 to 10 cores) was collected from the 0- to 6-inch depth of each replication. Soil samples were oven-dried, crushed; soil pH was measured in a 1:2 (volume:volume) soil-water mixture; soil nitrate was extracted with 0.025 *M* aluminum sulfate and measured with a specific-ion electrode (Donahue, 1992); and other soil nutrients were extracted with Mehlich-3 solution and the concentration of selected elements in the extracts was measured by inductively coupled plasma atomic emission spectroscopy (Dahlquist and Knoll, 1978). Soil organic matter was measured by weight loss-on-ignition and particle size analysis was performed by the hydrometer method (Arshad et al., 1996). Selected soil property means for both sites are listed in Table 2. The research areas were fertilized with KCl (0-0-60) and triple superphosphate (0-46-0) to supply 120 lb K_2O and 46 lb P_2O_5/acre, respectively.

Each study was arranged as a randomized complete block design with a factorial arrangement of four N-fertilizer sources (FPL, PPL, TCO, and urea) and five N rates plus a no N control. Each treatment was replicated five times. Each plot was 40-ft long and 12.6-ft wide allowing for four rows of cotton with 38-inch-wide row spacings. Each N source was applied at 30, 60, 90, 120, and 150 lb total N/acre (Table 3). The FPL used for the MSG82 was provided by a local manure-hauling contractor from Batesville, Ark., and FPL used for POG82 was from a litter-baling facility in northwest Arkansas. Pelleted poultry litter was purchased from a local fertilizer dealer and TCO was provided by MANCO Fertilizer Company (http://manncofertilizer.com/products.html). Sub-samples of each organic-N source were analyzed by the University of Arkansas Agricultural Diagnostic Laboratory using standard methods (Peters et al., 2003). Each organic N source was applied based on the total N analysis listed in Table 4.

Nitrogen treatments were hand-applied onto the soil surface and incorporated with a Do-All before planting (Table 1). Cotton ('Stoneville 4554B2RF') was planted on 7 and 21 May. Conventional tillage and pest management practices were followed and irrigation was managed according to the University of Arkansas Cooperative Extension Service Irrigation Scheduler Program. The center two rows of cotton in each plot were harvested with a spindle-type picker. Analysis of variance was performed using the GLM procedure of SAS. Sites were analyzed separately. When appropriate, mean separations were performed by the Waller-Duncan minimum significant difference (MSD) method at a significance level of 0.10.

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[1] 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, or exclusion of any other product that may perform similarly.

RESULTS AND DISCUSSION

Properties of Soil Amendments and Soil

Total N content of organic N sources, on as-is basis, ranged from 2.36% for FPL to 6.28% for TCO (Table 4). Organic N was the predominant form of N and NH_4-N was the predominant form of inorganic N. Top Choice Organic biosolid had the highest total P and C contents and the lowest moisture, total K, and C/N ratio. Analysis of soil samples collected before application of treatments indicated that the soil texture at POG82 was loam and at MSG82 was clay (Table 2). Mehlich-3-extractable P and K were 'Above Optimum' at both sites. Soil NO_3-N ranged from 4 to 9 ppm, suggesting cotton would respond positively to N fertilization at both sites.

Seedcotton Yield

The N-source-by-N-rate interaction had no significant influence on seedcotton yield at either site (Table 5). Averaged across N sources, N rate significantly increased seedcotton yield at MSG82, but not at POG82. At MSG82, averaged across all N sources, seedcotton yield ranged from 1,228 to 2,379 lb/acre and increased numerically and often significantly with increasing N-rate. When averaged across all N sources, application of 90 to 120 lb total-N/acre produced maximum seedcotton yields (Table 5). Although the interaction was not significant, data for MSG82 suggest that 90 lb urea-N/acre produced maximum seedcotton yields of about 3,000 lb/acre. In contrast, application of 150 lb total N/acre as FPL and TCO failed to increase yields above 2,000 and 2,500 lb/acre, respectively. Lack of response to N fertilizer rate at POG82 was somewhat unexpected, but we observed visual symptoms consistent with mild verticillium wilt across the field during the growing season. Cotton receiving no N produced relatively high yields and, regardless of N source and rate, N fertilizer increased seedcotton yields by <700 lb/acre.

Compared with the no N control, all N sources, averaged across N rates, significantly increased seedcotton yields, which ranged from 1,228 to 2,667 lb/acre at MSG82 (Table 6). At MSG82, seedcotton yields were greatest when urea was the N source, intermediate for cotton receiving TCO, and lowest for cotton receiving FPL and PPL. At POG82, seedcotton yields receiving urea were similar to the no N control and lowest among the four N sources. Cotton receiving TCO, FPL, and PPL produced similar yields that were numerically higher than yields produced with urea and always significantly greater than cotton receiving no N. Cotton yield results from each N rate and N source combination at POG82 (Table 5) suggest that cotton yields tended to decline as urea-N rate increased, but remained relatively constant across TCO-, FPL-, and PPL-N rates.

PRACTICAL APPLICATION

Fresh poultry litter, PPL, and TCO appear to have utility as low-grade macronutrient fertilizers for cotton production in Arkansas. The results of this one-year study on two representative soils in eastern Arkansas suggest that all N-fertilizer sources significantly increased seedcotton yield. However, on soils that require significant amounts of N to produce maximal yields, such as MSG82, the organic-N sources (TCO, FPL, and PPL) failed to produce seedcotton yields comparable to urea. Thus, the results from MSG82 suggest that TCO, FPL, and PPL can be used to provide some proportion of the cotton crop's N requirement and perhaps recommended amounts of P and/or K. Lack of cotton response to N rate at POG82 was attributed in part to mild verticillium wilt disease and perhaps high residual N in the soil profile that was not accounted for in the 6-inch-deep soil samples collected before planting. Additional field studies are needed to confirm the reproducibility of these results across sites and cropping seasons.

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Table 1. Selected agronomic information and dates of importance for two experiments conducted to evaluate the effect of N source and rate on cotton yield during 2008.

Site ID	Soil series	Previous crop	Soil amendments application date	Cotton planted	Predicted 1st square[z]	Predicted bloom[z]	Predicted 1st open boll[z]	Harvest date
MSG82	Sharkley clay	Corn	20-May	21-May	8-June	25-June	2-August	11-October
POG82	Dundee silt loam	Cotton	5-May	7-May	9-June	28-June	5-August	1-October

[z] Assuming that 475, 825, and 1675 Degree Days >60°F is required from planting to first square, first flower, and first open boll, respectively, as suggested by Oosterhuis, 1990.

Table 2. Selected soil chemical property and soil particle size means (0- to 6-inch depth) of soil samples taken before applying any soil amendments in a study evaluating the effects of N source and rate on cotton yield on a Sharkey clay (MSG82) and a Dundee silt loam (POG82) in Arkansas during 2008.

Site	Soil		Soil	Soil Mehlich-3-extractable nutrients							Soil particle size			
ID	pH[z]	SOM[y]	NO_3-N[x]	P	K	Ca	Mg	Mn	Cu	Zn	Sand	Silt	Clay	Texture
			----------	----------	----------	----------	(ppm)	----------	----------	----------	----------	(%)	----------	
MSG82	6.6	2.4	4	71	225	3572	685	79	4.2	5.7	25	26	49	Clay
POG82	6.3	2.0	9	78	143	1424	215	112	1.1	4.2	52	42	16	Loam

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

[y] SOM, soil organic matter determined by weight loss on ignition.

[x] NO_3-N measured by ion-specific electrode.

Table 3. Total N and product application rates for urea, two different fresh poultry litter (FPL) sources, pelleted poultry litter (PPL), and Top Choice Organic (TCO) biosolid used in fertilization of cotton experiments in Mississippi (MSG82) and Poinsett (POG82) counties in Arkansas during 2008.

Total	Amendment rate				
		FPL			
N rate	Urea	(POG82)	(MSG82)	PPL	TCO
(lb N/acre)	----------	----------	(lb of material applied/acre)	----------	----------
30	65	1,035	1,111	840	478
60	130	2,069	2,222	1,681	955
90	196	3,103	3,333	2,521	1,433
120	261	4,138	4,444	3,361	1,911
150	326	5,172	5,555	4,202	2,389

Table 4. Selected chemical property means (n = 4-8) for two fresh poultry-litter sources (FPL), pelleted poultry litter (PPL), and Top Choice Organic (TCO) biosolid used in N-fertilization trials conducted in Mississippi (MSG82) and Poinsett (POG82) counties during 2008.

				Total nutrient content (as is)					Inorganic N content	
N source	n	pH	Moisture	C	N	P[z]	K[y]	Ca	NO_3-N	NH_4-N
			----------	----------	----------	(%)	----------	----------	------(ppm)	------
FPL (MSG82)	4	8.4	36	24.2	2.36	0.98	1.77	1.58	229	5853
FPL (POG82)	4	8.5	34	22.3	2.95	1.85	3.09	2.55	92	5346
PPL	6	7.4	14	28.1	3.57	1.33	3.04	2.18	1530	2632
TCO	8	5.9	7	36.7	6.28	2.23	0.38	2.24	259	2075

[z] lb P_2O5/ton = %Total P on "as is" basis multiplied by 20 x 2.29.

[y] lb K_2O/ton = %Total K on "as-is" basis multiplied by 20 x 1.2.

Table 5. Seedcotton yield as affected by fresh poultry litter (FPL), pelleted poultry litter (PPL), Top Choice Organic (TCO) biosolid, and urea each applied at five total-N rates and N rate, averaged across N sources, on a Sharkey clay (MSG82) and Dundee silt loam (POG82) in Arkansas during 2008.

	MSG82					POG82				
	N source				N source	N source				N source
Total-N rate	FPL	PPL	TCO	Urea	means	FPL	PPL	TCO	Urea	means
(lb N/acre)	----------	----------	----------	----------	[seedcotton yield (lb/acre)]	----------	----------	----------	----------	----------
0		1228			1228		3228			3228
30	1501	1538	1601	1922	1647	3414	3586	3778	3605	3595
60	1569	1656	1678	2352	1786	3704	3468	3613	3414	3550
90	1734	1772	2285	3073	2100	3793	3693	3464	3309	3565
120	1655	1920	2181	2929	2172	3428	3668	3257	3499	3463
150	1945	1847	2535	3279	2379	3638	3837	3521	3108	3526
MSD 0.10[z]		interaction was NS			246		interaction was NS			NS
P-value		interaction = 0.1691			<0.0001		interaction = 0.1701			0.8141

[z] Minimum Significant Difference (MSD) as determined by Waller-Duncan Test at $P = 0.10$. NS = not significant at $P = 0.10$.

Table 6. Seedcotton yield as affected by fresh poultry litter (FPL), pelleted poultry litter (PPL), Top Choice Organic (TCO) biosolid, and urea, averaged across five total-N rates, and compared to the no N control (None) applied to a Sharkey clay (MSG82) and a Dundee silt loam (POG82) in Arkansas during 2008.

N source	MSG82	POG82
	---- Seedcotton yield (lb/acre) ----	
None	1228	3228
FPL	1670	3595
PPL	1755	3650
TCO	2036	3527
Urea	2667	3387
MSD at 0.10[z]	232	260
P-value	<0.0001	0.0693

[z] MSD, Waller-Duncan minimum significant difference.

Biosolids, Poultry Manure, and Urea Increase Corn Yield in Arkansas

M. Mozaffari, N.A. Slaton, J.R. Long, C.G. Herron, and C. Kennedy

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Supplemental nitrogen (N) fertilization is a prerequisite for producing maximum corn (*Zea mays* L.) grain yields in Arkansas. The market for corn has been favorable in recent years, but a large fraction of the increase in the farmers' income has been diverted to cover the record high N-fertilizer prices. In response, farmers have turned to fresh (FPL) and pelleted poultry litter (PPL) as alternative fertilizers. Heat-dried and pelleted biosolid is a high-organic matter and low-grade fertilizer that is being sold under the trade name of Top Choice Organic (TCO)[1] by some fertilizer dealers in Arkansas. There is very little information on nutrient availability of and corn yield response to poultry litter or biosolid applied to soils in eastern Arkansas. Arkansas growers who might be interested in using these soil amendments will benefit from research aimed at defining the N-fertilizer value of poultry litter and biosolids. The specific research objective was to evaluate the effect of FPL, PPL, TCO, and urea N-fertilizer sources applied at equal total-N rates on corn grain yield.

PROCEDURES

A replicated field experiment was conducted at the Lon Mann Cotton Research Station in Marianna, Ark., on a Calloway silt loam during 2008. Agricultural limestone was applied to the field at 2 ton/acre on 15 March. A composite soil sample was collected from the 0- to 6-inch depth of each replication (n=5) before applying any fertilizer. Soil samples were dried, crushed, and soil NO_3-N was extracted with 0.025 *M* aluminum sulfate and measured with a specific-ion electrode (Donahue, 1992). Other soil nutrients were extracted with Mehlich-3 solution and the concentrations of elements in the extracts were measured by inductively coupled plasma atomic emission spectroscopy. Soil particle size analysis was performed by the hydrometer method (Arshad et al., 1996). Selected soil properties are listed in Table 1.

Pelleted poultry litter was purchased from a local fertilizer dealer and TCO was provided by MANCO Fertilizer Company (http://manncofertilizer.com/products.html). Fresh poultry litter was obtained from a baling facility in northwest Arkansas. Sub-samples of FPL, PPL, and TCO were analyzed by the University of Arkansas Agricultural Diagnostic Laboratory using standard methods (Table 2, Peters et al., 2003). The experimental design was a randomized complete block with a factorial arrangement of four N sources (FPL, PPL, TCO, and urea) applied at five total-N rates (60, 120, 180, 240, and 300 lb total N/acre, Table 3) and compared to a no N control (0 lb N/acre). Each treatment was replicated five times. A blanket application of KCl (0-0-60), triple superphosphate (0-46-0), and $ZnSO_4$ (18% S and 24% Zn) was made to supply 120 lb K_2O, 46 lb P_2O_5, 6.7 lb Zn, and 5 lb S/acre on 15 April. All N-fertilizer treatments were also applied and incorporated on 15 April. Corn cultivar Pioneer 32B29 was planted on 22 April and emerged on 29 April. Corn management closely followed University of Arkansas Cooperative Extension Service recommendations for irrigated-corn production. Each plot was 25-ft long and 10-ft wide allowing for four rows of corn planted in 30-inch-wide rows. Corn plants in the center 2 rows of each plot were harvested with a plot combine on 17 September and grain yields were adjusted to 15.5% moisture content.

Analysis of variance was performed using the GLM procedure of SAS to evaluate the effect of N source and rate on corn grain yield. When appropriate, significant treatment means were separated with the Waller-Duncan minimum significant difference (MSD) method at a significance level of 0.10.

RESULTS AND DISCUSSION

Poultry Litter and Biosolid Properties

The TCO biosolid contained greater total N, C, and P contents than either poultry litter source, but its K content was much lower (Table 2). The TCO also had lower moisture and pH than poultry litter. The Ca contents were numerically similar among N sources. In all three N sources, organic N was the predominant form of N and NH_4-N was the predominant inorganic N form. All three amendments are potentially high-organic matter, low-grade N-P-K (FPL or PPL) or N-P (TCO) fertilizers.

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[1] 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, or exclusion of any other product that may perform similarly.

Corn Grain Yield

The N-source-by-rate interaction did not have a significant effect on corn grain yield (*P* = 0.5206). Corn grain yield was significantly affected by the main effects of N source and rate. Averaged across N sources, corn yields increased progressively and significantly as N rate increased and ranged from 89 to 217 bu/acre (Table 4). Maximum grain yield was produced by application of 300 lb N/acre and yields of corn receiving N were significantly higher than corn that received no N. Averaged across all N rates, grain yield was greatest for corn fertilized with urea and slightly lower for corn fertilized with FPL, PPL, or TCO, which all produced similar corn yields (Table 4).

PRACTICAL APPLICATIONS

Results from this one trial indicate that FPL, PPL, and TCO are high-organic matter, low-grade sources of N-P-K (PPL and FPL) or N-P (TCO) that could be used in corn fertilization programs. Corn grain yields were increased similarly by FPL, PPL, and TCO, but not to the same extent as corn fertilized with urea. The results suggest that while FPL, PPL, and TCO supply some plant-available N, they should be combined with conventional N fertilizers for producing maximum crop yields and preventing application of excessive P rates. Additional research is needed at multiple site-years for a reliable assessment of N availability from FPL, PPL, and TCO; and to develop science-based, field-tested guidelines for integrating these organic soil amendments into an economically and environmentally sustainable nutrient management strategy for Arkansas corn farmers.

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Research was funded by a gift from MANCO Fertilizers Inc. We wish to thank the staff of the Lon Mann Cotton Research Station and the University of Arkansas Soil Testing and Research Laboratory for their assistance. The University of Arkansas Division of Agriculture also provided support.

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Table 1. Selected soil chemical property and soil particle size distribution means (0- to 6-inch depth) of samples taken before planting corn in a N-fertilization study conducted at the University of Arkansas Lon Mann Cotton Research Station in Marianna, Ark., on a Calloway silt loam during 2008.

		Mehlich-3-extractable nutrients							Soil particle size			
Soil pH[z]	Soil NO_3-N[y]	P	K	Ca	Mg	Cu	Zn	SOM[x]	Sand	Silt	Clay	Texture
	----------	----------	----------	(ppm)	----------	----------	----------	(%)	----------	(%)	----------	
6.9	5	45	74	1199	193	0.9	3.4	1.16	6	78	16	silt loam

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

[y] NO_3-N measured by ion-specific electrode.

[x] SOM, soil organic matter determined by weight loss on ignition.

Table 2. Selected chemical property means of fresh poultry litter (FPL), pelleted poultry litter (PPL), and Top Choice Organic pelleted biosolid (TCO) on an 'as is' basis used in a N-fertilization experiment conducted at the University of Arkansas Lon Mann Cotton Research Station in Marianna, Ark., on a Calloway silt loam during 2008.

N source	n[z]	pH	H_2O	Total C	Total N	Total P	Total K	Total Ca	NO_3-N	NH_4-N
			----------	----------	(%)	----------	----------	----------	(ppm)	----------
FPL	5	8.1	34	22.3	2.95	1.85	3.09	2.55	92	5346
PPL	6	7.4	14	28.1	3.57	1.33	3.04	2.18	1530	2632
TCO	8	5.9	7	36.7	6.28	2.23	0.38	2.24	259	2075

[z] n = number of sub-samples analyzed.

Table 3. Total N and amendment rates for fresh poultry litter, pelleted poultry litter, biosolids (Top Choice Organic), and urea used in a N-fertilization experiment with corn conducted on a Calloway silt loam at the University of Arkansas Lon Mann Cotton Research Station in Marianna, Ark., during 2008.

	Amendment rate			
Total N rate	Urea	Fresh litter	Pelleted litter	Biosolid
(lb N/acre)	-- (lb material applied/acre) --			
60	130	2,069	1,681	955
120	261	4,138	3,361	1,911
180	391	6,207	5,042	2,866
240	521	8,276	6,723	3,822
300	652	10,345	8,403	4,777

Table 4. Corn grain yield as affected by N source, averaged across N rate, and N rate, averaged across N sources, in a N-fertilization experiment conducted at the University of Arkansas Lon Mann Cotton Research Station in Marianna, Ark., on a Calloway silt loam during 2008.

Total N rate	Corn yield (N source means)	N source	Corn yield (N rate means)
(lb N/acre)	(bu/acre)		(bu/acre)
0	89	None	89
60	123	Fresh litter	162
120	148	Pelleted litter	162
180	177	Biosolid	171
240	186	Urea	182
300	217		
MSD 0.10[z]	9		9
P value	<0.0001		<0.0001

[z] Minimum Significant Difference (MSD) as determined by Waller-Duncan Test at *P*= 0.10.

Wheat Yield And Soil Response To Biosolids And Urea

M. Mozaffari, N.A. Slaton, J.R. Long and C. Kennedy

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Soft red winter wheat (*Triticum aestivum* L.) yield is usually limited by nitrogen (N) deficiency more than any other nutrient. Thus, N fertilization is widely practiced to optimize wheat grain yield and quality. High synthetic fertilizer prices and recent interest in improving soil quality have resulted in a renewed interest in alternative high-organic matter fertilizers. Biosolids are high-organic matter byproducts of wastewater sludge treatment and contain plant essential nutrients such as N, P, and trace amounts of micronutrients. Utilization of biosolids as a source of plant nutrients is a sustainable practice that reduces the need for landfill space, recycles nutrients in the agroecosystem, and may improve soil quality. Most of the N in biosolids is in the organic form. Nitrogen availability from biosolids during a cropping season will depend on N-mineralization rate in soil, which is controlled by factors such as organic amendment properties, temperature, moisture, soil physical and chemical properties, amount of crop residue, and other characteristics of the cropping system. A review of literature shows a wide range of N mineralization rates for various biosolids in different regions and cropping systems and highlights the need for local studies on nutrient availability from biosolids (Barbarick et al., 1996; Binder et al., 2002).

A heat-dried, pelleted biosolid is being marketed in Arkansas by some fertilizer dealers under the trade name of Top Choice Organic (TCO, http://manncofertilizer.com/products.html)[1] with a minimum guaranteed chemical analysis of 5-3-0. Information on soil and crop response to TCO under soil and cropping conditions of Arkansas will benefit growers who may consider using TCO as an alternative fertilizer source. During the 2007-2008 growing season, we conducted a replicated field experiment to evaluate the effect of TCO in combination with urea on wheat grain yield and soil chemical properties.

PROCEDURES

The field experiment was conducted during the 2007-2008 cropping season on a Convent silt loam (Endoaquepts) at the University of Arkansas Lon Mann Cotton Research Station in Marianna, Ark. The Convent soil is an alluvial silt loam typical of soils used for wheat production in the Mississippi River Delta Region of Arkansas. The experimental site was planted in grain sorghum (*Sorghum bicolor* L.) in the summer of 2007 and sorghum residue was baled and removed before planting wheat. Agricultural limestone had been applied in spring of 2007 at the rate of 2 ton/acre. The experimental area was fertilized with triple superphosphate, muriate of potash, and elemental sulfur to supply 40 lb P_2O_5, 60 lb K_2O, and 20 lb S/acre to ensure that wheat yields were not limited by P, K, or S availability.

Soil samples were collected from the 0- to 6-inch depth prior to planting and fertilization and composited by replicate. Soil samples were processed and extracted with Mehlich-3 solution and the concentration of elements in the extract was measured by inductively coupled plasma atomic emission spectroscopy (Table 1). Soil nitrate (NO_3-N) was extracted with aluminum sulfate and measured with a specific-ion electrode (Donahue, 1992). Soil pH was measured in a 1:2 (volume: volume) soil-water mixture. Soil particle size analysis was performed by the hydrometer method (Arshad et al., 1996). In July 2008, following wheat harvest, soil samples were again collected from the 0- to 6-inch depth of selected plots and analyzed for the chemical properties described previously to determine how biosolid and urea amendments influenced soil chemical properties.

Sub-samples (n=6) of biosolid were analyzed by the University of Arkansas Agricultural Diagnostic Laboratory by standard methods described by Peters et al. (2003). The results of chemical analysis of biosolids were used to determine the amount of TCO needed to supply the required N rates. The average biosolid properties were pH 5.8, electrical conductivity 5217 µmhos/cm, 37.1% C, 0.2% K (0.24% K_2O), 2.0% P (4.58% P_2O_5), 1.8% Ca, 6.2% total N, 24 ppm NO_3-N, and 1204 ppm NH_4-N.

The experimental design was a randomized complete block with a total of 19 treatments that were replicated five times. Treatments consisted of four fall N sources including: no fall N, 40 lb urea-N/acre, 40 lb total N/acre as TCO, and 80

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[1] 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, or exclusion of any other product that may perform similarly.

lb total-N/acre as TCO with 4 or 5 late-winter/early-spring N rates of 40 to 160 lb total N/acre in 40 lb N increments (Table 2). The late-winter N was applied in single (40 lb N/acre) or split applications (rates >40 lb N/acre) on 7 February and 17 March 2008. Biosolid was applied at 666 and 1322 lb/acre to supply the 40 and 80 lb total-N/acre, respectively. All preplant-applied fertilizers and biosolids were broadcast on 31 October 2007 and mechanically incorporated within a few hours. Individual plots were 23-ft long, 7.5-ft wide, and contained 10 rows of wheat with 7.5-inch-wide row spacings.'Pioneer 26R22' wheat was drill seeded at 120 lb/acre on 31 October 2007. Winter wheat was managed using practices recommended by the University of Arkansas Cooperative Extension Service. The entire plot was harvested with a small-plot combine on 13 June 2008. Harvested grain was adjusted to a uniform moisture content of 13% before statistical analysis was performed.

Analysis of variance was performed using the GLM procedure of SAS to evaluate wheat grain yield and soil chemical property responses to fall N source and total-N rate. When appropriate the Waller-Duncan minimum significant difference (MSD) test was used to separate significant treatment means at significance level of 0.10.

RESULTS AND DISCUSSION

Grain Yield

Nitrogen application significantly increased wheat yield, highlighting the importance of N fertilization for producing optimum wheat yields (Table 3). Wheat yields in all treatments receiving N fertilizer ranged from 48 to 88 bu/acre and were significantly greater than the yield of wheat receiving no N (38 bu/acre). Statistically, application of 120 to 160 lb total-N/acre generally produced near maximal wheat yields. Fall applications of 40 lb N/acre as urea and TCO were equally effective in increasing wheat yield as long as they were used in combination with sufficient N applied in late winter. Comparison of like total-N rates (Table 2) among fall N sources showed fall N application (at planting) had no significant benefit to wheat yield. Wheat grain yields receiving 80 and 120 lb N/acre produced 60 and 100% greater yields, respectively, than wheat receiving no N.

Soil Chemical Properties

Soil pH, organic matter, and Mehlich-3-extractable K, Ca, Mg, Cu, and Zn were not affected significantly by fertilization treatments. However, soil NO_3-N and Mehlich-3-extractable P were significantly affected (Table 4). Soil NO_3-N tended to increase as late-winter, urea-N rate increased and was greater for fall-applied TCO than fall-applied urea. Mehlich-3 soil-test P in soil receiving either no fall N or 80 lb total-N/acre as TCO averaged 55 and 69 ppm, respectively. These soil-test results indicate that TCO is a potential source of N and P.

PRACTICAL APPLICATION

This single site-year of study suggests that N application was necessary to produce maximal wheat grain yield. Grain yields of wheat receiving N-fertilizer were significantly higher than wheat receiving no N, regardless of fall-N source and total-N rate. Under the conditions of this experiment, fall application of urea and pelleted biosolids was equally effective in promoting wheat yield as long as crops were supplemented with sufficient late-winter urea-N. Fall application of TCO at rates ≥80 lb total N/acre increased available soil NO_3-N and P. Given the diversity of soils and wheat cropping systems in eastern Arkansas, additional research at multiple sites is needed to evaluate the consistency of these results.

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Table 1. Selected soil chemical property means (0- to 6-inch depth) of samples taken before planting wheat at the University of Arkansas Lon Mann Cotton Research Station in Marianna, Ark., on a Convent silt loam in October 2007.

Soil	Soil	Mehlich-3-extractable nutrients							Soil particle size			
pH[z]	NO_3-N[y]	P	K	Ca	Mg	Cu	Zn	SOM[x]	Sand	Silt	Clay	Texture
	(ppm)							(%)				
7.2	20	49	78	1382	304	1.5	3.0	1.26	9	77	14	silt loam

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

[y] NO_3-N measured by ion-specific electrode.

[x] SOM, soil organic matter determined by weight loss on ignition.

Table 2. List of N sources, rates, and application dates for a field experiment conducted at the Lon Mann Cotton Research Station in 2007-2008 to evaluate wheat and soil response to fall application of N from Top Choice Organic (TCO)™ biosolid and urea.

Fall 2007 N application		Late-winter 2008 N application		
N Source	N rate	1st application (7 February)	2nd application (17 March)	Total N applied (fall + winter)
	(lb N/acre)			
None	0	0	0	0
None	0	40	0	40
None	0	40	40	80
None	0	80	40	120
None	0	80	80	160
Urea	40	0	0	40
Urea	40	40	0	80
Urea	40	40	40	120
Urea	40	80	40	160
Urea	40	80	80	200
TCO	40	0	0	40
TCO	40	40	0	80
TCO	40	40	40	120
TCO	40	80	40	160
TCO	40	80	80	200
TCO	80	0	0	80
TCO	80	40	0	120
TCO	80	40	40	160
TCO	80	80	40	200

Table 3. Effect of fall-applied, N-fertilizer source and late-winter-applied N rate on wheat grain yield in a trial conducted at the University of Arkansas Lon Mann Cotton Research Station in Marianna, Ark., on a Convent silt loam during the 2007-2008 cropping season.

Fall N	N application time and rate			Wheat
source	Fall N	Late-winter N	Total N	grain yield
	---------- (lb N/acre) ----------			(bu/acre)
None	0	0	0	38 i[z]
None	0	40	40	54 gf
None	0	80	80	66 dc
None	0	120	120	79 b
None	0	160	160	80 b
Urea	40	0	40	48 h
Urea	40	40	80	59 ef
Urea	40	80	120	79 b
Urea	40	120	160	80 b
Urea	40	160	200	88 a
TCO	40	0	40	49 hg
TCO	40	40	80	62 de
TCO	40	80	120	79 b
TCO	40	120	160	82 ab
TCO	40	160	200	84 ab
TCO	80	0	80	60 def
TCO	80	40	120	69 dc
TCO	80	80	160	81 b
TCO	80	120	200	84 ab
			P-value	<0.0001

[z] Means followed by the same letter are not statistically different at *P*=0.10 probability level.

Table 4. The effect of fall N source/rate and late-winter N rate on selected soil chemical property (0- to 6-inches) means for soil collected post-harvest in selected treatments on a Convent silt loam during the 2007-2008 cropping season.

Fall N	N application rate					Soil chemical property						
source	Fall N	Winter N	Total N	pH[z]	SOM[y]	NO_3-N[x]	P	K	Ca	Mg	Cu	Zn
	----(lb N/acre)----				(%)	----(ppm)----						
None	0	0	0	7.2	1.7	6	55	88	1210	260	1.7	1.4
Urea	40	0	40	7.4	1.7	10	55	84	1284	269	1.7	1.4
Urea	40	40	80	7.5	1.7	17	53	82	1305	283	1.7	3.7
Urea	40	80	120	7.2	1.6	19	50	80	1275	284	1.7	3.8
TCO	40	0	40	7.4	1.7	8	60	75	1321	176	1.8	4.0
TCO	40	40	80	7.3	1.7	16	58	77	1272	273	1.7	3.6
TCO	40	80	120	7.2	1.6	24	52	74	1251	267	1.8	4.0
TCO	80	40	120	7.3	1.7	24	69	89	1294	280	1.9	4.3
P value				0.5020	0.7257	<0.0001	0.0339	0.4433	0.3724	0.3879	0.1590	0.9233
MSD at 0.10[w]				NS	NS	5	9	NS	NS	NS	NS	NS

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

[y] SOM, soil organic matter determined by weight loss on ignition.

[x] NO_3-N measured by ion-specific electrode.

[w] Minimum Significant Difference as determined by Waller-Duncan Test at *P*=0.10. NS, not significant at 0.10.

Cotton Growth and Physiological Responses to Phosphorus Deficiency

D.M. Oosterhuis, A. Bibi, E. Gonias, and M. Mozaffari

BACKROUND INFORMATION AND RESEARCH PROBLEM

Phosphorus (P) is an essential element in plants required for vital structural and metabolic functions. A shortage of P will lead to a breakdown of plant membranes and reduce energy transfer within the plant, resulting in decreased growth and yield. Crop fertilization programs must insure adequate P to support the critical role of this element in plant metabolism and growth. Insufficient information exists about the effect of reduced P availability on plant growth. A better understanding of changes in the growth and physiological characteristics of cotton plants during the development of P deficiency will help us define field diagnostic techniques that improve P-fertilizer management recommendations.

The rapid introduction of modern cotton (*Gossypium hirsutum* L.) cultivars and changes in production practices during the past several decades have created a need to update the science base of cotton P-fertilization recommendations. Information on critical levels of nutrients such as P is an important component of this knowledge base. Phosphorus is mobile in the plant such that young leaves or developing bolls can be nourished from the labile P of older tissues (i.e., P is redistributed from older to younger parts). It is therefore important to understand the redistribution of P in the plant as P deficiency increases. This involves quantification of the effects of P deficiency on cotton growth and the determination of the critical tissue-P concentrations for optimum growth. In cotton, the critical P concentrations range from 0.20 to 0.31% (Crozier et al., 2004; Cox and Barnes, 2002). In Arkansas, a critical-P concentration range for petioles is not used because P is not recommended by the petiole monitoring program.

Improved P fertilizer recommendations and increasing P use efficiency will help increase the profitability of agricultural production and reduce the potential for offsite loss of P in drainage waters. The objectives of this study were to quantify the effects of P deficiency on changes in plant growth, leaf photosynthesis, plant dry matter accumulation and partitioning, and fruit set during the development of P deficiency.

PROCEDURES

The experiment was conducted in a growth chamber at the University of Arkansas Altheimer Laboratory in Fayetteville, Ark. The growth chamber was programmed for a 12-hour photoperiod, with day/night temperatures of 30/20°C and relative humidity of 60 to 80%. The cotton cultivar DPL444BR was planted in 2-L pots filled with washed sand. Each pot had a 2-cm-diameter hole in the base for drainage. After emergence, seedlings were thinned to one plant per pot. All pots were watered with one-half strength Hoagland's nutrient solution during the first four weeks after planting to maintain a sufficient nutrient and water supply. Four weeks after planting all pots where flushed with deionized water and separated into two groups: P sufficient and P deficient. The P-sufficient treatment continued to receive the half-strength nutrient solution with P, while the P-deficient treatment received half-strength Hoagland's nutrient solution without P.

Four plants in each treatment were harvested weekly for four weeks after the initiation of the P treatments. The effects of P deficiency on plant growth, dry matter accumulation, and partitioning were determined as described by Zhao and Oosterhuis (2002). The plants were partitioned into parts (e.g., leaves, main stem and branches, petioles, fruits, and roots) and each group of tissues was oven dried, weighed, and digested with concentrated HNO_3 and 30% H_2O_2 for determination of tissue-P concentrations. The effects of P deficiency on leaf photosynthesis, quantum yield of photosystem II (PSII), membrane leakage, and leaf chlorophyll content as determined by a SPAD meter were evaluated. The experiment was a randomized complete block design with five replications. A *t*-test was performed to determine whether significant ($P \leq 0.05$) differences existed between treatment means.

RESULTS AND DISCUSSION

Plant height was reduced significantly 3 weeks after withholding P (Fig. 1A), whereas leaf area was reduced significantly 2 weeks after treatment in P-deficient plants compared to P-sufficient plants (Fig. 1B). The effect of P on total plant dry matter was not observed until 3 weeks after withholding P (Fig. 1C). Phosphorus-deficient plants showed significantly less root dry weight 4 weeks after the initiation of the treatments compared to the P-sufficient plants (Fig. 1D).

Withholding P caused photosynthesis to significantly decline below that of cotton plants in the P-sufficient treatment 2, 3, and 4 weeks after treatments began (Fig. 2A). Chlorophyll fluorescence, measured as the quantum yield of PSII, provides a measure of plant stress, which was evident in the P-deficient plants 1 week after the P treatments were imposed and 3 weeks later (Fig. 2B). Membrane leakage also increased significantly by 3 and 4 weeks for cotton in the P-deficient treatment (Fig. 2C). The rapid effect of P deficiency on membrane leakage was expected in view of the critical role of P in the formation of phospholipids in plant membranes. Membrane leakage is a measure of cell integrity and provides a sensitive indicator of the plant stress suffered due to P deficiency. Finally, P deficiency caused significantly higher chlorophyll content 2, 3, and 4 weeks after the treatments were initiated (Fig. 2D).

PRACTICAL APPLICATION

The study quantified the effect of P deficiency on cotton plant growth. Plant height, leaf area, total dry weight, and root dry matter were all sensitive to a shortage of P.

Leaf area and root growth were particularly sensitive to P deficiency. In addition, the study documented the effect of P deficiency on the physiological responses of cotton plants. Phosphorus deficiency caused a reduction in leaf photosynthesis and quantum yield of PSII, while resulting in increased membrane leakage and chlorophyll fluorescence compared to P-sufficient plants. Furthermore, P deficiency resulted in significantly reduced root growth. These results help explain the effects of P deficiency on suppression of cotton growth and yield and provide information that may aid in diagnosing P deficiency in cotton production. The study will be continued under field conditions.

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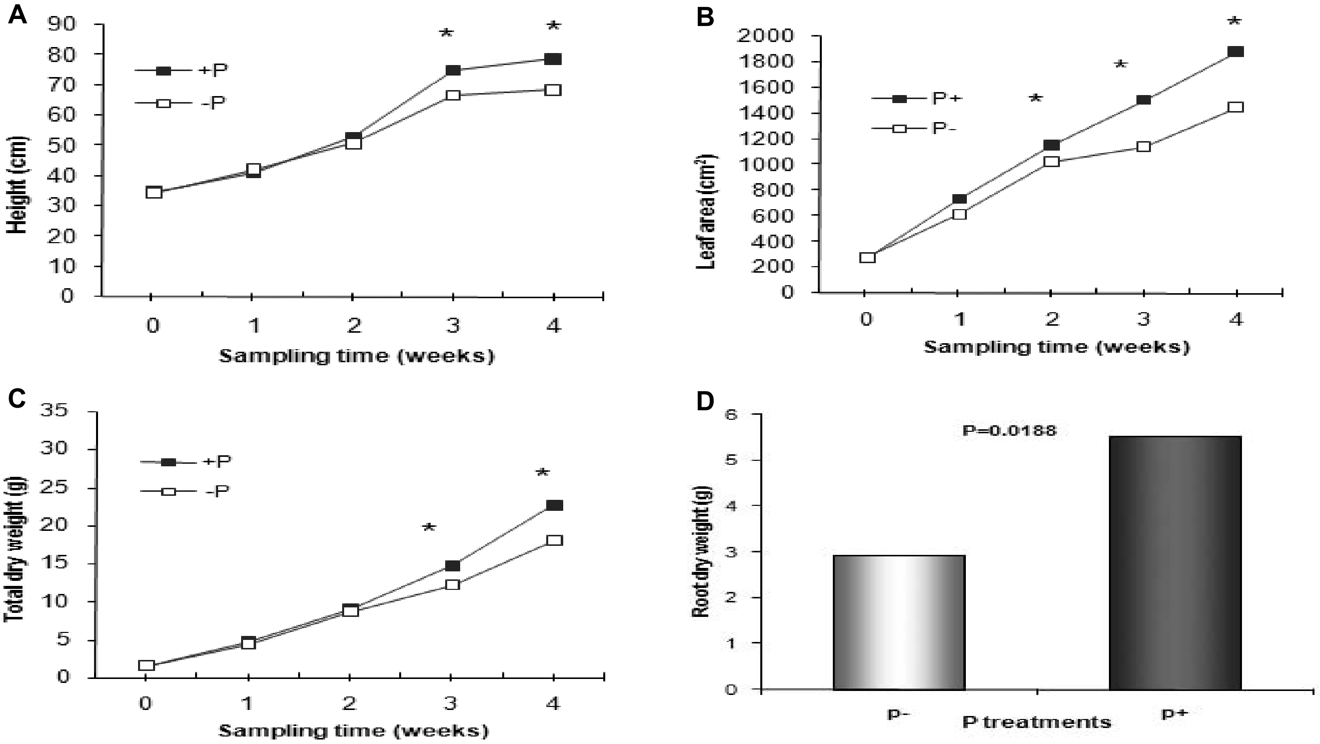

Fig. 1. The effect of P deficiency on (A) height, (B) leaf area (LA), (C) total dry weight measured weekly for 5 weeks starting 28 days after planting when P was withheld from the P treatment, and (D) root dry weight measured 4 weeks after treatments were initiated. The asterisk (*) indicates significant differences at $P \leq 0.05$ for measurements comparing P treatments within each week.

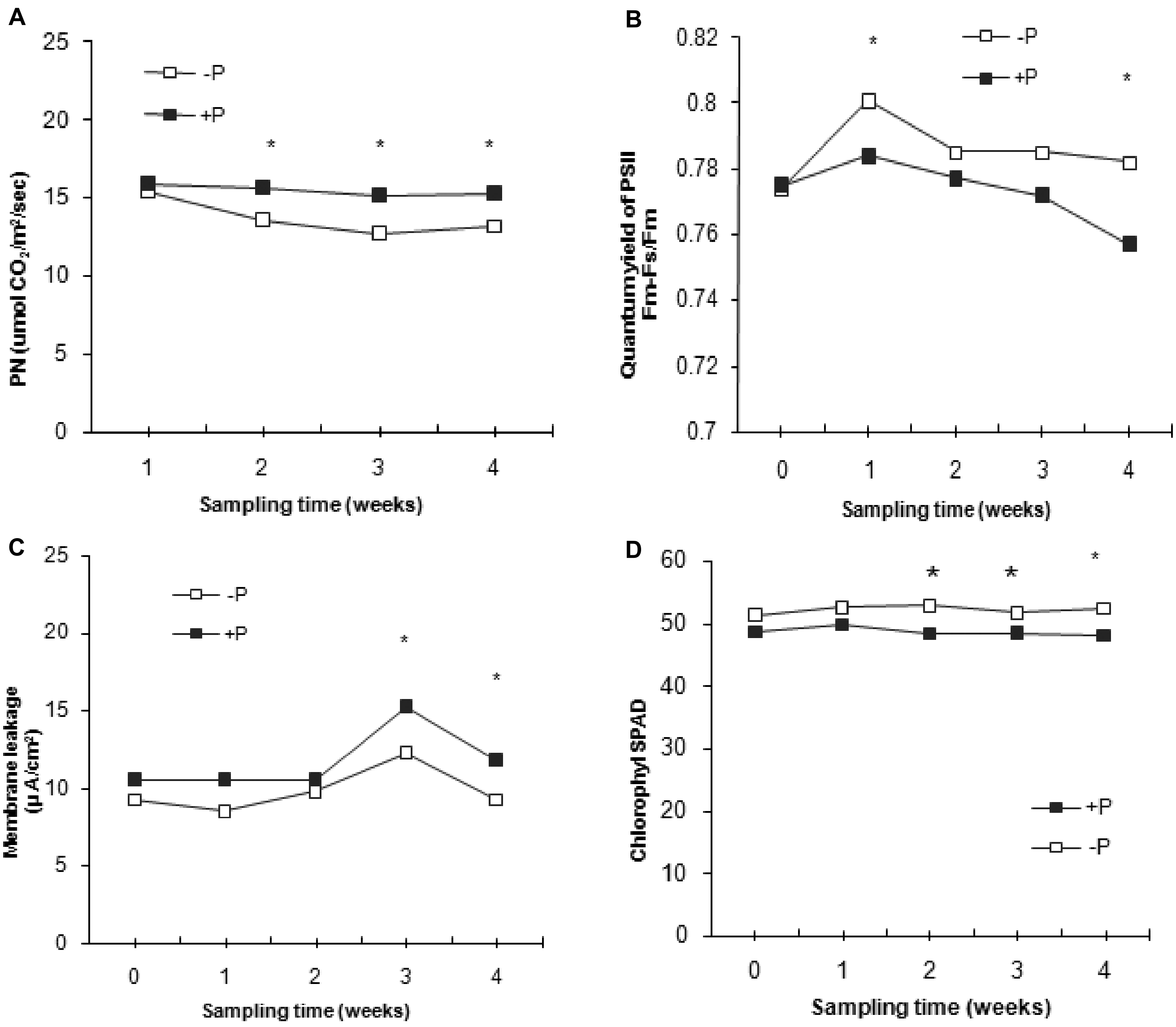

Fig. 2. The effect of P deficiency on (A) leaf photosynthesis (PN), (B) quantum yield of photosystem II (PSII), (C) membrane leakage, and (D) chlorophyll SPAD measured weekly starting 28 days after planting when P was withheld from the P-deficient treatment. The asterisk (*) indicates significant differences at *P*≤0.05 between P treatments within a sample week.

Bermudagrass Forage Response to Potassium Fertilization

N.A. Slaton, R.E. DeLong, C.G. Massey, B.R. Golden, and E. Maschmann

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Potassium (K) is an important macronutrient for forage production. Most grass forages take up and remove near equal amounts of N and K with estimates of about 45 lb of N and K_2O removed per ton of harvested bermudagrass forage compared to only 4 to 5 lb P/ton forage (12 to 15 lb P_2O_5/ton). Long-term use of poultry litter as a nutrient source for forage production has not increased soil-test K as most Arkansas soils used for forage production have Medium soil-test K levels. In situations where poultry litter can no longer be used or applied at limited rates, application of inorganic-K fertilizer will be needed to maintain adequate soil K and sustain high forage yields.

Research by Nelson et al. (1983) showed significant bermudagrass [*Cynodon dactylon* (L. Pers.)] yield increases from adequate K fertilization. Depending on the soil, small yield increases attributed to K fertilization often occurred during the first year of study and became larger during the second or third year as soil K became depleted. Within a season, the yield differences between fertilized and unfertilized soils often increased for late-season harvests. Potassium nutrition has also been related to stand persistence, disease resistance, and cold temperature tolerance to bermudagrass, which are all important management considerations for warm-season grass forages produced in Arkansas (Keisling et al., 1979)

Research investigating forage yield responses to K fertilization is essential to develop best nutrient management practices for growers and demonstrate the fertilizer rates that produce and sustain high forage yields and minimize production costs. The objective of this research was to evaluate how annual K-fertilizer rate influences warm-season grass yield and soil-test K.

PROCEDURES

Fertilization trials were initiated in April 2006 on a Captina silt loam with an established stand of common bermudagrass at the Arkansas Agricultural Research and Extension Center (AAREC) and in April 2007 on a Johnsburg silt loam in a field of established 'Midland' bermudagrass. Both fields were located in Washington County, Ark. The first and/or second years of results were reported by Slaton et al. (2007; 2008) and the second and third years of yield and soil-test results are described in this report. Each site will be referred to by the soil series. For each site, the same K rates have been applied to the same plots each year. The Johnsburg soil contained crabgrass, ryegrass, foxtail, and bermudagrass and is best described as a mixture of warm-season grasses. Precipitation during the spring and early summer of 2008 was above normal, allowing for the production of high forage yields, but air temperatures were below normal for much of the summer, which may have limited forage productivity.

Plots were 20-ft long at both sites and 5-ft wide for the Johnsburg soil and 6-ft wide for the Captina soil. For each site, composite soil samples were collected from each plot in January 2008 to a depth of 4 inches from each plot to monitor changes in soil-test K following previous applications of K fertilizer. Each composite soil sample consisted of eight soil cores. Soils were dried at 120°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). Soil samples were also extracted with 0.1 *M* HNO_3 to examine exchangeable and non-exchangeable soil K pools. In fall 2007, 2000 lb pelleted dolomitic lime/acre were applied to the Captina soil to maintain soil pH above 5.0.

Muriate of potash was applied in one to three applications for cumulative season-total rates equaling 0, 100 (100 × 1), 200 (100 × 2), 300 (100 × 3), 400 (133 × 3), and 500 (167 × 3) lb K_2O/acre. Potassium treatments were applied before green-up and/or following the first and second harvests. Phosphorus fertilizer (100 lb triple superphosphate/acre) was broadcast after the first and second harvests on the Captina soil. Potassium-fertilizer treatments were applied on 1 May (before green-up), 14 June following the first harvest, and 16 (Johnsburg) or 18 (Captina) July following the second harvest. Nitrogen fertilizer was applied (6 May for Captina and 12 May for Johnsburg soil) as 100 lb $(NH_4)_2SO_4$/acre plus 300 lb NH_4NO_3/acre at each site (~120 lb N/acre). Following the first (17 June for both sites) and second harvests (16 or 18 July for Johnsburg and Captina soils, respectively) 120 lb N/acre as either NH_4NO_3 or urea were applied for a season total of 360 lb N/acre.

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 inches every 28 to 35 days after each fertilization event. At the Captina site, bermdagrass was harvested on 12

June, 14 July, and 26 August. At the Johnsburg site, forage was harvested on 11 June, 15 July, and 21 August. The freshly cut forage was weighed by plot and eventually adjusted to a total dry weight expressed as lb dry forage/acre by recording the weight (~500-g) of a fresh forage subsample, which was subsequently dried to a constant weight in a forced draft oven at 60°C and weighed again. A shrink factor was calculated and used to adjust total fresh forage weight to a dry weight basis. Subsamples of forage from each harvest and trial were 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 calculation of K uptake and removal.

The K-rate experiments were randomized complete block designs with each annual K-fertilizer rate replicated five times per site. Analysis of variance procedures were conducted by site on 2008 data with the PROC GLM procedure in SAS (SAS Institute, Inc., Cary, N.C.). Forage yields were analyzed by harvest time and for the season total production. Mehlich-3 soil K data were analyzed as described above for each individual year and by using a split-plot treatment structure where annual P-rate was the whole plot and year was the sub-plot. When appropriate, mean separations were performed using Fisher's Protected Least Significant Difference method at a significance level of 0.10.

RESULTS AND DISCUSSION

Soil-Test Potassium

Within each site, Mehlich-3 soil K was uniform among plots before the first year of annual K-fertilizer application was initiated (Table 2). Following one or two years of K application, Mehlich-3 soil K was different among K-fertilizer rates. Within each year after fertilization, Mehlich-3 K increased gradually as soil-test K increased. When Mehlich-3 soil-test K data were analyzed as a split-plot, the annual K rate by year interaction was significant at both sites ($P<0.0001$). At the Johnsburg site, the mean Mehlich-3 K was classified as 'Above Optimum' for all K rates at the start of 2007, but, after one year of cropping soil receiving ≥300 lb K_2O/acre/year, remained in the 'Above Optimum' level. Soil receiving 0 and 100 lb K_2O/acre/year K had declined to a 'Medium' (91-130 ppm) Mehlich-3 K level. Comparing between years on the Johnsburg soil showed Mehlich-3 K declined between years when 0 to 200 lb K_2O/acre/year were applied, remained constant when 300 or 400 lb K_2O/acre/year were applied, and increased when 500 lb K_2O/acre/year were applied. For the Captina soil, Mehlich-3 K among all annual K rates in 2006 was classified as 'Medium' and declined to a 'Low' level in 2007 and 2008 for soil receiving no K. Comparing Mehlich-3 soil K between years 2006 and 2008 on the Captina soil showed Mehlich-3 K declined when 0 to 200 lb K_2O/acre/year were applied and increased when 300 to 500 lb K_2O/acre/year were applied. Results for HNO_3 extractable K on the Captina soil were comparable to the description of Mehlich-3 results except that application of 300 lb K_2O/acre/year maintained HNO_3-extractable K. Overall, soil-test K results from both soils indicate that available soil K declines rapidly when K-fertilizer rate is inadequate.

Potassium Trial - Captina soil

Forage yields on the Captina soil in 2008 were affected significantly by K fertilization for each harvest and the season total (Table 3). Bermudagrass receiving 0, 100, and 200 lb K_2O/acre/year could be visually identified throughout the year by a darker green color, brown spot on leaves, and reduced growth. Season-total forage yields receiving no K produced only 41 to 43% of the yield produced by the highest yielding annual K rates (300 to 500 lb K_2O/acre), and remained relatively constant across each harvest. Relative yield potential of forage receiving no or sub-optimal K rates has declined each year of this study (Slaton et al., 2007; 2008).

Forage K concentrations were below 1.5%, the established critical concentration, for forage receiving 0 lb K_2O/acre/year for all harvests (Table 4). Application of 100 lb K_2O/acre/year increased tissue K above the 1.5% K critical level, but failed to maximize yield (Table 3). In general, K concentrations increased as annual K rate increased. When adequate K was applied to maximize yields (≥300 lb K_2O/acre/year) tissue K remained relatively constant (not compared statistically) across harvests (Table 4). Season-total K uptake increased as K rate increased to 400 lb K_2O/acre/year and accounted for more K removed than added for each annual K rate except 500 lb K_2O/acre/year. Based on season-total yield and K uptake, the rate of K removal ranged from 16 to 43 lb K_2O/ton for 0 to 200 lb K_2O/acre/year and K removal by annual-K rates that produced the greatest yields (Table 3) ranged from 56 to 64 lb K_2O/ton (Table 4). Recovery of K fertilizer applied in 2008, calculated by difference, was high and ranged from 76 to 105%. The high K-fertilizer recovery values may be attributed to plant uptake of some K applied in 2006 and 2007. Adequate soil moisture in 2008 may also have enhanced soil K movement and uptake.

Potassium trial - Johnsburg soil

The mixed-grass forage grown on the Johnsburg soil showed no significant yield response to K fertilization for the June harvest (Table 3). Forage yield for the July and August harvests and season-total were significantly affected by annual K-fertilizer rate. Annual application of >200 K_2O/acre resulted in significant yield increases compared to the unfertilized control. Maximum forage yields were produced by application of 300 to 500 lb K_2O/acre/year. Forage receiving no K for the last two years produced 78 to 84% of the yield produced by forage receiving 300 to 500 lb K_2O/acre/year. In 2007, the first year of this trial, K fertilization benefitted only the third harvest, but the magnitude of yield increase was not large enough to influence season-total yield (Slaton et al., 2008)

Tissue K concentration and total K uptake were not affected by annual K application rate for the June harvest (Table 5). However, for the July harvest, both tissue K and total-K uptake were significantly affected by annual K-fertilizer rate.

Forage K concentration of the no K control declined below 1.0% and was significantly lower than forage receiving K-fertilizer. Forage receiving 100 lb K_2O/acre/year also contained significantly lower K concentrations than forage receiving rates >100 lb K_2O/acre/year, which had similar K concentrations. Tissue analysis for the August harvest has not been completed. For the June harvest, K removal among annual K rates was relatively constant and ranged from 42 to 54 lb K_2O/ton of harvested forage. However for the July harvest, which responded positively to K fertilization, K removal among annual rates ranged from 20 to 57 lb K_2O/ton with K rates that produced maximum yields removing 53 to 57 lb K_2O/ton. Based on season-total K uptake and yield, the K content of harvested forage was greater in 2007, ranging from 53 to 79 lb K_2O/ton (Slaton et al., 2008).

PRACTICAL APPLICATION

The second (Johnsburg soil) and third (Captina soil) year of this research showed that bermudagrass forage harvested for hay removes large amounts of K and causes rapid depletion of soil-test K. Results suggest that 300 lb K_2O/acre/year are needed to maximize bermudagrass forage yields that range from 5 to 6 ton/acre/year. Lower annual rates of K application help maintain forage yields, but may not allow for maximum yield potential. Potassium deficiency may reduce forage yield potential by as much as 50 to 60%. Fields cropped to bermudagrass and managed for moderate to high yields should be soil sampled at least once every two years or every year to insure that K is not limiting yield potential.

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Table 1. Selected soil chemical property means (*n* = 30; 0-to 4-inch depth) for bermudagrass fertilization trials conducted on Captina and Johnsburg silt loams in Washington County, Ark., since 2006 or 2007.

Soil series	Year	Soil pH	Mehlich-3 extractable nutrients P	K	Ca	Mg	S	Na	Fe	Mn	Zn	Cu
			(mg/kg)									
Captina	2006	5.0	121	116	710	71	29	11	179	193	6.9	1.6
Captina	2007	5.3	109	--^{z}	629	76	21	6	163	123	6.2	1.9
Captina	2008	4.7	127	--^{z}	527	72	24	8	177	91	5.7	1.7
Johnsburg	2007	6.5	1284	207	2919	94	13	33	225	69	45.6	7.5
Johnsburg	2008	6.1	1255	--^{z}	2804	80	15	47	215	47	46.1	8.6

[z] Soil-test K values as affected by treatment are listed in Table 2.

Table 2. Mehlich-3 and total HNO_3-extractable (non-exchangeable + exchangeable) soil K in 2006 or 2007 before K fertilization and 2007 and 2008 as affected by annual K-fertilizer rate at two sites.

	Johnsburg silt loam		Captina silt loam					
Annual K	Mehlich-3 K		Mehlich-3 K			HNO_3 K		
rate	2007	2008	2006	2007	2008	2006	2007	2008
(lb) K_2O/acre	(ppm)							
0	207	102	113	85	69	427	382	322
100	198	115	118	124	73	440	438	333
200	210	138	125	128	96	462	463	359
300	225	204	108	176	171	473	539	476
400	192	208	106	211	214	430	590	542
500	209	288	121	240	275	440	647	618
LSD0.10	NS[z]	21	NS	25	35	NS	47	50
p-value	0.7555	<0.0001	0.3633	<0.0001	<0.0001	0.6413	<0.0001	<0.0001
LSD0.10	24[y] or 30[x]			15[y] or 27[x]			41[y] or 50[x]	
p-value	<0.0001			<0.0001			<0.0001	

[z] NS, not significant (P>0.10).

[y] Compare annual K-rate means within a year.

[x] Compare any two K-rate means across years.

Table 3. Individual harvest (by month) and season-total forage yields as affected by annual K-fertilization rate for trials conducted on Captina and Johnsburg silt loams in Washington County, Ark., during 2008.

Season total K_2O	Rate and application	Johnsburg silt loam (year 2)				Captina silt loam (year 3)			
rate	frequency	Total	June	July	August	Total	June	July	August
(lb K_2O/acre)		[Forage yield (lb/acre)]							
0	--	9737	4636	2740	2361	5599	2236	1770	1593
100	100 × 1[z]	10824	4877	3409	2538	9775	4300	2859	2616
200	100 × 2	10973	4724	3456	2793	11814	4492	3945	3377
300	100 × 3	11561	4679	3603	3279	13021	5104	4184	3733
400	133 × 3	11848	4745	3617	3486	13611	5239	3947	4425
500	167 × 3	12529	4751	4134	3644	13576	5047	4482	4047
LSD(0.10)		1223	NS[y]	570	477	878	460	283	428
p-value		0.0159	0.9959	0.0153	0.0005	<0.0001	<0.0001	<0.0001	<0.0001
C.V., %		10.0	14.5	15.0	14.5	7.2	9.6	7.3	11.9

[z] Potassium fertilizer applied in one to three split applications including at greenup and following selected harvests.

[y] NS, not significant (*P*>0.10).

Table 4. Individual harvest (by month) and season-total bermudagrass forage K concentrations and total K uptake as affected by annual K-fertilization rate for a trial conducted on a Captina silt loam in Washington County, Ark., during 2008.

	Forage K Concentration (by harvest)			Forage K_2O Uptake (by harvest)			
Total K_2O rate	June	July	August	Total	June	July	August
(lb K_2O/acre)	(% K)			(lb K_2O/acre)			
0	0.79	0.61	0.54	45	22	13	10
100	1.64	1.11	0.84	150	85	38	27
200	1.88	2.15	1.24	255	102	102	51
300	2.25	2.56	2.12	362	138	129	95
400	2.68	2.89	2.51	438	168	137	133
500	2.70	2.73	2.42	427	163	146	118
LSD(0.10)	0.42	0.31	0.29	34	22	12	16
p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
C.V., %	19.5	14.0	16.6	11.3	17.9	11.6	20.7

Table 5. Mixed forage K concentrations and total K uptake for the first (June) and second (July) harvests as affected by K-fertilization rate for a trial conducted on a Johnsburg silt loam in Washington County, Ark., during 2008.

	Forage K concentration (by harvest)		Total K_2O uptake	
Total K_2O rate	June	July	June	July
(lb K_2O/acre)	--------------------(% K)-------------------		------------ (lb K_2O uptake/acre)-----	
0	2.04	0.84	114	28
100	2.24	1.37	132	56
200	1.73	2.33	98	98
300	2.17	2.26	123	98
400	2.05	2.21	115	96
500	2.20	2.33	127	116
LSD(0.10)	NS[z]	0.28	NS	19
p-value	0.7535	<0.0001	0.7622	<0.0001
C.V., %	27.5	13.6	32.1	21.6

[z] NS, not significant (P>0.10).

Bermudagrass Forage Response to Phosphorus Fertilization Rate

N.A. Slaton, C.G. Massey, R.E. DeLong, B.R. Golden, and E. Maschmann

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Bermudagrass [*Cynodon dactylon* (L. Pers.)] is grown for hay and pasture that helps sustain cattle production in western Arkansas. Poultry litter has been the primary nutrient source applied to forages in western Arkansas for a number of years. However, poultry litter application to forages in many western Arkansas fields will decline due to regulations that limit the rate or sometimes prohibit its application on soils that contain high soil-test P or have features that are conducive to P transport via run-off. Sustaining high forage yields will require judicious use of other nutrient sources and soil amendments.

Verifying the agronomic need for P fertilization of forages and reducing soil-test P in soils with above optimum soil-test P levels by intensive forage management are common questions that need geographic-specific research. The time required to reduce above-optimum, soil-test P levels via phytoremediation to environmentally acceptable levels is an important aspect for long-term management of land and manure resources. Furthermore, research investigating forage yield response to P fertilization is essential to develop agronomically and environmentally sound, soil-test-based nutrient management practices for growers. The research objectives were to evaluate i) how P-fertilizer rate influences warm-season forage grass yield and ii) soil-test P across time.

PROCEDURES

Fertilization trials were initiated in April 2006 in a field of common bermudagrass on a Captina silt loam at the Arkansas Agricultural Research and Extension Center (AAREC) and in April 2007 in a field of 'Midland' bermudagrass on a Johnsburg silt loam in Washington County, Ark. The first and/or second year results from P and K trials were reported by Slaton et al. (2007; 2008) and the second and third year of these trials are described in this report. Each site will be referred to by soil series. At both sites, the same P rates have been applied to the same plots each year. The Captina soil had been used for hay production and grazing with a history of manure application. Forage at the Johnsburg site was a mixture of crabgrass, ryegrass, foxtail, and bermudagrass with the dominant grass species in 2008 being crabgrass and bermudagrass.

Plots were 20-ft long at both sites and 5-ft wide for the Johnsburg site and 6-ft wide for the Captina site. Composite soil samples were collected from each plot in January 2008 to a depth of 4 inches to monitor changes in soil-test P following P treatment applications in previous years. Each composite soil sample consisted of eight soil cores. Soils were dried at 120°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 soil-test method. Selected soil chemical property means for each test are listed in Table 1. In fall 2007, 2000 lb pelleted dolomitic lime/acre were applied to the Captina soil to maintain soil pH.

Triple superphosphate (0-46-0) was applied in one, two, or three split applications for cumulative rates equaling 0, 45 (45 lb P_2O_5 × at green-up), 90 (45 lb P_2O_5 × 2 at green-up and following harvest 1), 135 (45 lb P_2O_5 × 3 at green-up and following harvest 1 and 2), 180 (60 lb P_2O_5 × 3 at green-up and following harvest 1 and 2), and 225 lb P_2O_5/acre (75 lb P_2O_5 × 3 at green-up and following harvest 1 and 2). For the Johnsburg soil, only the 0, 45, 90, and 135 lb P_2O_5/acre rates were evaluated with applications made as described for the same rates as applied to the Captina soil. Phosphorus-fertilizer treatments were applied on 1 May (before green-up), 14 June following the first harvest, and 16 (Johnsburg) or 18 (Captina) July following the second harvest. Potassium fertilizer (100 lb K_2O/acre) was applied on 1 May (before green-up at both sites), and when N fertilizer was applied to each test. At greenup N fertilizer was applied (6 May for Captina and 12 May for Johnsburg soil) as 100 lb $(NH_4)_2SO_4$/acre plus 300 lb NH_4NO_3/acre at each site (~120 lb N/acre). Following the first (17 June for both sites) and second harvests (16 or 18 July for Johnsburg and Captina soils, respectively), 120 lb N/acre as either NH_4NO_3 or urea were applied resulting in a season total of 360 lb N/acre.

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 inches. At the Captina site, forage was harvested on 12 June, 14 July, and 26 August. At the Johnsburg site, forage harvest was performed on 11 June, 15 July, and 21 August. The freshly cut biomass from each plot was weighed and eventually adjusted to a total dry weight expressed as lb dry forage/acre by recording the weight (~500-g) of a subsample of fresh forage, which was subsequently dried to a constant weight in a forced draft oven at 60°C and weighed again for dry weight.

A shrink factor was calculated and used to adjust total fresh forage weight to a dry weight basis. Subsamples of forage from the P- and K-fertilization trials were 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 calculation of P and K uptake and removal. Tissue analysis for the third harvest on the Johnsburg soil is not yet complete.

Each annual P-fertilizer rate was replicated 5 times for the Captina soil and 4 times for the Johnsburg soil. For both studies, analysis of variance was conducted by site with the PROC GLM procedure in SAS (SAS Institute, Inc., Cary, N.C.). Forage yields were analyzed by harvest time and for season-total production for 2008. Soil-test P data were analyzed as described above for each individual year and using a split-plot treatment structure where annual P-rate was the whole plot and year was the sub-plot. When appropriate, mean separations were performed using Fisher's Protected Least Significant Difference method at a significance level of 0.10.

RESULTS AND DISCUSSION

Precipitation during the spring and early summer of 2008 was above normal, allowing for the production of high forage yields. Precipitation measured at the AAREC totaled 35.1 inches from April through September 2008 compared to the normal amount of 21.3 inches. At least 4.6 inches of rain were received each month. Although rainfall was above normal, air temperatures were slightly below normal and may have inhibited bermudagrass growth.

Soil-Test P

Mehlich-3-extractable soil-P concentrations on the Johnsburg soil in 2008 were statistically similar among the six P-fertilizer rates with an average of 1053 ppm and P-rate means varying from 1046 to 1063 ppm (Table 2). The average soil-test P in 2008 was significantly greater (P=0.0328) than in 2007 (1020 ppm), but was not affected by annual P-fertilizer rate (P=0.6421) or the P-rate × year (P=0.3432) interaction. All 2008 soil-test P means would be classified as 'Above Optimum' by University of Arkansas guidelines. Based on the soil-test P, no forage yield benefit from P fertilization was expected.

Soil-test P on the Captina soil was affected by the annual P rate × year interaction (P<0.0001, Table 2). Compared to the initial soil-test P values in 2006, following the two years of fertilization, soil-test P declined when 0 to 45 lbs P_2O_5/acre/year were applied, remained constant when 90 lb P_2O_5/acre/year were applied, and increased when >90 lb P_2O_5/acre/year were applied. The unfertilized control soil-test P level in 2008 was still considered 'Above Optimum' (>50 ppm) and would receive an agronomic recommendation of 0 lb P_2O_5/acre. After two years of fertilization and cropping, 2008 soil-test P on the Captina soil changed by 0.45 ppm P/1 lb P_2O_5 applied (ppm Mehlich-3 P = 79 + 0.445x; r^2 = 0.83).

Phosphorus Trial - Captina soil

On the Captina soil, unlike the results of 2006 and 2007 (Slaton et al., 2007; 2008), P-fertilizer rate had a significant influence on bermudagrass yields for season-total and individual harvest yields in June and August (Table 3). Season-total yield was maximized by application of 135 lb P_2O_5/acre/year. Bermudagrass receiving no P fertilizer for the duration of the 3-year trial produced 86 to 89% of the maximum yield potential of forage receiving P. These data suggest that to achieve maximal forage yield potential, P fertilization may be required on some soils that have Mehlich-3 extractable P >50 ppm. In previous years, significant yield responses to P fertilization were obtained only for the third harvest and the magnitude of these differences was not large enough to influence season-total yield (Slaton et al., 2007; 2008).

Phosphorus concentrations of forage receiving no P were always ≥0.25% (Table 4) for each harvest and considered sufficient (Plank and Campbell, 2000). Phosphorus rate influenced forage-P concentrations for each harvest. Application of P rates ≥45 or 90 lb P_2O_5/acre/year, depending on harvest, increased forage P concentrations. Total P_2O_5 equivalent uptake by harvested forage was affected significantly by annual-P rate for each individual harvest and the season-total with the greatest numerical difference among treatments occurring for the first harvest (Table 4). Season total P_2O_5 removal exceeded the annual P-fertilizer rate only for the 0 and 45 lb P_2O_5/acre/year rates. Total-P removal and addition were nearly balanced for the 90 lb P_2O_5/acre/year rate. Based on the season-total yield and P_2O_5-equivalent uptake, harvested forage contained 11.6 to 15.6 lb P_2O_5/ton with the removal rate increasing numerically as annual-P rate increased. Plant recovery of fertilizer P added in 2008, calculated by difference, ranged from 16 to 24% .

Phosphorus Trial - Johnsburg soil

For the Johnsburg soil, P fertilization had no significant influence on forage yield (Table 3). Likewise, P concentration and total-P uptake in forage harvested in June or July were not statistically different among treatments (Table 5). Forage P concentrations ranged from 0.38 to 0.49% P depending on harvest and P rate. Although forage P concentrations were not statistically compared between sites, P concentrations were numerically greater for forage grown on the Johnsburg soil (Table 5) than the Captina soil (Table 4), which was consistent with 2007 results (Slaton et al., 2008). Based on the individual harvest yield and P_2O_5-equivalent uptake, harvested forage contained 17.6 to 20.6 lb P_2O_5/ton.

PRACTICAL APPLICATION

The third year of research on the Captina soil indicated that soil-test P is gradually declining when the P-fertilizer rate is less than the amount of P removed by harvested forage. After two years of cropping, the soil-test P in soil receiving no P has declined from 112 ppm to 86 ppm. When net P balance (P inputs - removals) is used to assess the change in soil-test P after two complete harvest cycles, Mehlich-3 soil P changed by 1 ppm for each 4 lb net-P_2O_5 equivalent added or removed. Yield data suggest that a nominal amount of P fertilizer is needed to maintain maximal forage yield potential on the Captina soil even though soil-test P remains above optimum. In contrast to the Captina soil, the Johnsburg soil, which has soil test P >1000 ppm, forage yield did not benefit from P fertilization in 2008 and soil-test P failed to decline after one cropping cycle, regardless of P rate. Research at the Captina soil site will be continued for a fourth year.

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Table 1. Selected soil chemical property means (0- to 4-inch depth) for bermudagrass fertilization trials conducted on a Captina silt loam and Johnsburg silt loam in Washington County, Ark., since 2006 or 2007.

		Soil	Mehlich-3-extractable nutrients									
Test	Year	pH	P	K	Ca	Mg	S	Na	Fe	Mn	Zn	Cu
			(mg/kg)									
Captina	2006	5.1	116	113	613	60	26	9	179	193	7.8	1.5
Captina	2007	5.2	--[z]	213	587	63	21	5	167	147	6.5	1.7
Captina	2008	4.8	--[z]	130	476	57	20	7	169	100	4.7	1.4
Johnsburg	2007	6.6	1020	229	2611	86	13	12	236	89	29.2	5.2
Johnsburg	2008	6.3	--[z]	127	2572	76	15	30	225	53	30.4	5.5

[z] Soil-test P values as affected by treatment are listed in Table 2.

Table 2. Mehlich-3 soil P in 2008 as affected by annual P-fertilizer rate applied in 2006 and 2007 on a Captina silt loam and in 2007 on a Johnsburg silt loam.

	Mehlich-3 P				
	Johnsburg silt loam		Captina silt loam		
Annual P rate	2007	2008	2006	2007	2008
(lb P_2O_5/acre)	(ppm)				
0	1046	1046	112	97	86
45	999	1063	123	98	97
90	1033	1051	114	113	103
135	989	1054	115	116	152
180	--	--	118	144	152
225	--	--	112	151	184
LSD0.010[z]	NS	NS	NS	17	15
P-value	0.5069	0.5266	0.7687	0.2590	<0.0001
LSD0.10[y]	NS (*P*=0.3432)		11[x] or 12[w] (*P*<0.0001)		

[z] LSD0.10 for analysis conducted by year.

[y] LSD0.010 for the annual-P rate × year interaction for analysis of variance using a split-plot treatment structure.

[x] To compare any two K-rate means within the same year.

[w] To compare any two means among years.

Table 3. Individual harvest (by month) and season total forage yields as affected by annual P fertilization rate for trials conducted on Captina and Johnsburg silt loams in Washington County, Ark., during 2008.

Season Total P_2O_5 rate	Application frequency	Johnsburg silt loam (year 2)				Captina silt loam (year 3)			
		Total	June	July	August	Total	June	July	August
(lb P_2O_5/acre)		[Forage yield (lb/acre)]							
0	--	9674	2905	3528	3241	11680	4262	3704	3714
45	45 × 1[z]	9555	2813	3746	2996	12810	5152	3752	3906
90	45 × 2	10202	3589	3792	2821	12371	4660	3792	3919
135	45 × 3	9831	3108	3746	2977	13153	5030	4010	4113
180	60 × 3	--	--	--	--	13616	5286	4069	4261
225	75 × 3	--	--	--	--	13296	5067	3960	4269
LSD(0.10)		NS[y]	NS	NS	NS	595	432	NS	310
p-value		0.5550	0.1053	0.7999	0.2568	0.0002	0.0059	0.1375	0.0334
C.V., %		6.7	13.5	11.1	9.1	4.3	8.1	6.3	7.0

[x] Phosphorus fertilizer applied in three split applications including at greenup and following selected harvests.

[y] NS, not significant (*P*>0.10).

Table 4. Individual harvest (by month) and season total bermudagrass forage P concentrations and total-P uptake as affected by annual P-fertilizer rate for a trial conducted on a Captina silt loam in Washington County, Ark., during 2008.

	Forage P concentration (by harvest)			Forage total P uptake (by harvest)			
Total P_2O_5 rate	June	July	August	Season	June	July	August
(lb P_2O_5/acre)	(% P)			(lb P_2O_5/acre)			
0	0.26	0.26	0.25	68	25	22	21
45	0.27	0.28	0.26	79	31	24	23
90	0.28	0.32	0.28	83	30	28	25
135	0.31	0.33	0.30	95	37	30	28
180	0.32	0.34	0.29	97	38	32	28
225	0.34	0.37	0.31	104	40	33	31
LSD(0.10)	0.021	0.022	0.023	4.4	4	3	3
P-value	<0.0001	<0.0001	0.0010	<0.0001	<0.0001	<0.0001	<0.0001
C.V., %	6.5	6.5	7.5	4.6	11.5	8.0	9.7

Table 5. Mixed forage P concentrations and total-P uptake for the first (June) and second (July) harvests as affected by annual P-fertilization rate for a trial conducted on a Johnsburg silt loam in Washington County, Ark., during 2008.

	Forage P concentration (by harvest)		Forage total P uptake	
Total P_2O_5 rate	June harvest	July harvest	June harvest	July harvest
(lb P_2O_5/acre)	(% P)		(lb P_2O_5/acre)	
0	0.45	0.40	30	32
45	0.41	0.38	26	33
90	0.45	0.43	37	37
135	0.49	0.41	35	35
LSD(0.10)	NS[z]	NS	NS	NS
P-value	0.4651	0.3029	0.1740	0.3996
C.V., %	14.7	8.6	21.2	12.6

[z] NS, not significant (*P*>0.10)

Canola Response to Nitrogen, Sulfur, Phosphorus, and Potassium Fertilization in Arkansas

N.A. Slaton, R.E. DeLong, M. Emerson, R.K. Bacon, and J. Kelly

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Canola (*Brassica rapa*) is an oilseed crop that is related to broccoli (*Brassica oleracea* var *Italica*) and turnip (*Brassica campestris* var *Rapifera*). The name 'canola' actually stands for 'Canadian oil, low acid'. Canola's low erucic acid content differentiates it from rapeseed (*Brassica napus*) and is sometimes referred to as LEAR or 'low erucic acid rapeseed.' Canola seed contains about 40% oil and increasing its production in the southern U.S. is of interest for biofuel production.

Canola is grown on just over 1.1 million acres in the U.S. with about 90% of the acreage in North Dakota where it is planted in the spring (USDA-NASS, 2008). The average canola yield in the U.S. usually ranges from about 1200 to 1600 lb/acre (24 to 32 bu/acre). In the southern USA, canola is planted in the fall and harvested in the late spring similar to winter wheat (*Triticum aestivum*). For canola to be successfully grown and adopted by growers, agronomic recommendations regarding appropriate fertilizer rates must be developed. Fertilizer recommendations from the University of Kentucky suggest canola should receive about 120 lb N/acre (Herbeck and Murdock, 1992), performs best when soil pH is between 6.0 and 7.0, is sensitive to P deficiency, and seldom responds to S despite its high S requirement. Our overall research goal is to develop research-based fertilizer recommendations for canola varieties adapted to Arkansas. Our research objectives were to determine canola yield responses to i) P and K fertilizer rates, ii) S fertilization, and iii) N fertilizer rate, source, and application time in eastern Arkansas.

PROCEDURES

Fertilization experiments were established on a Dewitt silt loam at the Rice Research Extension Center (RREC) near Stuttgart, Ark., in October 2007. Experiments were also initiated at the Pine Tree Branch Station, but stand establishment failed due to problems with seed flow through drill tubes. At the RREC, trials were established in a field that was fallowed in summer 2007. Individual plots measuring 20-ft long by 6.5-ft wide were flagged for each nutrient trial. Before seeding and fertilizer application, composite soil samples (n = 2 or 3) were collected from the 0- to 4-inch depth from each pair of replicates for each nutrient study area. Soil samples were oven-dried at 60°C, crushed, and passed through a 2-mm sieve. Soils were analyzed for organic matter by weight loss on ignition, soil water pH in a 1:2 soil weight:water volume mixture, and plant-available nutrients were extracted using the Mehlich-3 method and quantified by inductively coupled plasma spectroscopy. Soil from the N study was also analyzed for NH_4-N (11 ppm) and NO_3-N (40 ppm) by extracting soil with 1 *M* KCl. Selected soil chemical property means are listed in Table 1.

Canola variety AR377 was planted into a conventionally tilled seedbed on 5 October 2007 with a small-plot drill at a seeding rate of 6 lb/acre. Each plot contained seven rows (7-inches wide) of canola. The research area received 1 pt Treflan/acre prior to seeding to aid in controlling weeds. The P- and K-rate trials each included five fertilizer rates (0, 40, 80, 120, and 160 lb P_2O_5 or K_2O/acre) as triple superphosphate or muriate of potash, respectively, which were broadcast to the soil surface shortly after planting (1 November 2007). Triple superphosphate (~60 lb P_2O_5/acre) was applied to the K-rate trial and muriate of potash (60 lb K_2O/acre) was applied to the P-rate trial. Zinc (10 lb Zn/acre) and B (1 lb B/acre) fertilizers were also applied to each trial. Each trial was a randomized complete block design with six replications.

The N-fertilization trial was seeded as described for the P and K trials and also received blanket applications of P, K, Zn, and B fertilizer. Treatments in the N trial served to satisfy two primary objectives: 1) to identify the proper N rate and application time combinations that allow for near maximal yield production and 2) to identify whether S fertilizer is needed to maximize canola yield. For the first objective, N was applied in single or split applications at 0, 45, 75 (45+30), 105 (45+60), 135 (60+75), and 165 (80+85) lb N/acre as a combination of ammonium sulfate (21-0-0-24) and urea (46-0-0). Ammonium sulfate was applied at a rate of 100 lb/acre as part of the first split with the balance of each N rate supplied as urea. Nitrogen fertilizer was applied on 15 January, 10 February, and/or 12 March. With regard to N application time, N treatments can be categorized as applied in i) January and February (Jan-Feb) or ii) February and March (Feb-Mar). The one exception was for the 165 lb N/acre rate, which was applied in two splits (80+85) in Jan-Feb or three splits (60+60+45) which were grouped into the Feb-Mar timing. The eleven N treatments in this study were a randomized complete block arranged as a 2 (time of application) × 5 (total N rate) factorial and compared to an unfertilized (0 lb N/acre) control with four replications.

Four additional N treatments were included in the N trial to examine whether S is needed to maximize canola yield. Nitrogen was applied exclusively as urea at total N rates of 105 (45+60) and 135 (60+75) lb N/acre in two split applications made in Jan-Feb or Feb-Mar to correspond with the previously described treatments applied as a combination of ammonium sulfate and urea. For this objective, only treatments applied at 105 and 135 lb N/acre were compared, which resulted in a randomized complete block design with a 2 (N application times) × 2 (N sources) × 2 (N rates) factorial arrangement with four replications.

The uppermost, mature leaves (20) were collected from selected plots and trials at the late-boot growth stage (stage 3.3), dried to a constant moisture, ground to pass a 1-mm sieve, digested with concentrated HNO_3 and 30% H_2O_2, and analyzed for elemental concentrations. The late-boot stage (also called green bud) is when flower buds are visible from above with few, if any, open flowers (Anonymous, 2005). In the P and K rate trials, leaf samples were collected from all treatments, but in the N trial, samples were collected only from the no N control and all plots receiving 105 lb N/acre. Tissue analysis data from the N study was a randomized complete block with a 2 (N sources) × 2 (N application times) factorial treatment structure compared to a no N control with four replicates.

A 15-to 16-ft long section of each plot was harvested with a small-plot combine at maturity. Canola seed moisture was adjusted to 8.5% for final yield calculations and converted to bushels per acre based on 50 lb/bushel. All research plots received an insecticide application in January to control aphids. A sub-sample of the harvested canola seed was saved and whole seeds (~0.25 g) were digested as described previously for leaf analysis. Seed from selected treatments of the N-rate study were also analyzed for N content by combustion.

For each study or objective, analysis of variance was conducted with the PROC GLM procedure in SAS v9.1 (SAS Institute, Inc., Cary, N.C.) using the designs mentioned previously for each trial and measurement. When appropriate, mean separations were performed using Fisher's Protected Least Significant Difference method at a significance level of 0.10.

RESULTS AND DISCUSSION

Nitrogen Trials

Canola yields were affected by the N rate × application time interaction (Table 2). When N rates were 75 and 135 lb N/acre, there were no yield differences between N application times. Differences among N application times occurred for 45, 105, and 165 lb N/acre rates, but showed no consistent trend favoring one application time. When 45 lb N/acre were applied in a single application, yields were higher when N was applied in early January rather than February. Likewise, canola yields were numerically greater when 105 lb N/acre were split-applied in January-February than when split between February-March. The greatest numerical canola yield of 60 bu/acre was produced by 165 lb N/acre applied in a three-way split.

Sulfur was not needed to maximize canola yields on the Dewitt silt loam. No significant differences existed for the main effects of N source, rate, and application time or for any of the possible two- and three-way interactions among the main effects (Table 3). Averaged across N sources and application times, canola yields averaged 54 bu/A for 105 lb N/acre and 56 bu/acre for 135 lb N/acre. These results suggest that S may not be needed on a routine basis for canola production on silt loam soils in eastern Arkansas. Tissue S concentrations also support this conclusion as all sampled treatments contained S concentrations (Table 4) greater than the proposed critical value of 0.47% (Plank and Tucker, 2000). Plants receiving N in January and February tended to have lower concentrations of each nutrient (including S), which might be related to the amount of plant growth at the time of sampling (i.e., dilution effect).

Harvested canola seed concentrations of P (0.93%), K (0.98%), Ca (0.46%), Mg (0.37%), S (0.51%), Na (15 ppm), Fe (66 ppm), Mn (68 ppm), Zn (54.9 ppm), Cu (3.6 ppm), and B (12.8 ppm) were not affected by N application time or N source (data not shown). Only seed N concentration was significantly affected by N application time. Seed N concentration from the no N control contained lower N (2.92% N, LSD0.10 = 0.18% N) than seed from plants receiving N applied in January-February (3.17 % N) or February-March (3.38% N), when averaged across N sources. Application of 105 lb N/acre in February-March resulted in significantly greater seed N concentrations than when N was applied in January-February.

Phosphorus and Potassium Trials

Soil test nutrient levels on the Dewitt silt loam were classified as medium for K (91 to 130 ppm) and very low for P (<16 ppm, Table 1). Based on these levels, canola grown on this soil would be tentatively expected to respond positively to P fertilization, but not to K fertilization. Although the soil pH was also below optimum, lime had been applied prior to seeding but had not had enough time to react when soil samples were collected.

Application of all P rates, except 80 lb P_2O_5/acre, resulted in significant and positive canola seed yield increases (Table 5). Tissue P concentrations increased as P-fertilizer rate increased. The proposed critical level for recently matured canola leaves at early flowering is 0.37% (Plank and Tucker, 2000). Based on leaf samples, plants contained sufficient P concentrations only when >40 lb P_2O_5/acre were applied. All other nutrients were generally sufficient and were affected minimally by P rate.

Canola yields were not significantly affected by K-fertilizer rate (Table 6). However, tissue K concentrations were below the suggested critical concentration of 2.15% K (Plank and Tucker, 2000) for all rates <120 lb K_2O/acre. The lack of a positive yield response to K fertilization suggests the proposed critical tissue concentration may be too high for canola grown in Arkansas, but additional research is needed to verify this hypothesis. All other plant nutrients were present at a sufficient level and were affected nominally by K rate.

Seed analysis showed K-fertilizer rates significantly affected K, Zn, and B concentrations in harvested seed among the three K rates selected for analysis (Table 7). Seed K concentrations increased significantly as K rate increased suggesting that canola seed may accumulate K luxuriously since canola yield was not affected by K fertilization (Table 6). Although seed B and Zn concentrations were significantly different among the 0, 80, and 160 lb K_2O/acre rates, no consistent trend was apparent and the magnitude of difference was relatively small (Table 7).

Phosphorus fertilizer rate significantly influenced harvested seed concentrations of P, K, Ca, Mg, Mn, and Zn (Table 7). For each of these nutrients except Mn and Zn, seed concentrations increased with an increase in P rate. For Zn and Mn, seed concentrations increased significantly when P rate was increased from 0 to 80 lb P_2O_5/acre, but the addition of 160 lb P_2O_5/acre caused no additional Mn or Zn accumulation. Canola yields were increased by application of ≥40 lb P_2O_5/acre (Table 5), which suggests that, under the conditions of this trial, canola seed accumulated these macronutrients as P availability and plant growth increased. The seed nutrient concentrations from all three nutrient (N, P, and K) trials were equal to or higher than those reported by Jackson (2000) for spring-planted canola in Montana and are likely sufficient. Jackson (2000) also showed that canola seed oil content declined as N rate increased, but the optimal oil and seed yields per unit area occurred at similar N rates.

PRACTICAL APPLICATION

Canola variety 'AR 377' required 105 to 135 lb N/acre to produce near maximal yields on a Dewitt silt loam that was summer fallowed in 2007 and had a relatively high level of residual inorganic N. Canola grown following high-residue crops like corn, grain sorghum, and rice may require slightly greater N rates. Canola yields were affected very little by N application time when near optimal N rates were applied in split applications in January and February or February and March. However, application of N in January and February resulted in more vigorous early-season growth and may be the reason for slightly lower nutrient concentrations in plant tissues observed in late March. Although canola is known to have a high S requirement, S fertilization was not needed to maximize yield on this Dewitt silt loam. Although numerous site-years of research are required to correlate and calibrate soil-test P and K, canola exhibited the expected responses to fertilization based on our current interpretations of soil-test P and K.

The nutrient concentration of harvested canola seed was often affected by fertilization (i.e., application rate, source, and/or application time). Using average seed nutrient concentration values of 3.0% N, 0.80% P, and 0.95% K, the nutrient removal rates of harvested canola seed were equivalent to about 1.5 lb N/bu, 0.9 lb P_2O_5/bu, and 0.6 lb K_2O/bu.

During this first year of research, we learned that plots for canola need to be wider (>6.5 ft) than typically used for wheat. Wider plots (7.5-to 8.0-ft wide) will allow greater space between plots for examining plant growth and collecting plant samples in individual plots. Furthermore, corrugated tubes that deliver seed to the drill's disk opener may inhibit continuous seed flow and result in non-uniform seed placement.

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Table 1. Selected soil chemical property means for N, P, and K fertilization experiments established on a Dewitt silt loam in October 2007.

	Organic	Soil	Mehlich-3-extractable nutrients								
Study	matter	pH	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
	(%)		(ppm)								
Potassium	2.4	5.2	11	110	1247	164	12	294	106	1.3	1.9
Phosphorus	2.6	5.1	12	116	1338	182	12	293	109	1.8	1.8
Nitrogen	2.6	5.5	22	144	1582	218	12	336	95	5.6	2.2

Table 2. Canola seed yield response to N-fertilizer rate and application time on a Dewitt silt loam.

	Nitrogen application time	
Total N rate	January-February	February-March
(lb N/acre)	(bu/acre)	
0	39	
45	48	41
75	50	50
105	57	51
135	56	55
165	52	60
P-value	0.0345	
LSD(0.10)	4	

Table 3. Canola seed yield response to N source, rate, and application rate on a Dewitt silt loam.

	105 lb N/acre		135 lb N/acre	
N Source	Jan-Feb	Feb-March	Jan-Feb	Feb-March
(lb N/acre)	(bu/acre)			
Ammounium sulfate + urea	57	51	56	55
Urea	54	55	55	56
P-value	0.3281			
LSD(0.10)	NS[z]			

[z] NS, not significant (*P*>0.10).

Table 4. Canola leaf nutrient concentrations at development stage 3.3 as affected by N source and application time for selected treatments including 0 (None) and 105 lb N/acre as either urea or ammonium sulfate plus urea (AS+Urea) applied in split applications during January-February (Jan-Feb) or February-March (Feb-Mar).

	S		K		P		Zn	
N Source	Jan-Feb	Feb-Mar	Jan-Feb	Feb-Mar	Jan-Feb	Feb-Mar	Jan-Feb	Feb-Mar
	(%)						(ppm)	
None	0.53		1.73		0.36		44.2	
Urea	0.69	0.91	1.85	2.26	0.41	0.43	62.1	79.4
AS + Urea	0.73	0.86	1.92	2.27	0.41	0.43	69.4	74.0
P-value	0.0396		0.8234		0.9178		0.4455	
LSD(0.10)	0.04		NS[z]		NS		NS	

[z] NS, not significant (*P*>0.10).

Table 5. Canola seed yield and leaf nutrient concentration at development stage 3.3 responses to P-fertilizer rate on a Dewitt silt loam.

	Grain	Nutrient							
P-fertilizer rate	yield	P	K	Ca	Mg	S	Mn	Zn	B
(lb P_2O_5/acre)	(bu/acre)	------------------	------------------ (%)	------------------	------------------	------------------	------------	(ppm) ------------	------------
0	43	0.23	1.93	1.65	0.18	0.72	209	69.3	23.2
40	50	0.33	2.02	1.83	0.20	0.73	206	74.2	27.1
80	46	0.39	1.89	1.77	0.20	0.74	222	90.1	27.5
120	50	0.44	1.82	1.86	0.21	0.78	163	76.9	24.0
160	49	0.49	1.80	1.86	0.22	0.81	185	85.8	27.7
P-value	0.049	0.001	0.322	0.168	0.005	0.101	0.093	0.485	0.319
LSD(0.10)	4	0.03	NS[z]	NS	0.02	NS	NS	NS	NS

[z] NS, not significant ($P>0.10$).

Table 6. Canola seed yield and leaf nutrient concentration at development stage 3.3 responses to K-fertilizer rate on a Dewitt silt loam.

	Grain	Nutrient							
K-fertilizer rate	yield	K	P	Ca	Mg	S	Mn	Zn	B
(lb K_2O/acre)	(bu/acre)	------------------	------------------ (%)	------------------	------------------	------------------	------------	(ppm) ------------	------------
0	55	1.67	0.39	1.75	0.23	0.76	175	64.2	24.9
40	53	1.78	0.40	1.82	0.22	0.76	179	71.9	25.4
80	50	2.04	0.41	1.85	0.21	0.77	152	65.7	26.2
120	48	2.25	0.43	1.95	0.22	0.80	209	84.9	25.3
160	50	2.49	0.41	1.88	0.21	0.76	199	91.6	24.0
p-value	0.192	0.001	0.690	0.217	0.178	0.426	0.166	0.009	0.983
LSD(0.10)	NS[z]	0.18	NS	NS	NS	NS	NS	13.8	NS

[z] NS, not significant ($P>0.10$).

Table 7. Canola seed nutrient concentration as affected by P or K fertilization rates for trials conducted on a Dewitt silt loam.

Fertilizer	Nutrient										
rate	P	K	Ca	Mg	S	Na	Fe	Mn	Zn	Cu	B
(lb K_2O/acre)	------------	------------	(%) ------------	------------	------------	------------	------------	------------	(ppm) ------------	------------	------------
0	0.76	0.92	0.44	0.34	0.55	17	71	68	56.5	2.8	13.2
80	0.83	0.94	0.45	0.35	0.51	16	72	69	55.2	2.8	12.8
160	0.82	0.99	0.44	0.34	0.54	17	74	73	57.4	3.0	13.5
P-value	0.1135	0.0111	0.3851	0.6472	0.2056	0.4889	0.8018	0.1229	0.0765	0.5106	0.0882
LSD(0.10)	NS[z]	0.03	NS	NS	NS	NS	NS	NS	1.6	NS	0.5
(lb P_2O_5/acre)	------------	------------	(%) ------------	------------	------------	------------	------------	------------	(ppm) ------------	------------	------------
0	0.62	0.87	0.40	0.31	0.54	16	70	63	52.6	3.1	12.8
80	0.76	0.93	0.43	0.33	0.53	16	71	72	57.1	2.7	13.3
160	0.89	1.01	0.46	0.36	0.53	18	69	74	56.2	2.8	13.3
P-value	<0.0001	<0.0001	0.0001	<0.0001	0.3524	0.2270	0.7150	0.0004	0.0089	0.3556	0.1863
LSD(0.10)	0.03	0.03	0.01	0.01	NS	NS	NS	4	2.2	NS	NS

[z] NS, not significant ($P>0.10$).

Soybean Response to Phosphorus and Potassium Fertilization

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Soybean [*Glycine max* (L.) Merr.] production on silt- and sandy-loam soils in Arkansas often requires that phosphorus (P) and potassium (K) fertilizers be applied to maximize yield potential. Fertilizer use surveys conducted by the USDA show that Arkansas soybean growers typically apply P and K fertilizers to about 33% of the soybean acreage at average rates of 51 lb P_2O_5 and 68 lb K_2O/acre (USDA-NASS, 2005). Phosphorus and K fertilizer application rates and state average soybean yields have increased gradually across time while the planted acreage has declined. The average yields for irrigated soybean are commonly >40 bu/acre, which is 10 bu/acre or more higher than non-irrigated soybean yields (AASS, 2005). These data plus other changes in soybean production practices (i.e., herbicide technology, earlier seeding dates, and production of early-maturing cultivars) all indicate that the management of soybean is being intensified to maximize yields and profits.

Fertilization of soybean grown on soils with low cation exchange capacity is important and can represent a significant expense to growers. For example, in the South Central U.S. the average prices of muriate of potash and triple superphosphate in 2007 were approximately \$566/ton (\$0.46/lb K_2O) and \$887/ton (\$0.96/lb P_2O_5), respectively (USDA-NASS, 2008). Based on these prices, the cost of 0-40-60, a relatively low rate of fertilizer, is \$66.00/acre, which requires a 6 to 9 bu/acre yield increase to recover fertilizer costs when soybean prices range from \$8.00 to 10.00/ bu.

Many growers and consultants have questioned whether existing P and K fertilizer recommendations for soybean, developed from research in the 1970's and 1980's, are adequate to maximize and sustain high crop yields or are economical. The overall research goals were to i) correlate Mehlich-3 soil-test P and K with soybean yield and ii) calibrate the appropriate P and K fertilizer rates needed to produce optimum soybean yields for irrigated soybean production.

PROCEDURES

Phosphorus and K fertilization trials with soybean were established at three Agricultural Experiment Stations (Cotton Branch Experiment Station, CBES; Pine Tree Branch Station, PTBS; and Rice Research Extension Center, RREC) and two commercial production fields during 2008. Specific soil and agronomic information for each site are listed in Table 1. Each location will be referred to by the site name listed in Table 1. In the commercial fields, P and K fertilizers were applied to the surrounding field but not to the area where research plots were established.

A maturity group IV or V soybean cultivar was grown at each site. For the study conducted in the commercial fields, cultivar selection, planting, and management were performed by the cooperating grower. Management with respect to seeding rate, irrigation, and pest control at all sites closely followed recommendations from the University of Arkansas Cooperative Extension Service.

At each site, individual plots were 16- to 25-ft long by 10-to 24-ft wide with each nutrient trial positioned in adjacent plot areas. Before fertilizer was applied to the research tests, a composite soil sample was collected from the 0- to 4-inch depth from each replicate (n = 4-6) for each nutrient study area. Soil samples were oven-dried at 55°C, 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 Tables 2 and 3.

Potassium trials included five rates (0, 40, 80, 120, and 160 lb K_2O/acre) of muriate of potash, which were broadcast to the soil surface shortly before or after planting. Triple superphosphate (~60 lb P_2O_5/acre) was broadcast to the soil surface to ensure that P was not yield limiting. Granular B fertilizer (1.0 lb B/acre) was applied to all sites except the RREC and CBES. Each trial was a randomized complete block design with four to six replications.

Phosphorus fertilization trials were established adjacent to each K-rate trial. Triple superphosphate fertilizer was broadcast to the soil surface shortly after planting at rates equal to 0, 40, 80, 120, and 160 lb P_2O_5/acre. Muriate of potash (60 to 120 lb K_2O/acre) was broadcast to the soil surface to ensure that K was not yield limiting. Granular B fertilizer (1.0 lb B/acre) was applied to all sites except CBES and RREC. Each trial was a randomized complete block design with six or seven replications.

The P and K rate trials at the RREC were established and cropped to rice in 2007 with designated plots receiving the same P and K rates in both 2007 and 2008. The PTBS-39 and -40 trials were established in 2001 and have been cropped to rice (*Oryza sativa* L., odd years) and soybean (even years) with the same K rates being applied annually to designated plots. Thus, these sites represent cumulative crop responses to annual P and K fertilization rate. In contrast, all other sites represent soil that has been fertilized uniformly across time.

Trifoliate leaves (15) were collected from each plot 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.

RESULTS AND DISCUSSION

K-Rate Trials

The University of Arkansas soil-test guidelines for soybean showed that soil-test K (Table 2) at the Poinsett-2 was 'Low' (61 to 90 ppm); Poinsett-1, PTBS-40, and PTBS trials were 'Medium' (91 to 130 ppm); and PTBS-39, RREC, and CBES were 'Optimum' (131 to 175 ppm). Little or no positive yield response to K fertilization was expected at sites having medium or optimum soil-test K, but 50 lb K_2O/acre are suggested to maintain soil-K fertility.

Soil-test K at the long-term K trials, PTBS-39 and -40, has been affected by annual K application rate following 7-years of K fertilization (Table 4). However, soil-test K in both PTBS-39 and -40 was unexpectedly high compared to values in previous years (Slaton et al., 2008). In 2007, rice yields were increased significantly from K fertilization in both trials and soil-test K was <60 ppm. Despite the high 2008 soil-test K values, K-deficiency symptoms were visible within weeks after emergence on soybean that received 0 lb K_2O/acre/year. The soil-test K results may be from sampling error or other poorly understood mechanisms that influence extractable K at the time of sampling, but not K availability to the subsequent soybean crop.

The second year of the K-rate trials at the RREC showed soil-test K increased as K-fertilizer rate increased. Soil receiving 0 and 40 lb K_2O/acre/year showed a slight decline from samples collected before rice was planted in 2007, while soil receiving >40 lb K_2O/acre/year showed a numerical increase in soil-test K. Rice grown in 2007 showed no positive yield response to K fertilization.

Potassium concentrations in recently matured trifoliate leaves at the R2 growth stage were affected by K fertilization at 6 of 7 sites (Tables 4 to 6). Trifoliate K concentrations were not affected significantly by K-fertilizer rate at the CBES, the site with the greatest soil-test K (Table 2), but did show a trend to increase as K rate increased (Table 6). Trifoliate-leaf K concentrations in soybean receiving no K were <1.5%, the established critical K concentration, at all sites except CBES and RREC (Tables 4 to 6). The low K concentrations in soybean receiving no K suggest that soybean yields should have been increased from K fertilization at 5 of the 7 sites. Potassium fertilization increased trifoliate leaf K concentrations above 1.5% at all sites except Poinsett-1.

Soybean yields were increased significantly by K fertilization only at the three PTBS sites (Tables 4, 5, and 7). The positive yield responses to K fertilization at PTBS-39 and -40 were not surprising since the same K-fertilizer rates have been applied to these plots since 2002 (Table 4). The significant yield increases to K fertilization coupled with the higher than expected soil-test K at PTBS-39 and -40 are of concern. Reasons why the soil-test K was higher than expected are unknown at this time. The positive yield response at PTBS (Table 6) was also somewhat surprising because the soil-test K was 125 ppm (Medium) and near the low boundary of the Optimum level (131 to 175 ppm). Although soybean yields among K rates at each of the two Poinsett sites were not significantly different ($P>0.10$) using the LSD test, a single-degree-of-freedom comparison of soybean yields receiving K against no K showed the overall response to K fertilization was significant at Poinsett-2. Potassium fertilization was not expected to increase soybean yields at RREC and CBES as soil at these sites contained Optimum levels of soil-test K.

P-Rate Trials

The University of Arkansas soil-test guidelines for soybean showed that soil-test P (Table 3) was 'Very Low' (<16 ppm) at Poinsett-2; 'Low' at Poinsett-1, PTBS, and RREC (16 to 25 ppm); and 'Optimum' (36 to 50 ppm) at CBES. The second year of the long-term P-fertilization trial at the RREC showed that soil-test P changed by ±4 ppm from samples collected in spring 2007 despite having P-application rates up to 160 lb P_2O_5/acre applied in 2007 (Table 5).

Phosphorus concentrations in recently matured trifoliate leaves at the R2 growth stage were significantly affected by P application rate at 2 of 5 sites including Poinsett-2 (Table 8) and RREC (Table 5), which had the lowest soil-test P values. Soil-test P was ≤22 ppm at at Poinsett-1 and PTBS (Tables 3 and 5) and trifoliate leaf P concentrations of the unfertilized controls were 0.30 and 0.24%, respectively, but concentrations did not increase significantly as P rate increased (Tables 5 and 8).

Soybean yields were not significantly affected by P fertilization at any site during 2008 (Tables 5 and 9). Based on soil-test P, P fertilization was expected to benefit soybean yields at Poinsett-2, PTBS, and RREC, which had the lowest soil-test P values (Table 3). Previous P-fertilization trial results have suggested that soybean is most likely to respond positively to P fertilization when soil-test P is <20 ppm. Closer examination of the soil properties of responsive sites also shows that soil pH is usually <6.5, suggesting that soybean grown on soils with low Mehlich-3 soil P and high pH may be less responsive to P fertilization. Soil pH was >7.0 at all 2008 sites except the RREC and CBES. Soil at CBES had an 'Optimum' soil-test P level and a pH of 5.7. Soil-test P at the RREC was 'Low' and had a pH of 5.4 when soil samples were collected several months before planting. Due to the low pH at the RREC, 1 ton lime/acre was applied in March to raise pH and may have affected the response of soybean to P fertilization.

PRACTICAL APPLICATION

Soybean response to K fertilization was predicted with good accuracy by the Mehlich-3 soil test method, but Mehlich-3 P does not appear to accurately differentiate between P-deficient and sufficient soils cropped to soybean. Additional research is needed to identify whether other soil-test parameters, such as pH, or soil-test methods can be used with soil-test P to improve the accuracy of identifying soils that require P to produce near maximum soybean yields. Phosphorus-fertilization trials with soybean have been conducted on 26 sites since 2004 with yields responding positively to P fertilization at only five sites (19%). The five responsive sites had soil-test P <20 ppm, but eight other trial sites having soil-test P <20 ppm failed to respond to P fertilization. The frequency of positive responses to P fertilization suggests that many Arkansas silt loams do not currently need supplemental P to maximize soybean yields or, alternatively, broadcasting P fertilizer to the soil surface, even at relatively high rates, is not an effective method of fertilization. In contrast, K-fertilization trials on many of the same soils show positive yield responses have occurred in 20 of 36 field trials, making K fertilization a critical component for maximizing soybean yield potential.

ACKNOWLEDGMENT

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Table 1. Selected soil and agronomic management information for P and K fertilization trials conducted in 2008.

Site	County	Soil series	Cultivar	Tillage - previous crop[z]	Row spacing	Plant date
					(inches)	(month/day)
CBES	Lee	Convent	Schillinger 495	Conv./Soybean	38	May 30
PTBS	St. Francis	Calhoun	Armor 47G7	Conv./Soybean	15	May 21
PTBS39	St. Francis	Calhoun	Armor 47G7	No-till/Rice	15	May 21
PTBS40	St. Francis	Calhoun	Armor 47G7	No-till/Rice	15	May 21
RREC	Arkansas	Dewitt	Armor47G7	Conv./Rice	7.5	May 21
Poinsett-1	Poinsett	Hillemann	UA4805	Conv./Rice	7.5	May 24
Poinsett-2	Poinsett	Hillemann	Asgrow 5501	Conv./Rice	7.5	May 31

[z] Conv., conventional tillage.

Table 2. Selected soil chemical property means (*n* = 4-6) of the unfertilized control in K-fertilization trials conducted at seven sites during 2008.

	Soil	Organic	Mehlich-3-extractable nutrients										
Site	pH	matter	P	K	Ksd[z]	Ca	Mg	S	Na	Fe	Mn	Zn	Cu	B
		(%)	(ppm)										
K rate trials													
CBES	5.9	1.8	40	155	14	1025	178	10	10	209	232	2.6	1.6	0.1
PTBS	7.9	3.1	18	125	15	2452	409	11	29	217	298	4.5	1.2	0.3
PTBS39	7.7	–[y]	19	131	25	2881	432	17	73	381	205	7.8	1.5	0.3
PTBS40	7.4	–[y]	15	110	12	2087	416	16	75	373	143	9.6	1.5	0.3
RREC	5.2	–[x]	20	139	11	865	142	16	105	680	107	5.5	1.1	0.3
Poinsett-1	7.9	2.9	47	114	18	3148	327	26	124	426	133	9.7	0.5	0.7
Poinsett-2	7.9	2.7	8	87	12	3271	429	79	94	466	178	4.9	0.5	0.2

[x] Ksd is the standard deviation of the mean soil-test K concentration.

[y] Soil organic matter was not measured in 2008, but in 2006 the soil organic matter, averaged across all plots, ranged between 2.9 and 3.3%.

[x] Soil organic matter was not measured in 2008, but in 2007 the soil organic matter, averaged across all plots, was 2.3%.

Table 3. Selected soil chemical property means (*n* = 6-7) of the unfertilized control plots in P-fertilization trials conducted at five sites during 2008.

	Soil	Organic	Mehlich-3-extractable nutrients										
Site	pH	matter	P	Psd[z]	K	Ca	Mg	S	Na	Fe	Mn	Zn	Cu	B
		(%)	(ppm)										
P rate trials													
CBES	5.7	1.9	45	5	164	1075	189	10	10	207	193	1.8	1.4	0.1
PTBS	8.1	2.9	18	3	102	2817	413	10	29	303	234	5.4	0.9	0.3
RREC	5.4	–[y]	16	2	145	717	107	15	59	597	133	5.5	1.4	0.2
Poinsett-1	7.9	2.8	22	4	83	2865	313	21	105	464	105	7.6	0.6	0.6
Poinsett-2	7.9	2.7	6	1	93	3366	421	64	80	429	174	5.0	0.4	0.2

[z] Psd is the standard deviation of the mean soil-test P concentration.

[y] Soil organic matter was not measured in 2008, but in 2007 the soil organic matter, averaged across all plots, was 2.0%.

Table 4. Soil-test K, trifoliate-leaf K (at R2 stage), and seed yield data means from tests 39 and 40 at PTBS in 2008 as affected by annual soil-test K rate (same K rates applied since 2001).

Annual K rate	Soil-test K[z]	HNO_3 K[y]	R2 Trifoliate	Seed yield
(lb K_2O/acre/yr)	(ppm)		(% K)	(bu/acre)
PTBS 39				
0	131	405	1.23	53
40	130	392	1.50	64
80	138	426	1.65	68
120	145	453	1.80	70
160	159	487	1.85	72
LSD(0.10)	18	37	0.17	7
P-value	0.0121	<0.0001	<0.0001	0.0022
C.V., %	10.8	6.9	9.7	10.1
PTBS 40				
0	110	362	1.32	55
40	113	430	1.59	68
80	113	383	1.68	68
120	133	411	1.72	66
160	147	511	1.93	68
LSD(0.10)	13	107	0.16	8
P-value	0.0001	0.0775	0.0003	0.0508
C.V., %	6.8	16.5	7.5	9.3

[x] Soil K extracted with Mehlich-3.

[y] Soil K extracted with 1 *M* HNO_3.

Table 5. Soil-test P and K (Mehlich-3), trifoliate leaf P and K (at R2 stage) concentration, and seed yield means from the second year of long-term P and K fertilization trials at the Rice Research and Extension Center in 2008 as affected by annual P and K rate (same rates applied since 2007).

Annual nutrient rate	2007 Soil-test K	2008 Soil-test K	R2 Trifoliate	Seed yield
(lb K_2O/acre/yr)	----------------------(ppm)-----------------------		(% K)	(bu/acre)
0	148	139	1.56	74
40	150	144	1.72	71
80	152	167	1.71	74
120	148	160	1.71	74
160	150	167	1.74	73
LSD(0.10)	NS^z	12	0.09	NS
P-value	0.9867	0.0006	0.0182	0.7571
C.V., %	8.3	7.4	5.4	6.8

Annual nutrient rate	2007 Soil-test P	2008 Soil-test P	R2 Trifoliate	Seed yield
(lb P_2O_5/acre/yr)	----------------------(ppm)-----------------------		(% P)	(bu/acre)
0	20	16	0.32	70
40	19	17	0.32	73
80	19	19	0.33	69
120	19	21	0.35	71
160	19	22	0.35	73
LSD(0.10)	NS	2.8	0.02	NS
P-value	0.7243	0.0047	0.0161	0.3509
C.V., %	8.3	14.7	6.2	5.3

[z] NS, not significant (*P*>0.10).

Table 6. Trifoliate-leaf K concentration of soybean at the R2 stage response to K-fertilizer rate at four sites during 2008.

K rate	CBES	PTBS	Poinsett-1	Poinsett-2
(lb K_2O/acre)	-- (% K)--			
0	1.71	1.26	1.12	1.14
40	1.76	1.36	1.26	1.53
80	1.78	1.42	1.22	1.45
120	1.80	1.43	1.38	1.63
160	1.83	1.52	1.41	1.72
LSD(0.10)	NS^z	0.09	0.12	0.17
P-value	0.2842	0.0012	0.0026	0.0004
C.V., %	5.3	6.5	8.3	8.8

[z] NS = not significant (*P*>0.10).

Table 7. Soybean seed yield response to K-fertilizer rate at four sites during 2008.

K rate	CBES	PTBS	Poinsett-1	Poinsett-2
(lb K_2O/acre)	--(bu/acre) --			
0	58	67	66	64
40	58	70	67	69
80	57	72	64	71
120	58	74	72	70
160	57	74	73	73
LSD(0.10)	NS^z	3	NS	NS
P-value	0.8729	0.0020	0.1449	0.1420
C.V., %	3.9	4.2	9.4	6.5

[z] NS, not significant (*P*>0.10).

Table 8. Trifoliate-leaf P concentration of soybean at the R2 stage response to P-fertilizer rate at four sites during 2008.

P rate	CBES	PTBS	Poinsett-1	Poinsett-2
(lb P_2O_5/acre)	---------- (% P) ----------			
0	0.42	0.30	0.24	0.28
40	0.44	0.31	0.24	0.29
80	0.44	0.29	0.23	0.31
120	0.42	0.31	0.25	0.34
160	0.44	0.31	0.23	0.35
LSD(0.10)	NS[z]	NS	NS	0.03
P-value	0.1086	0.4661	0.1387	0.0007
C.V., %	4.2	5.9	6.7	9.7

[z] NS = not significant (P > 0.10).

Table 9. Soybean yield response to P-fertilizer rate at four sites during 2008.

P rate	CBES	PTBS	Poinsett-1	Poinsett-2
(lb P_2O_5/acre)	---------- (bu/acre) ----------			
0	53	70	69	68
40	54	71	70	72
80	54	70	71	74
120	54	69	68	69
160	54	72	64	70
LSD(0.10)	NS[z]	NS	NS	NS
P-value	0.9935	0.8273	0.3879	0.7333
C.V., %	7.3	6.1	9.6	10.1

[z] NS = not significant (*P*>0.10).

Soybean Response to Poultry Litter and Inorganic Fertilizer

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Poultry litter application to fields that will be cropped to legumes is desirable because legumes biologically fix N_2 gas from the atmosphere, allowing manures to be applied at rates needed only to satisfy crop P and/or K requirements. The need to export the nutrients in poultry litter from western Arkansas to areas of intensive cropping and fertilizer use plus recent increases in commercial fertilizer prices have increased interest in using poultry litter as an alternative to P and K fertilizers. Soybean [*Glycine max* (L.) Merr.] yield has responded favorably to poultry litter in Mississippi (Adeli et al., 2005). Initial research in Arkansas comparing soybean yield response to poultry litter and commercial fertilizers (Slaton, unpublished data) has shown mixed results. Trials established at the Rice Research Extension Center (Dewitt silt loam) and Northeast Research Extension Center (Sharkey-Steele complex) showed no yield benefit from poultry litter or equivalent P and K rates from commercial fertilizers on soils that had high soil-test K and medium or lower soil-test P. However, several trials established on silt loam soils west of Crowley's Ridge have shown significant yield increases from poultry litter that were sometimes greater than yields produced with equivalent rates of P and K fertilizer.

Our primary research objective was to evaluate soybean yield and leaf nutrient concentration responses to poultry litter compared to various inorganic fertilizer combinations. The overall goals of this research were to determine the availability of P and K in poultry litter and establish whether poultry litter provided any potential yield benefits above those provided by adequate rates of commercial fertilizers.

PROCEDURES

Trials were established at three sites in 2008, including a Calhoun silt loam at the Pine Tree Branch Station (PTBS) and two grower fields in Poinsett County (Poinsett-1 and Poinsett-2) with each having soil mapped as a Hillemann silt loam. Soybean (PTBS) and rice (Poinsett-1 and Poinsett-2) were grown in the research areas during 2007. At the PTBS, the research site was tilled shallowly, study boundaries were flagged, soil samples were collected, treatments were applied, and soybean was seeded. At the two grower fields, the growers kept fertilizer applied to the surrounding field off of the research area, performed tillage, planted soybean, and we then collected soil samples and applied the treatments to the soil surface about 1 day before the soybean emerged. At each site a composite soil sample was collected to a depth of 4 inches from each replicate's (*n*=6 per site) unfertilized control before fertilizer application. Soil samples were oven-dried, crushed to pass a 2-mm sieve, and analyzed for soil pH (1:2 soil weight: water volume ratio); soil organic C; and total N by combustion; Mehlich-3 extractable nutrients were determined by inductively coupled plasma spectroscopy (ICPS). Selected mean soil chemical properties are listed in Table 1. Granular B fertilizer (1.0 lb B/acre) was broadcast just before or after planting at all sites to insure B was not yield limiting.

Poultry litter was obtained in fall 2007 directly from a poultry house at the University of Arkansas Savoy Poultry Production facility. Broilers had been grown for 18 months before litter removal. Three subsamples of litter were analyzed for total nutrient content and showed litter averaged 3.35% total N, 1.47% P, 3.06% K, 20.3% moisture and had a mean pH of 8.7. Poultry litter treatments were weighed for each site to provide the equivalent of 70 (low rate) and 140 (high rate) lb P_2O_5/acre, and stored in sealed plastic bags until litter was applied. The 'Low' and 'High' P_2O_5 poultry litter rates corresponded to 2080 and 4159 lb moist litter/acre and supplied 76 and 152 lb K_2O/acre, respectively.

Inorganic-fertilizer treatments were prepared to provide the same equivalent amount of total P_2O_5/acre as poultry litter or a similar amount of plant-available N (PAN) as the low and high poultry litter rates. The PAN of poultry litter was estimated to be 67% of its total N content. When inorganic-N fertilizer was added with P and K fertilizers or applied by itself, 'Super Urea' (Agrotain International, St. Louis, Mo.) was used as the N source and applied at 47 and 93 lb N/acre for the low and high rates, respectively. Super Urea was used because it contains both a urease and nitrification inhibitor, which would help reduce fertilizer-N losses.

At the PTBS, Armor 47G7 soybean was drill seeded on 21 May into plots that were 13-ft wide and 20-ft long and contained 10 soybean rows spaced 15 inches apart. The drill provided some incorporation of surface-applied fertilizers and poultry litter, which were applied before seeding. Soybean was drilled into conventionally tilled seedbeds at Poinsett-1 (Asgrow 5501) and Poinsett-2 (UA4805) with soybean rows spaced 7-inches apart on 31 and 24 May, respectively, by the cooperating farmers. Individual plots were 10-ft wide and 25-ft long.

Trifoliate leaves (15) were collected from each plot 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. An 18-to 22-ft long section from the middle rows of each plot was harvested with a plot combine. Soybean moisture was adjusted to 13% for final yield calculations. Each experiment was a randomized complete block design with treatments structured as 2 (rate) × 4 (nutrient source) factorial plus a no fertilizer control. Each treatment was replicated six times per site. Analysis of variance was conducted with the PROC GLM procedure in SAS v9.1 (SAS Institute, Inc., Cary, N.C.) using a split-plot treatment structure where site-year was the whole plot and the rate × source factorial was the subplot. When appropriate, mean separations were performed using Fisher's Protected Least Significant Difference method at a significance level of 0.10.

RESULTS AND DISCUSSION

The University of Arkansas soil-test guidelines for soybean showed that soil-test K (Table 1) was 'Medium' (<91-130 ppm) at the PTBS and Poinsett-1 and 'Optimum' at Poinsett-2. Soil-test P was 'Very Low' at Poinsett-1, 'Low' at PTBS, and 'Optimum' at Poinsett-2. Recommended fertilizer rates would have ranged from 0 to 100 lb P_2O_5/acre to 0 to 60 lb K_2O/acre.

Soybean yields were affected significantly by all three main effects (site, nutrient source, and rate) and the interaction between nutrient rate and source. Soybean yields, averaged across nutrient sources and rates, were in order of decreasing yield Poinsett-1 (70 bu/acre, LSD = 2 bu/acre) > Poinsett-2 (67 bu/acre) > PTBS (64 bu/acre). Soybean yields, averaged across sites, receiving no fertilizer or N only produced equal yields that were significantly lower than yields of soybean receiving poultry litter or PK fertilizers (Table 2). Soybean receiving low and high rates of NPK fertilizer produced equal yields that were similar to low rates of PK and poultry litter. However, soybean yields increased significantly when PK and poultry litter were applied at high rates. Soybean receiving the high rate of poultry litter produced the greatest overall yield.

Trifoliate leaf K concentrations were affected by the source × rate (Table 2) and site × rate interactions (Table 3). Trifoliate leaves of soybean receiving no fertilizer (or litter) and N only contained low and similar K concentrations that were lower than soybean receiving P and K at low and high rates (Table 2). Soybean receiving low rates of PK, NPK, and poultry litter had similar trifoliate leaf K concentrations that were always lower than soybean that received the high rate of fertilizer or litter. In general, the site × nutrient rate interaction showed that trifoliate leaf K concentrations responded differently to nutrient rate among sites (Table 3). At the PTBS and Poinsett-2, leaf K concentrations increased with each increment of nutrient addition. At Poinsett-1, leaf K concentrations of soybean receiving the low and high nutrient rates were similar and greater than the K concentration of soybean receiving no fertilizer or poultry litter.

Trifoliate leaf P concentrations of soybean were affected by the site × nutrient rate (Table 3) and site × nutrient source interactions (Table 4). At the PTBS and Poinsett-1, trifoliate leaf P concentrations remained constant regardless of the nutrient rate applied. At Poinsett-2, the high nutrient rate increased leaf P concentrations above the values of the low rate and control (None), which were similar (Table 3). The site × nutrient source interaction also showed that trifoliate leaf P concentrations changed significantly only at Poinsett-2 among nutrient sources (Table 4).

PRACTICAL APPLICATION

Trials to evaluate soybean response to poultry litter showed that soybean yields were increased similarly by P and K fertilizers and poultry litter applied at rates that supplied 70 lb P_2O_5 and 76 lb K_2O/acre. However, application of poultry litter at a rate that supplied 140 lb P_2O_5 and 152 lb K_2O/acre produced greater yields than an equivalent rate of P and K fertilizers. Trifoliate leaf P and K concentrations suggest that fertilizer and poultry litter applied at equal P and K rates provide similar amounts of plant-available P and K to soybean. Thus, all of the P and K in poultry litter should be considered as plant available.

Application of N with P and K fertilizers showed no benefit on soybean yield or nutrient uptake, but the lack of response to N does not rule out the possibility that soybean may be responding to the N in poultry litter. Poultry litter may provide greater N availability later in the growing season (i.e., after blooming when the demand for N by soybean is greatest) than inorganic-N fertilizer applied at planting. Tissue analysis results showed that other essential elements (e.g., B, Zn, Cu, etc.) were present in sufficient amounts and should not have been yield limiting. Further investigations should include a time of poultry litter application (i.e., several months before planting) treatment to better evaluate whether slowly available N is contributing to improved soybean yields. Furthermore, it should be noted that poultry litter does not always increase soybean yields above that of inorganic fertilizers. Reasons why relatively high rates (2 ton/acre) of poultry litter appeared to stimulate soybean yields on some soils are not known. Research evaluating soybean response to poultry litter will be continued in 2009.

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Table 1. Selected soil chemical property means (*n* = 6) of poultry litter fertilization trials conducted at three sites during 2008.

	Soil	Total soil		Mehlich-3-extractable nutrients										
Site	pH	C	N	P	K	Ca	Mg	S	Na	Fe	Mn	Zn	Cu	B
		----(%)-----		(ppm)										
PTBS	8.2	1.43	0.12	17	105	2574	375	10	25	228	310	3.0	1.3	0.4
Poinsett-1	8.1	1.21	0.11	6	103	3734	474	76	98	469	211	5.9	0.4	0.2
Poinsett-2	7.8	1.29	0.12	40	135	3539	398	26	133	478	114	11.8	0.6	0.8

Table 2. Soybean seed yield and trifoliate leaf K concentration at the R2 stage responses to the nutrient source × application rate interaction, averaged across three silt loam soil sites in 2008.

	Yield		Tissue K	
Fertilizer source	Low rate	High rate	Low rate	High rate
	(bu/acre)		(% K)	
No fertilizer control	61		1.21	
N only	62	61	1.21	1.15
PK	68	72	1.45	1.58
NPK	69	68	1.45	1.60
Poultry litter	70	76	1.45	1.63
LSD0.10	3.2		0.059	
P-value	0.0248		0.0004	

Table 3. Soybean trifoliate leaf P and K concentrations, averaged across nutrient sources, at the R2 growth stage as affected by the site and nutrient rate interaction.

	Potassium			Phosphorus		
Site	None	Low	High	None	Low	High
	(% K)			(% P)		
PTBS	1.21	1.33	1.45	0.32	0.31	0.32
Poinsett-1	1.13	1.33	1.32	0.27	0.27	0.27
Poinsett-2	1.29	1.50	1.71	0.33	0.33	0.36
LSD0.10[z]	0.066			0.011		
LSD0.10[y]	0.238			0.049		
P-value	0.0001			0.0089		

[z] LSD0.10 to compare nutrient rate means within a site.

[y] LSD0.10 to compare any two means.

Table 4. Trifoliate-leaf P concentrations, averaged across nutrient addition rates, at the R2 growth stage of soybean at the R2 stage response to K-fertilizer rate at three sites during 2008.

Fertilizer source	PTBS	Poinsett-1	Poinsett-2
	(% P)		
None	0.32	0.27	0.33
N only	0.31	0.27	0.32
PK	0.32	0.26	0.35
NPK	0.32	0.28	0.35
Poultry litter	0.32	0.27	0.36
LSD0.10[z]	0.015		
LSD0.10[y]	0.066		
P-value	0.0031		

[z] LSD0.10 to compare nutrient rate means within a site.

[y] LSD0.10 to compare any two means.

Wheat and Double-Cropped Soybean Yield Response to Phosphorus and Potassium Rate and Fertilization Strategy

N.A. Slaton, R.E. DeLong, J. Shafer, B. Golden, E. Maschmann, and S. Clark

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Double-cropped soybean [*Glycine max* (Merr) L.] has accounted for about 17% of the total harvested soybean acres in Arkansas during the past ten years, but has fluctuated between 5 and 23% depending on wheat (*Triticum aestivum* L.) acreage (USDA-NASS, 2007). The average yield of double-cropped soybean between 1997 and 2006 ranged from 23 (1998) to 37 (2003) bu/acre compared with 25 to 40 bu/acre for full-season soybean. Double-cropped soybean can have excellent yield potential provided that wheat harvest is timely and environmental conditions are favorable for stand establishment. The net profitability from any cropping system depends on sound management recommendations that optimize yield potential and minimize production costs.

Most silt loam soils in Arkansas require phosphorus (P) and potassium (K) fertilization to maintain soil productivity or prevent yield losses from P and K deficiencies when cropped to wheat and/or soybean. Information regarding the most economically and agronomically efficient P and K fertilization strategies for wheat followed by double-cropped soybean is lacking. One of the most common questions is whether to apply the recommended P and K for both crops to wheat in the fall or to split the total recommended fertilizer rates between the wheat and soybean crops. Both strategies have advantages and disadvantages. For example, application of all the fertilizer in the fall or winter to wheat may reduce custom application costs, but the availability of the applied nutrients to soybean may be reduced due to nutrient losses, uptake and removal by harvested wheat, and/or soil fixation. The objective of this study was to evaluate wheat and double-cropped soybean yield and plant nutrient status responses to P and K fertilization rate and application strategy.

PROCEDURES

Field studies were established in November 2007 into a conventionally tilled seedbed at the Pine Tree Branch Station on a Calloway silt loam following soybean in rotation. Phosphorus and K studies were established in two adjacent areas to accommodate plots that were 25-ft long and 13-ft wide and separated from adjacent plots by a 12-to 24-inch wide alley. A composite soil sample (0- to 4-inches) was taken from each unfertilized control replicate to determine initial soil chemical properties before wheat was seeded. Soil was oven-dried at 60°C, 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. A second set of composite soil samples was collected in June 2008 following wheat harvest to gauge how soil-test P and K may have changed in the unfertilized controls following wheat growth and harvest (Table 1).

For the P experiment, triple superphosphate (0-46-0) was applied at total rates of 0, 50, 100, 150, and 200 lb P_2O_5/acre in one or two split applications to simulate two fertilization strategies for wheat followed by double-cropped soybean. The first fertilization strategy involved applying the entire P rate (0, 50, 100, 150, and 200 lb P_2O_5/acre) in late fall (7 Dec.) and the second strategy was to apply one-half (0, 25, 50, 75, and 100 lb P_2O_5/acre) the total P rate to wheat in the fall and the remaining one-half following wheat harvest. The second split application of P fertilizer was broadcast onto the soil surface on 26 June after wheat straw was burned. The experiment was a randomized complete block with a split-plot treatment structure where P rate was the main plot and fertilization strategy was the subplot. Each treatment was replicated five times. Potassium fertilizer was applied in the fall (90 lb K_2O/acre) and again in the late-spring after wheat harvest (60 lb K_2O/acre) before soil samples were collected to ensure that K was not yield limiting for wheat or soybean production.

For the K experiment, muriate of potash (0-0-60) was applied at total rates of 0, 60, 120, 180, and 240 lb K_2O/acre in one or two equal split applications using similar procedures as described for the P experiment. Phosphorus fertilizer was applied in the fall (60 lb P_2O_5/acre) and again in the late-spring after wheat harvest (46 lb P_2O_5/acre) before soil samples were collected to ensure that P was not yield limiting for wheat or soybean production.

'Pat' (P trial) or 'Roane' (K trial) wheat was drill-seeded (7.5-inch row spacing) on 2 November at a rate of 120 lb/acre into a conventionally tilled seedbed. Nitrogen fertilizer was applied in two split applications on 11 February 2008 [100 lb $(NH_4)_2SO_4$/acre + 150 lb urea/acre] and again on 17 March 2008 [87 lb urea/acre].

Whole, aboveground plant samples were taken at Feekes stages 10.5 (near 100% heading) to determine dry matter accumulation and whole-plant P and K concentrations. A 3-ft section of the first inside row was cut at the soil surface, placed in a paper bag, oven dried at 60°C to a constant weight, and ground to pass a 1-mm sieve. A 0.25 g sub-sample was digested in concentrated HNO_3 and 30% H_2O_2 and analyzed for nutrient concentration. At maturity, grain yields were measured by harvesting the middle of each plot with a small-plot combine. Grain samples were weighed and analyzed for moisture content to calculate grain yield. Grain yields were adjusted to a uniform moisture content of 13% moisture. Following wheat harvest, the remaining wheat was harvested and straw was burned. Due to dry soil conditions, the area was flooded, drained, and soybean (NK S52-F2) was planted no-till in 15-inch-wide rows on 7 July 2008 with emergence occurring on 13 July. Soybean was irrigated as needed during the season.

Trifoliate leaf samples (15) were collected from the middle of each plot at the R2 growth stage (August 28). Trifoliate leaf samples were processed and analyzed as described for wheat tissue samples. At maturity, the eight middle soybean rows were harvested with a plot combine and grain was processed as described for wheat and adjusted to 13% moisture.

For each experiment, treatments were arranged as randomized complete block design with a split-plot treatment structure where nutrient rate was the whole plot and fertilization strategy was the subplot. Treatments were replicated five times at each site. Data for each crop were analyzed separately. Analysis of variance procedures were conducted with the PROC GLM procedure in SAS v9.1 (SAS Institute, Inc., Cary, N.C.). 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 also used to compare selected treatments or groups of treatments.

RESULTS AND DISCUSSION

In November 2007, the average Mehlich-3-extractable P in the P fertilization trial was 'Medium' (26 to 35 ppm, Table 1). Soil-test K was 'Low' (61 to 90 ppm) in the K-fertilization trial. Based on the University of Arkansas fertilizer guidelines for winter wheat, the recommended P and K fertilizer rates for the P trial were 50 lb P_2O_5 and 60 lb K_2O/acre for wheat plus an additional 40 lb P_2O_5 and 40 lb K_2O/acre for the double-cropped soybean. For the K trial, the recommendation was 50 lb P_2O_5 and 90 lb K_2O/acre for wheat plus an additional 40 lb P_2O_5 and 60 lb K_2O/acre for the double-cropped soybean.

The second set of soil samples collected from unfertilized controls in June 2008 following wheat harvest and burning of wheat stubble showed that soil-test P remained in the Medium level for each trial (Table 1). However, in the K-fertilization trial, soil-test K declined from 75 (Low) to 53 ppm (Very Low). Soil-test K showed only a small numerical decline (96 to 89 ppm) in the P fertilization trial probably because K fertilizer was applied to the wheat following collection of the fall soil samples. Most other soil-test parameters were comparable between sample times.

Phosphorus Trial - Wheat

Wheat dry matter production at Feekes stage 10.5 was not affected (*P*>0.10) by the main effects of application strategy (*P*=0.3978) and P rate (*P*=0.2093) or the P rate × strategy interaction (*P*=0.8813). Wheat dry matter at heading averaged across all treatments was 6247 lb/acre (data not shown).

Whole-plant P concentrations at Feekes stage 10.5 were not affected by the P rate × strategy interaction (*P*=0.9486) or by P rate (*P*=0.6137, Table 2). As expected, wheat P concentrations were greater (*P*=0.0546) when all P was applied in the fall (0.165% P) than for P that was split applied between wheat and soybean (0.157% P, LSD0.10 = 0.007).

Wheat grain yields were affected (*P*>0.10) by P fertilization rate (*P*=0.0048), but not by application strategy (*P*=0.1260) or the interaction (*P*=0.3049, Table 2). Wheat yields, averaged across P rates, were similar for P fertilizer applied in the fall (64 bu/acre) and split applied between wheat and the following soybean crop (63 bu/acre). When averaged across application strategy, wheat yield increased as P rate increased to 150 lb P_2O_5/acre. Means for each P treatment (Table 2) indicate that wheat receiving 50 lb P_2O_5/acre did not produce maximal yield as wheat that received this rate produced 61 or 62 bu/acre. Wheat that received 75 (150 lb P_2O_5/acre split) or 150 lb P_2O_5/acre produced 65-66 bu/acre. These data clearly suggest that application of the proper P rate in the fall is critical for maximizing wheat yield potential.

Potassium Trial - Wheat

Wheat dry matter accumulation at Feekes stage 10.5 was not significantly affected by the main effects or their interaction (P>0.30 for all) and averaged 6742 lb/acre across all treatments (data not shown). Whole-plant K concentrations were affected significantly by only K rate (*P*=0.001, Table 3), but not by application strategy (*P*=0.1104) or the interaction (*P*=0.4098). Wheat receiving the greatest K rate contained greater tissue K than all other treatments. Although not significant, when averaged across K rates, wheat receiving all K at planting (1.22% K) contained numerically greater K concentrations than when one-half of the K rate was fall applied (1.16% K).

Wheat grain yields were not affected by application strategy (*P*=0.2782) or their interaction, but were different among K application rates (*P*=0.0921), averaged across application strategies (Table 3). Wheat yields were highest when at least 60 lb K_2O/acre were applied in the fall, regardless of application strategy.

Phosphorus Trial - Soybean

Soybean trifoliate leaf P concentrations were not affected significantly by P rate (*P*= 0.4889), application strategy (*P*= 0.4675), or their interaction (*P*= 0.5089, Table 4). Leaf P concentration of soybean averaged 0.35% and ranged from 0.34 to 0.36% among treatments, showing no trend among application strategy and rate combinations (Table 4). The established critical concentration for P in trifoliate leaves at flowering is 0.30%, suggesting P was sufficiently available to maximize soybean yields. Seed yield was not significantly affected by P fertilizer rate (*P*=0.4142), application strategy (*P*=0.9921), or their interaction (*P*=0.6414; Table 4). The average soybean yield was 40 bu/acre.

Potassium Trial - Soybean

Potassium application rate (*P*<0.0001, Table 5), averaged across strategies, and application strategy (*P*=0.0004), averaged across P rates both significantly affected soybean leaf K concentration. Soybean receiving <180 lb K_2O/acre, averaged across application strategy, had deficient (<1.5% K) trifoliate-leaf K concentrations. This was not surprising since K-deficiency symptoms and plant growth differences were observed. Trifoliate K concentrations between fertilization strategies, averaged across K rates, showed that splitting the K between wheat and soybean consistently enhanced soybean leaf K concentrations (1.33% K) compared to application of all K before wheat planting (1.25% K).

Soybean yields were significantly affected by K rate (*P* <0.0001), but not by application strategy (*P*= 0.8691) or the 2-way interaction (*P*=0.9521). Fertilizer application strategy had no significant effect on soybean yield, despite the differences in tissue K concentration, and showed no trend across K rates with yields averaging 29 bu/acre for each application strategy. Only K application rate, averaged across application strategy, significantly increased soybean yield (Table 5). Application of 180 lb K_2O/acre or greater was required to maximize soybean yield and increase trifoliate leaf K concentration above 1.5%.

PRACTICAL APPLICATION

The primary issue addressed by this research was whether P and K fertilizer for wheat and double-cropped soybean should be applied in a single application or split-applied with a proportion of fertilizer being applied to each crop. Positive and significant yield increases from P fertilization were measured for wheat only. Potassium fertilization significantly increased yields of both wheat and soybean with the yield increases (36 to 64%) for soybean being much greater than those for wheat (8 to 13%). Given the soil-test P and K levels in each trial, these results were not surprising since wheat is generally more responsive to P fertilization than soybean and soybean is more responsive to K fertilization. Fertilizer rate was the only factor that significantly affected wheat and soybean yields. These data suggest that K fertilizer can be applied in a single application in the fall provided that the proper rate for both crops is applied. For P, the trial results indicate only that wheat responded to P applied in the fall. Since soybean did not respond to P fertilization it is not known whether a split application of P is of direct benefit on soils where soybean would also respond favorably to P fertilization. Although further trials are needed to verify the consistency of this response, P fertilization trials with full-season soybean indicate that soybean yields are seldom increased from P fertilization unless soil-test P is <20 ppm. Thus, in most silt loam soils used for wheat and soybean production in Arkansas, application of sufficient P to maximize wheat yields should suffice for the following soybean crop.

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Table 1. Selected soil chemical property means (*n* = 5, from each unfertilized control) in fall 2007 and June 2008 for P and K fertilization trials with wheat and double-cropped soybean.

		Soil	Mehlich-3-extractable nutrients									
Crop	SOM	pH	P[z]	K[y]	Ca	Mg	S	Na	Fe	Mn	Cu	Zn	B
	(%)		(ppm)										
Phosphorus													
Fall 2007	3.6	7.1	28	96	1504	224	14	35	194	205	1.6	1.4	0.2
June 2008	3.3	7.1	27	89	1411	202	20	38	268	383	1.7	1.2	0.1
Potassium													
Fall 2007	3.3	7.4	26	75	1612	237	11	34	204	190	1.6	1.4	0.2
June 2008	3.0	7.6	28	53	1547	213	18	40	301	377	1.6	1.3	0.1

[z] Standard deviation (*n*=5) of soil-test P in P trials was 4 ppm in October 2007 (before wheat) and 4 ppm in June 2008 (after wheat).

[y] Standard deviation (*n*= 5) of soil-test K in K trials was 10 ppm in October 2007 (before wheat) and 12 ppm in June 2008 (after wheat).

Table 2. Wheat whole-plant P concentrations at Feekes stage 10.5 as affected by the non-significant interaction between P rate and application strategy and wheat yields as affected by P rate, averaged across strategies, for a P-fertilization trial conducted during the 2007-2008 growing season on a Calloway silt loam.

	Fertilizer application strategy		
Total P fertilizer rate	Single application (Fall application)	Split application (½ fall & ½ spring)	Average across fertilization strategies
(lb P_2O_5/acre)	(Whole plant % P)		
0	0.16	0.15	0.16
50	0.17	0.15	0.16
100	0.16	0.15	0.16
150	0.17	0.16	0.16
200	0.17	0.17	0.17
LSD(0.10)	NS[z]		NS
(lb P_2O_5/acre)	(bu/acre)		
0	61	61	61
50	61	62	61
100	66	61	64
150	67	66	67
200	69	66	66
LSD(0.10)	NS		3

[z] NS = not significant (*P*>0.10).

Table 3. Wheat whole-plant K concentrations at Feekes stage 10.5 as affected by the non-significant interaction between K rate and application strategy and wheat yields as affected by K rate, averaged across strategies, for a K-fertilization trial conducted during the 2007-2008 growing season on a Calloway silt loam.

	Fertilizer application strategy		
Total K fertilizer rate	Single application (Fall application)	Split application (½ fall & ½ spring)	Average across fertilization strategies
(lb K_2O/acre)	(Whole plant % K)		
0	0.97	1.04	1.00
60	1.15	1.07	1.11
120	1.36	1.20	1.28
180	1.38	1.18	1.28
240	1.51	1.45	1.48
LSD(0.10)	NS[z]		0.17
(lb K_2O/acre)	(bu/acre)		
0	64	62	63
50	67	62	64
100	71	71	71
150	64	66	65
200	71	66	68
LSD(0.10)	NS		4

[z] NS = not significant (*P*>0.10).

Table 4. Soybean (double-crop) trifoliate leaf P concentrations at the R2 stage and seed yields as affected by P fertilizer rate, averaged across strategies, in the P-fertilization trial conducted during 2008 on a Calloway silt loam.

Total P fertilizer rate	Trifoliate-leaf P concentrations	Seed yield
(lb P_2O_5/acre)	(% P)	(bu/acre)
0	0.34	40
50	0.36	39
100	0.34	38
150	0.35	38
200	0.36	41
LSD(0.10)	NS[z]	NS

[z] NS = not significant (*P*>0.10).

Table 5. Soybean (double-crop) trifoliate leaf K concentrations at the R2 stage and seed yields as affected by K rate, averaged across application strategy, in the K-fertilization trial conducted during 2008 on a Calloway silt loam.

Total K fertilizer rate	Trifoliate-leaf K concentrations	Seed yield
(lb K_2O/acre)	(% K)	(bu/acre)
0	1.07	22
60	1.23	30
120	1.33	31
180	1.51	34
240	1.54	36
LSD(0.10)	0.07	3.6

Wheat Grain Yield Response to Nitrogen Source or Amendment and Application Time

N.A. Slaton, R.J. Norman, R.E. DeLong, S. Clark, J. Branson, E. Maschmann, and B. Golden

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Nitrogen (N) is generally the most limiting nutrient for soft red winter wheat (*Triticum aestivum* L.) production in Arkansas. Environmental conditions during the late winter when most N fertilizer is applied to wheat vary from year to year and may influence N uptake by wheat. The April freeze that caused widespread wheat grain yield losses during 2007 made many Arkansas wheat growers question whether to apply N early or delay the initial N application in an effort to delay wheat development and reduce the risk of freeze damage. Delaying N application to wheat may also increase the likelihood of ammonia (NH_3) volatilization of surface-applied urea-N.

Ammonia volatilization from urea applied to winter wheat is assumed to be negligible due to cool temperatures and more frequent rainfall during February and March when N is commonly applied. Griggs (2004) evaluated NH_3 volatilization from urea and ammonium sulfate applied to winter wheat during February and March using a closed-chamber method. Results showed that NH_3 volatilization from urea accounted for 13% of the applied urea-N compared to <1% of the applied N for ammonium sulfate. These results suggest that when air temperatures and moisture are favorable, NH_3 volatilization can result in significant N losses during the winter months. However, Griggs (2004) also reported that total-N uptake and wheat grain yield were not different between N sources, averaged across several N rates, suggesting that NH_3 volatilization within the chambers may have been greater than what occurred in the field.

The urease inhibitor, [N-(n-Butyl)-thiophosphoric triamide, NBPT] marketed under the name of Agrotain, is being used extensively to reduce NH_3 volatilization from surface-applied urea for the production of summer-grown crops (e.g., rice, *Oryza sativa* L.). Questions have been asked whether Agrotain should also be applied to urea fertilizer that will be applied in the late winter to winter wheat. Research in Missouri suggests that wheat fertilized with Agrotain-treated urea has, on average, produced 4 bu/acre greater yields than wheat receiving unamended urea (P.C. Scharf, personal communication, 2008). Polymer-coated urea fertilizer is also being used to reduce urea-N losses to summer grown crops (e.g., corn, *Zea mays* L.) in the Midwest and is being evaluated by various researchers for use in winter wheat. Our primary research objectives were to evaluate whether 1) wheat yields benefit from urea treated with Agrotain, 2) polymer-coated urea has utility as a late-winter N fertilizer for winter wheat, and 3) N application time influences wheat grain yield.

PROCEDURES

Experiments to evaluate wheat response to different N sources and application times were established at the Pine Tree Branch Station (PTBS) on a Calloway silt loam and the Rice Research Extension Center (RREC) on a Dewitt silt loam in fall 2007. Soybean [*Glycine max* (Merr) L.] was the previous crop grown in summer 2007 at each site. The RREC trial was destroyed by a tornado in May 2008 and will not be reported. Composite soil samples were collected from the 0-to 4-inch depth at planting. Samples were oven-dried at 60°C, crushed to pass a 2-mm sieve, and analyzed for pH (1:2 soil weight: water volume mixture), Mehlich-3-extractable nutrients, and total C and N by combustion (Table 1).

Triple superphosphate and muriate of potash fertilizers were blanket applied (~100 lb/acre) to ensure these nutrients were not yield limiting. 'Roane' wheat was drill-seeded (7.5-inch rows) on 2 November at the PTBS. The seedbed was conventionally tilled and the seeding rate was approximately 100 lb/acre.

Nitrogen fertilizer treatments included an unfertilized control (no N), a standard recommendation rate of 125 lb N/acre as urea applied in two split applications of 75 lb N/acre on February 10 and 50 lb N/acre on March 12, and four different N fertilizers applied at a total rate of 75 lb N/acre in a single application including urea; urea plus Agrotain (4 qt/ton urea); Environmentally Smart N (ESN, 44% N; polymer-coated urea); and a 50:50 mixture of urea and ESN. The four N fertilizers were applied at four different times including 10 February, 28 February, 12 March, and 25 March for a total of 18 treatments. A composite soil sample was collected from each replicate to determine the soil moisture content on each date that fertilizer was applied, except 10 February. Soil samples were placed in a weighed plastic bag, sealed, weighed (wet wt), dried for 5-7 days at 60°C, weighed (dry wt), and gravimetric soil moisture was calculated. The dates and amounts of rainfall following N application were recorded on-site or obtained from a local weather station (Fig.1). Wheat was harvested with a small-plot combine. Grain yields were calculated and adjusted to a uniform moisture content of 13% for statistical analysis.

Fertilizer treatments were arranged in a randomized complete block design with a 4 × 4 factorial structure. The unfertilized control and the standard of 125 lb N/acre were used only as reference treatments for yield and were not included in the statistical analysis. Each treatment was replicated 4 times. Analysis of variance was conducted with the PROC GLM procedure in SAS v9.1 (SAS Institute, Inc., Cary, N.C.). Mean separations were performed using Fisher's Protected Least Significant Difference method at significance levels of 0.05 and 0.10.

RESULTS AND DISCUSSION

Wheat developed slowly due to the late planting date and below-normal temperatures from February through April. Wheat reached Feekes stages 7 and 10.5 during the first and last weeks of April, respectively, which is about 2 or 3 weeks later than normal. Delaying N application time until March 25 also delayed wheat heading by an estimated 7 days. Gravimetric soil moisture content for N applied on 28 February, 12 March, and 25 March averaged 27, 27, and 23% at the PTBS. Soil moisture content for N applied on 10 February was estimated to be similar to the other times and was visually described as a dry soil surface.

Rainfall during February and March totaled 10.0 inches at the PTBS. At least 0.7 inches of rainfall occurred at the PTBS within 48 hours of N applications made on 10 February, 28 February, and 12 March (Fig. 1). For N applied on March 25, rainfall did not occur until 6 days after N fertilizer was applied. During the 5 days following N fertilizer application, daily maximum air temperatures averaged 44°F after 10 February, 66°F after 28 February, 63°F after 12 March, and 66°F after 25 March. The 25 March N application time had the greatest difference in wheat yields between urea and Agrotain-treated urea and the 5 days after N application were warm with no precipitation.

The no N control yield at PTBS was 22.9 bu/acre (Table 2). The standard recommendation of 125 lb N/acre as urea produced yields that were slightly greater than the best yielding treatments receiving 75 lb N/acre. An adjacent N rate study showed that wheat yields peaked (69 to 75 bu/acre) with the greatest applied urea-N rates of 160 and 200 lb N/acre (split applied in early February and early March; unpublished data, 2008). Based on this information, application of 75 lb N/acre can be considered a sub-optimal N rate and yield differences among N sources should reflect relative efficiency of N uptake within each application time.

The interaction between N application and N source was not statistically significant (Table 2), but the main effects of application time and source were significant at the 0.10 and 0.05 levels, respectively (Tables 3 and 4). Wheat yields, averaged across N sources, tended to decline as N application time was delayed (Table 3). Although the yield decline from delayed N application was significant, it was not as great (<5 bu/acre) as expected and could be related to increased N losses as temperatures increased (Fig. 1). Among N sources, averaged across application times and evaluated with the 0.10 LSD value, wheat yields decreased in the order of urea + Agrotain > urea > ESN + urea > ESN, suggesting that Agrotain-treated urea enhanced N uptake by wheat at all application times (Table 4). The difference between yields of wheat fertilized with urea and Agrotain-treated urea was only at the 0.10 level. Although the interaction between N source and application time was not significant (Table 2), the results suggest the yields for urea and Agrotain-treated urea were numerically comparable when applied in February, with the greatest difference occurring for N applied on 25 March. Application of ESN alone failed to produce wheat yields that were comparable to urea or Agrotain-treated urea, suggesting that ESN may need to be applied earlier than February to allow sufficient N release to optimize wheat yield potential. When urea was mixed with ESN, yields increased compared to ESN alone but were not as high as Agrotain-treated urea. Thus, for ESN to be a sufficient N source for wheat, it may need to be applied earlier or with a greater proportion of urea.

PRACTICAL APPLICATION

Results from the PTBS site suggest i) treating urea with Agrotain may provide some yield benefit to winter wheat, especially when N is applied in March, and ii) delaying N fertilization may slightly decrease wheat yield potential. Additional research is needed to verify the consistency of these results across sites, wheat seeding times, soils, and/or years before recommendations can be made to growers regarding whether to use Agrotain-treated urea for wheat fertilization. The polymer-coated urea, ESN, may have utility to reduce the number of N applications, but data suggest that it will likely have to be blended with urea, applied prior to early February, or both to be an efficient N source for winter wheat. Furthermore, research is needed to assess the risk of ESN fertilizer movement when it is surface-applied and followed by rainfall events that produce significant runoff. Additional research will be initiated in fall 2008 to address these issues.

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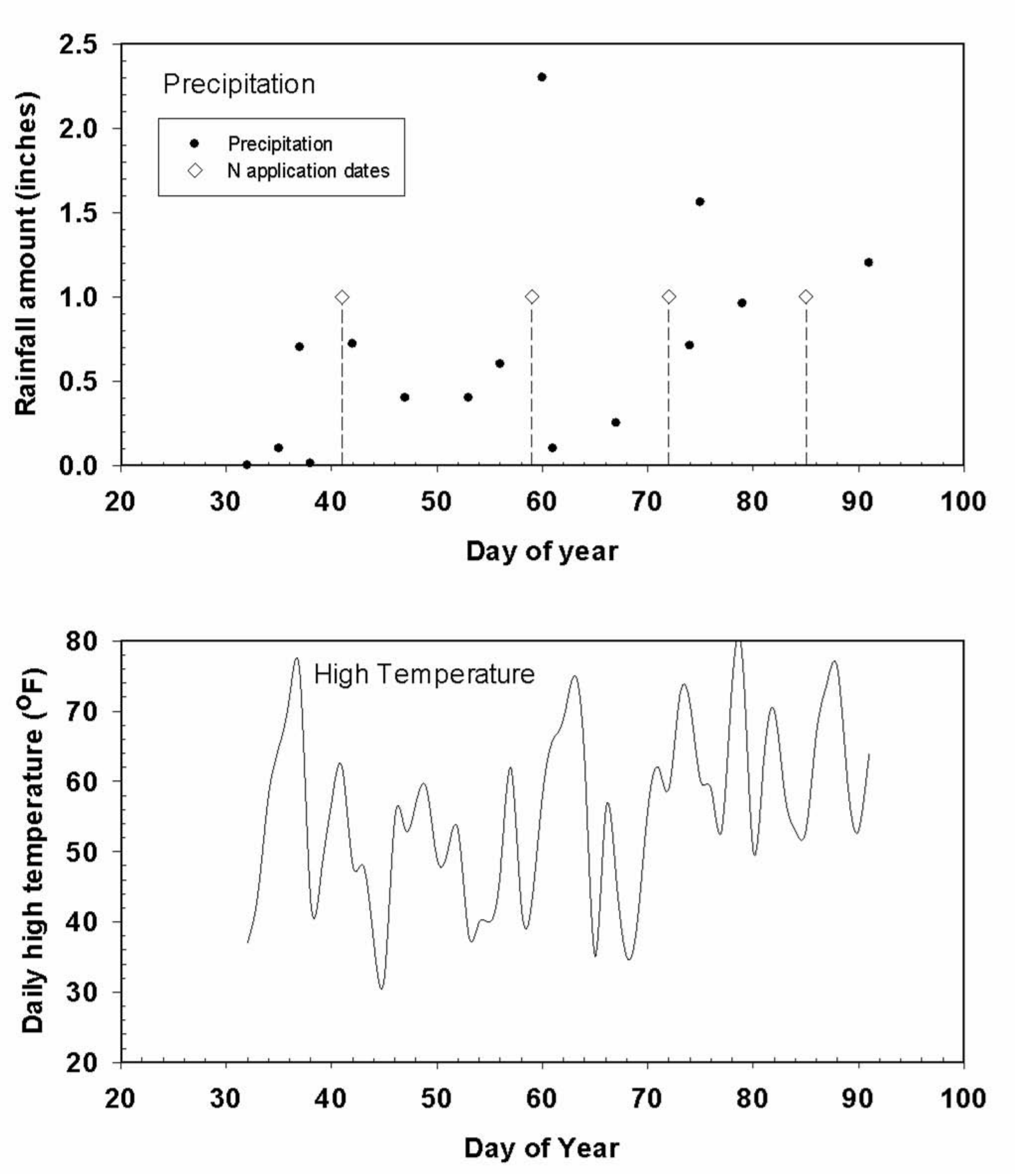

Figure 1. Daily high temperature and rainfall amounts during February and March 2008 at Pine Tree Branch Station (temperature data from Wynne, Ark., and rainfall from Pine Tree Station; day of year 32 to 60 is February and 61 to 91 is March).

Table 1. Selected soil chemical property means (n = 2) for a trial established at the Pine Tree Branch Station (PTBS) during the 2007-2008 growing season.

	Total		Soil	Mehlich-3-extractable nutrients										
Site	C	N	pH	P	K	Ca	Mg	S	Na	Fe	Mn	Cu	Zn	B
	-----(%)-----			---------------- (ppm) ----------------										
PTBS	1.3	0.13	7.0	22	71	1499	230	13	36	202	218	1.5	1.2	0.1

Table 2. Winter wheat yield means for each N source and time of application combination at the Pine Tree Branch Station during the 2007-2008 growing season.

N source[z]	February 10	February 28	March 12	March 25
	----------------(bu/acre) ----------------			
Control[y]	22.9			
Standard[y]	62.9			
Urea	56.7	55.6	50.0	49.3
Agrotain	55.0	57.1	53.9	60.2
ESN + Urea	54.8	49.5	44.4	44.4
ESN	46.1	44.9	45.2	40.4
P-value	0.2651			
LSD(0.10)	NS[x]			

[z] Control = no N; Standard = 125 lbs urea-N/acre applied in two split applications; urea (75 lb N/acre); Agrotain (75 lb N/acre) is urea treated with Agrotain, ESN is Environmentally Smart N fertilizer (75 lb N/acre); and urea + ESN is a 50:50 mixture of each fertilizer (75 lb N/acre).

[y] Treatments not included in statistical analysis.

[x] NS = not significant (P>0.10).

Table 3. Winter wheat grain yields as affected by N application time, averaged across N sources, at the Pine Tree Branch Station during the 2007-2008 growing season.

N application time	Grain yield
	(bu/acre)
February 10	53.1
February 28	51.8
March 12	48.6
March 25	48.6
P-value	0.0605
LSD(0.05)	4.0
LSD(0.10)	3.3

Table 4. Winter wheat grain yields as affected by N fertilizer source, averaged across N application times, at the Pine Tree Branch Station during the 2007-2008 growing season.

N fertilizer source	Grain yield
	(bu/acre)
Urea + Agrotain	56.5
Urea	52.9
ESN + Urea	48.5
ESN	44.1
P-value	<0.0001
LSD(0.05)	4.0
LSD(0.10)	3.3

Wheat Grain Yield Response to Phosphorus and Potassium Fertilizer Rate

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Fertilization of soft red winter wheat (*Triticum aestivum* L.) represents about 60% of the direct crop production expenses in Arkansas (Stiles and Kelley, 2008). Wheat often responds positively to phosphorus (P) fertilization and Slaton et al. (2005) estimated the critical Mehlich-3 P concentration for wheat following rice in the rotation to be 32 ppm. However, less is known about wheat response to potassium (K) fertilization as few studies have been conducted to correlate and calibrate wheat response to K fertilization. Sweeney et al. (2000) reported that K fertilization increased yields and reduced leaf rust severity of wheat cultivars rated as susceptible to leaf rust. Snyder and Mascagni (1998) reported similar benefits of P and K fertilization on wheat yields and disease suppression in Louisiana. According to the most recent wheat fertilization survey including Arkansas, P and K fertilizers were applied to 28% of the soft red winter wheat acreage in Arkansas with an average application rate of 37 lb P_2O_5 and 48 lb K_2O/acre (USDA-NASS, 2001).

The recent increases in fertilizer prices have increased the costs of wheat production and require research to insure that soil-test-based fertilizer recommendations be evaluated for accuracy. During the 2007-2008 growing season, P and K fertilization trials were established with the ultimate goals of i) identifying the critical soil P and K availability index (Mehlich-3) values for which winter wheat requires fertilization, and ii) calibrating the appropriate fertilizer rates that should be recommended for each soil-test level.

PROCEDURES

Field studies were established during the fall of 2007 to evaluate the effect of P and K fertilization rate on wheat yield. Tests were located at the Pine Tree Branch Station (PTBS) on a Calhoun silt loam following rice (*Oryza sativa* L.) and the Rice Research Extension Center (RREC) on a Dewitt silt loam following soybean [*Glycine max* (Merr) L.]. The soil series, wheat cultivar, previous crop, and dates of agronomic importance for each site are listed in Table 1.

Individual plots consisted of 9 rows (7- to 7.5-inch row spacings) of wheat that were 20-ft long and separated from adjacent plots by a 12- to 24-inch-wide alley. A composite soil sample (0- to 4-inch depth) was taken from each replicate at each 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, organic matter by weight loss on ignition, and soil water pH. Mean values of selected soil chemical properties are listed in Table 2.

'Beretta' wheat was drill-seeded (100 to 120 lb seed/acre) on 5 November at PTBS and 7 November at RREC. Potassium fertilizer (100 lb muriate of potash/acre) was applied to P trials and P fertilizer (130 lb triple superphosphate/acre) was applied to K trials in the late fall (6 Dec.) to ensure these nutrients were not yield-limiting factors. For wheat following rice at the PTBS, 100 lb urea/acre were broadcast on 6 December to stimulate growth. After wheat was seeded, P-fertilizer treatments were applied to the soil surface at rates of 0, 30, 60, 90, and 120 lb P_2O_5/acre as triple superphosphate and K-fertilizer treatments were applied to the soil surface at rates of 0, 40, 80, 120, and 160 lb K_2O/acre as muriate of potash (Table 1).

Whole, aboveground plant samples were taken at Feekes stage 10.5 (heading) at both sites to determine whole-plant P and K concentrations. Whole-plant samples were also collected from P-rate trials at Feekes stage 6 or 7. For all plant samples, a 3-ft section of the first inside row was cut at the soil surface, placed in a paper bag, oven dried at 60°C to a constant weight, weighed for dry matter accumulation, and ground to pass a 1-mm sieve. A 0.25 g sub-sample was digested in concentrated HNO_3 and 30% H_2O_2 and analyzed for nutrient concentration. At maturity, grain yields were measured by harvesting the middle 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 six replicates per treatment. 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.). Mean separations were performed using Fisher's Protected Least Significant Difference method at a significance level of 0.10.

RESULTS AND DISCUSSION

Site Descriptions

The soil-test level associated with the average Mehlich-3-extractable P was classified as 'Low' (17 to 25 ppm) at RREC and 'Medium' (26 to 35 ppm) at PTBS (Table 2). Based on the University of Arkansas fertilizer guidelines for winter wheat, the recommended P-fertilizer rates were 70 lb P_2O_5/acre for RREC and 50 lb P_2O_5/acre for PTBS. Recommendations were designed to build and maintain soil-test P concentrations in the 'Medium' (26 to 35 ppm) soil-test category for wheat yields of 70 bu/acre. For K trials, the average Mehlich-3-extractable K was 'Optimum' (131 to 175 ppm) at both sites with a recommended rate of 0 lb K_2O/acre.

Wheat Response to K-fertilizer Rate

Wheat dry matter yield was not affected by K-fertilizer rate at either site (data not shown) with average aboveground biomass yields at Feekes stage 10.5 of 5461 lb/acre at PTBS and 8334 lb/acre at the RREC. Whole-plant K concentrations at Feekes stage 10.5 were not affected by K-fertilization rate at either site (Table 3). Wheat yields were also not statistically different among K-fertilizer rates when assessed using the Fishers Protected LSD method (Table 4). Single-degree-of-freedom contrasts comparing the yield of wheat receiving no K against the average yield of wheat receiving K suggested wheat yields declined slightly at the PTBS from K fertilization.

Wheat Response to P-Fertilizer Rate

Whole-aboveground dry matter accumulation at Feekes stage 6 was not affected by P rate at the PTBS (*P*=0.8869, average dry matter = 1395 lb/acre), but was affected at RREC (*P*=0.0753, data not shown). At the RREC, application of 30 and 60 lb P_2O_5/acre increased dry matter 22 to 27% above the no P control (2962 lb/acre), which had the lowest numerical dry matter. Wheat at RREC was slightly more developed (Feekes stage 7) than wheat at PTBS (stage 6) when sampled. Whole-plant P concentrations at Feekes stage 6 or 7 were significantly affected by P rate at both sites (Table 3) with tissue P generally increasing as P rate increased. Although significant differences existed among P rates at the PTBS, plant P concentrations ranged from 0.47 to 0.55% P, suggesting P was adequate for normal growth. In comparison, at the RREC, wheat tissue P ranged from 0.24 to 0.43% among P rates.

By Feekes stage 10.5, wheat dry matter accumulation at the PTBS was not different among P rates (average dry matter = 4978 lb/acre, data not shown) and whole-plant P concentrations were similar among P-fertilizer rates ranging from 0.21 to 0.24% P (Table 3). The no P control contained 0.21% P, suggesting this concentration was sufficient for normal wheat production or at least for the yield level produced in this trial (Table 4). Wheat grain yields were not affected by P fertilization at the PTBS. Our previous research has noted that wheat grown on alkaline soils may be less responsive to P fertilization compared with wheat grown on slightly acidic soils.

At the RREC, wheat dry matter accumulation was no longer different among P rates (average dry matter = 8544 lb/acre) by Feekes stage 10.5, although the unfertilized control had the lowest numerical dry matter (8188 lb/acre). The tissue P concentrations had declined to <0.20% P for all rates, except the highest applied rate of 120 lb P_2O_5/acre (Table 3). Single-degree-of-freedom contrasts showed the yield of wheat receiving no P (41 bu/acre) was significantly less than the average yield of wheat receiving P (average yield = 47 bu/acre). Numerical yields ranged from 46 to 48 bu/acre with application of 60 to 120 lb P_2O_5/acre.

PRACTICAL APPLICATION

Wheat yields were not affected by K fertilization on two soils that had Optimum soil-test K levels, suggesting the current interpretation for Optimum is accurate. Additional sites with lower than Optimum soil-test K levels are needed to assess the accuracy of the current soil-test K boundaries for winter wheat. For P, soil-test-based recommendations accurately predicted that wheat yield would respond positively to P fertilizer at the RREC, which had a soil-test P of 17 ppm. Although no positive yield increase from P fertilization was measured at the PTBS, this response was not unexpected for a soil with a Medium soil-test P level (26 ppm). The recommended P rate of 50 lb P_2O_5/acre serves to replace P removed by harvested grain and, for large fields, account for field areas that test below the field average and would likely respond positively to P fertilization.

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Table 1. Selected agronomic information for P- and K-rate trials with winter wheat conducted during the 2007-2008 growing season.

				Date of event		
Site	Soil series	Cultivar	Previous crop	Plant	Fertilizer applied	Harvest
				(month/day)		
RREC	Dewitt	Beretta	Soybean	Nov 5	Dec 5	June 4
PTBS	Calhoun	Beretta	Rice	Nov 7	Dec 6	June 10

Table 2. Selected soil chemical property means (*n* = 6) of phosphorus and potassium fertilization trials with winter wheat conducted during the 2007-2008 growing season.

Nutrient - Site	SOM	Soil pH	P[z]	K[y]	Ca	Mg	S	Na	Fe	Mn	Cu	Zn	B
			Mehlich-3-extractable nutrients										
	(%)		(ppm)										
Phosphorus													
RREC	2.0	6.1	17	135	884	166	7	73	236	133	1.3	0.7	0.2
PTBS	2.5	7.3	26	156	1672	398	12	56	219	139	2.0	1.7	0.2
Potassium													
RREC	2.0	5.9	13	143	904	167	9	80	226	162	1.4	0.6	0.2
PTBS	2.1	7.6	32	172	2119	416	14	68	183	196	1.9	1.4	0.3

[z] Standard deviation (*n*=6) of soil-test P in P trials was 3 ppm for the RREC and 2 ppm for PTBS.

[y] Standard deviation (*n*=6) of soil-test K in K trials was 13 ppm for the RREC and 26 ppm for PTBS.

Table 3. Winter wheat whole-plant P concentrations at Feekes (FK) stages 6 and 10.5 as affected by P fertilizer rate and K concentrations at FK stage 10.5 as affected by K fertilizer rate at two sites during the 2007-2008 growing season.

	PTBS		RREC		Potassium trial (FK 10.5)		
P rate	FK 6	FK 10.5	FK 6	FK 10.5	K rate	PTBS	RREC
(lb P_2O_5/acre)	(% P)				(lb K_2O/acre)	(% K)	
0	0.47	0.21	0.24	0.12	0	1.76	1.91
30	0.49	0.24	0.30	0.15	40	1.70	1.91
60	0.49	0.24	0.34	0.17	80	1.80	1.88
90	0.55	0.23	0.40	0.19	120	1.77	2.03
120	0.54	0.24	0.43	0.22	160	1.83	1.98
P-value	0.0004	0.1201	<0.0001	<0.0001	*P*-value	0.3241	0.4704
LSD(0.10)	0.04	NS[z]	0.06	0.029	LSD(0.10)	NS	NS

[z] NS = not significant (*P*>0.10).

Table 4. Winter wheat grain yields as affected by P and K fertilizer rate at two sites during the 2007-2008 growing season.

Phosphorus trials			Potassium trials		
P Rate	PTBS	RREC	K rate	PTBS	RREC
(lb P_2O_5/acre)	-------------- (bu/acre)	-----------------	(lb K_2O/acre)	--------------- (bu/acre)	--------------
0	41	41	0	46	35
30	41	45	40	44	37
60	41	47	80	44	39
90	44	48	120	46	37
120	47	46	160	42	40
P-value	0.7448	0.1115	*P*-value	0.3119	0.4038
LSD(0.10)	NS[z]	NS	LSD(0.10)	NS	NS
P vs No P[y]	0.5116	0.0215	K vs No K[y]	0.0770	0.1263

[z] NS = not significant (*P*>0.10).

[y] Comparison using single-degree-of-freedom contrast to evaluate the yield of wheat receiving no P or K to wheat receiving P and K fertilizer.

Winter Wheat Response to Inorganic Nitrogen Fertilizer and Poultry Litter Applied in Fall and Late Winter

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Soft red winter wheat (*Triticum aestivum* L.) requires nitrogen (N) fertilizer to produce optimal yields on most soils in Arkansas. Nitrogen fertilizer is typically applied as urea at total rates ranging from 90 to 160 lb N/acre depending on yield potential, previous crop, and soil texture. Research has shown that efficient uptake of fertilizer N occurs when urea is applied in split applications in late winter with the first split usually applied in early- to mid-February (~Feekes stage 3) and the second application made about 3 weeks later at jointing (Feekes stage 5). Bashir et al. (1997) determined that wheat recovery of urea-N by Feekes stages 8-9 was about 74% with this N-management strategy. While the recommended rates and times of urea application remain an efficient system of fertilization, recent increases in inorganic-N fertilizer prices and the surplus of poultry litter (PL) in western Arkansas have stimulated interest in alternative N sources for winter wheat as well as other crops grown in eastern Arkansas.

Poultry litter contains a relatively low concentration of N (3 to 4% N) compared with inorganic N fertilizers, but also contains other essential nutrients that are often applied as inorganic fertilizer to optimize wheat growth and yield. Research has established some recommendations for estimating plant-available N (PAN) in PL for summer-grown crops such as corn (*Zea mays* L., Bitzer and Sims, 1988; Sims, 1987). However, few studies have described the inorganic-N equivalence of PL for winter grown crops.

Temperature influences the mineralization rate of organic N in manure, which may also influence estimates of plant-available N and the synchrony between plant-N uptake and organic N mineralization. Clark and Mullins (2004) reported that fresh, pelleted, and granulated PL applied based on estimates of PAN (~55-60% of organic N mineralized) produced equal grain yields as like rates of inorganic-N fertilizer with all N sources applied at Zadoks stage 25 or 30 (Feekes 3-5). However, the maximum numerical yield differences between the unfertilized control and the highest yielding treatments receiving N were <23 bu/acre during the 3-year study, suggesting that only low N rates were needed to maximize yields.

The primary objective of this research was to determine the urea-N equivalence or plant-available N of PL applied to winter wheat. Our hypothesis was that the PAN in PL would be less than the values typically reported for summer crops like corn and cotton (i.e., 50 to 60% PAN) because the cooler temperatures following fall application would limit mineralization of organic-N.

PROCEDURES

Field studies were established at the Pine Tree Branch Station on a Loring silt loam (2006) following rice (*Oryza sativa* L.) in rotation and a Calloway silt loam (2007) following soybean [*Glycine max* (Merr.) L.] in rotation. Before applying treatments, composite soil samples (0 to 4 inches) were collected from each replicate to characterize soil chemical properties. Soil samples were dried at 60°C, crushed to pass a 2-mm sieve, and analyzed for soil pH, Mehlich-3-extractable nutrients, KCl extractable inorganic N, and total N and C (Table 1).

Each year fresh broiler litter was obtained directly from a poultry house and analyzed for chemical properties (Table 2). Litter obtained in 2006 was from a commercial poultry grower, had been in the house for about 12 months, and rice hulls were used as the bedding material. In 2007, litter was obtained from the University of Arkansas Savoy Poultry Production unit and had been in the house for about 18 months with rice hulls and wood shavings as the bedding material. Litter was stored in sealed 18 gal containers between collection and analysis of four composite samples of litter (Table 2). The amount of PL needed for each plot was calculated based on the average, moist (i.e., 'as is') total N concentration, weighed, and placed into plastic bags that were sealed until the litter was applied. In preparation for chemical analyses, litter samples were mixed thoroughly using a coffee bean grinder. Total N and C were determined by combustion, and litter NH_4-N and NO_3-N concentrations were determined by extracting a 0.5 g sub-sample of ground litter with 2 *M* KCl, and the NH_4-N and NO_3-N concentrations of filtrates were determined by colorimetery. The concentrations of P, K, and other elements were determined by digestion of a 0.5-to 1.0-g sub-sample of ground litter using the concentrated HNO_3 and 30% (w/w) H_2O_2 method.

Wheat was drill-seeded on 24 October 2006 (AgriPro 'Beretta') and 5 November 2007 ('Roane') at a rate of 120 lb/acre into conventionally tilled seedbeds. Each plot was 6.5-ft wide × 20-ft long and contained nine rows (7.5-inches wide) of wheat. Litter was applied at total-N rates of 0, 60, 120, 180, 240, and 300 lb total-N/acre, which corresponded to, on average, 0, 1800, 3600, 5400, 7200, and 9000 lb moist litter/acre, respectively. In 2006, litter was broadcast to the soil surface on 24 October before drill seeding wheat and to the surface of different plots in December to evaluate how time of application influenced wheat grain yield and N uptake (Table 3). In 2007, litter was applied only in early December. For wheat planted in fall 2006, urea was applied at rates of 0, 30, 60, 90, 120, and 150 lb N/acre. The following year, urea-N rates were increased to 0, 40, 80, 120, 160, and 200 lb N/acre. Urea-N rates greater than 80 to 90 lb N/acre were applied in two applications with the first application equaling 80 or 90 lb N/acre and the second application accounting for the balance of the remaining N. Dates for each N application are listed in Table 3. Plots designated to receive urea-N were fertilized with 70 lb P_2O_5 as triple superphosphate and 60 lb K_2O as muriate of potash per acre at planting.

Aboveground samples of wheat were collected from a 3-ft long section from an inside row at the Feekes stage 10.1 (2006) or 10.5 (2007, Table 3). Plant samples were dried in a forced-draft oven at 60°C until reaching a constant weight, weighed for dry matter accumulation, and ground to pass a 1-mm sieve for total-N analysis by combustion. Total-N uptake was calculated by multiplying dry matter by N concentration. At maturity, grain yields were measured by harvesting each plot with a small-plot combine. Grain yields were adjusted to a uniform moisture content of 13%.

Each experiment was a randomized complete block with treatments defined by two or three N sources (urea, PL applied in October, and/or PL applied in December), applied at five N rates, and replicated four times. The N rates for PL were identical each year, but urea-N was applied at different rates between site-years and lower total-N rates than poultry litter. Two (2007-2008) or three (2006-2007) no N controls (0 lb N/acre) were included in each replication. Grain yield, dry matter accumulation, and total aboveground N uptake data were subjected to analysis of variance using the PROC GLM procedure of SAS v9.1 (SAS Institute, Inc., Cary, N.C.). When appropriate, treatment means were separated using Fishers Protected Least Significant Difference method (LSD) with significance interpreted at the 0.05 level.

Treatment means for net-N uptake at Feekes stage 10.1 or 10.5 and net grain yield were calculated across replicates for each site-year by subtracting the average total-N uptake or grain yield recorded from the mean of each N source and rate combination. Mean net-N uptake and grain yield data were initially regressed on N-rate allowing for both linear and quadratic terms with coefficients depending on N-source. Site-years were analyzed separately since trials contained different urea-N rates and poultry litter application times. Non-significant ($P > 0.05$) model terms were removed sequentially and the model was refit until the final model was obtained. Differences among regression coefficients, which varied by N source, were determined using the standard error.

RESULTS AND DISCUSSION

Aboveground dry matter accumulation and total N uptake by Feekes stage 10.1 and 10.5 were significantly affected by treatment during both years (Tables 4 and 5). For both years, dry matter and N uptake tended to increase as N rate increased, regardless of source. Although urea-N was applied at lower N rates than poultry litter, dry matter, total N uptake, and grain yields were consistently greater for urea-N, indicating more efficient N uptake of urea-N by wheat.

Total N uptake of wheat receiving no N was 14 lb N/acre in 2006-2007 (following rice) and 26 lb N/acre in 2007-2008 (following soybean, Tables 4 and 5). Net-N uptake was a linear function of N rate, which varied among N sources with N uptake being greater when urea was the N source. Regression analysis of net-N uptake showed aboveground recovery of urea-N by Feekes stage 10.1 to 10.5 was numerically comparable between site-years and ranged from 40 to 45% (Table 6). In contrast, the average wheat recovery of poultry litter N ranged from 8 to 12%. In the 2006-2007 trial, net-N uptake was similar for litter applied in October and December, suggesting no disadvantage to delaying litter application.

Overall the PAN in litter appears to be lower than the 50 to 60% PAN values commonly stated for upland, summer-grown crops like corn (Bitzer and Sims, 1988). The exact fate of fall- or winter-applied poultry litter N is unknown, but ammonia volatilization, denitrification, immobilization, and/or runoff/ leaching of inorganic N are possible pathways that may contribute to low N uptake by wheat. Mineralization of organic N in fall and winter months when air and soil temperatures are likely to be low may reduce N availability to winter wheat.

Wheat receiving no N produced average yields of 13 and 23 bu/acre in 2006 and 2007, respectively (Tables 4 and 5). Grain yield of wheat following rice in 2006 increased linearly as N rate increased, with the rate of increase being greatest for wheat fertilized with urea-N (Table 6). In 2007, wheat yields increased curvilinearly across urea-N rates. For wheat fertilized with poultry litter, the intercept, linear, and quadratic coefficients were not different than zero, but the overall numerical trend suggests yields increased linearly as poultry litter N rate increased.

Total grain yield regressed against total-N uptake across all site-years and treatments showed wheat yields increased linearly as N uptake increased with 10 lb N uptake/acre required to produce 7.5 bu wheat/acre [Yield bu/acre = 7.3 + (0.76 × N uptake), $r^2 = 0.87$ where x = total aboveground N uptake at Feekes stage 10.1-10.5]. Regressing average total-wheat yield against total applied N rate for each source, except wheat yield receiving 200 lb N/acre, showed wheat yield increased at a rate of 0.40 bu/lb applied urea-N and 0.084 bu/lb poultry litter N. The ratio (4.8) of these slope values suggests that poultry litter N must be applied at nearly five times greater rates as urea to produce equal yields. Alternatively, each unit of poultry litter N is only about 21% as efficient as urea-N.

PRACTICAL APPLICATION

Poultry litter applied from October through December provided little plant-available N for winter wheat grown in eastern Arkansas. Nitrogen uptake efficiency for poultry litter ranged from 8 to 12% of the total applied N compared to 40 to 45% for urea applied in February and March. Based on the ratio of N recovery efficiency between urea and poultry litter, poultry litter N rates would need to be 4 to 5 times greater than urea-N applied in late-winter to produce equivalent wheat N uptake, assuming little or no appreciable N uptake occurs following wheat heading. Grain yield data showed similar results as net N uptake and suggested that about 5 lb poultry litter N/acre are equivalent to 1 lb urea-N/acre for producing wheat grain.

Poultry litter is likely a viable source of P and K that can be used as an alternative to triple superphosphate and muriate of potash fertilizers. Based on results from these two trials, a preliminary recommendation can be made to growers on how to adjust late-winter urea-N rates on fields that have received fall-applied poultry litter. For every 100 lb total N/acre applied as poultry litter, late-winter applied urea-N rates should be reduced by about 20 lb urea-N/acre. This preliminary recommendation is specific for poultry litter applied in late October through December. Poultry litter applied before or after this window may provide more or less plant-available N to wheat. The N-P_2O_5-K_2O nutrient content of poultry litter should be determined before litter is applied since the nutrient content of poultry litter can vary.

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Table 1. Selected soil chemical property means (0- to 4-inch depth) for samples taken before seeding N-fertilization trials with winter wheat during 2006-2007 (2006) and 2007-2008 (2007).

	Previous	Soil	Total	Total	Soil	Soil	Mehlich-3-extractable soil nutrients							
Site-year	crop	pH	C	N	NO_3-N	NH_4-N	P	K	Ca	Mg	S	Mn	Zn	Cu
			(%)				(ppm)							
2006	Rice	7.4	1.36	0.12	10.7	15.0	15	130	1792	238	19	170	1.6	1.7
2007	Soybean	7.2	1.33	0.13	2.0	22.6	28	140	2023	341	18	200	1.4	1.7

Table 2. Selected chemical property means of fresh poultry litter analyzed 'as is' and used in fertilization trials for winter wheat conducted during 2006-2007 and 2007-2008.

		Litter source	
Property	Unit	2006	2007
n (subsamples)		4	4
Moisture	%	21.0	21.2
pH	--	8.0	8.2
Total C	%	29.6	30.9
Total N	%	3.47	3.17
NH_4-N	mg/kg	2393	2757
NO_3-N	mg/kg	1156	63
Total P	%	1.22	1.42
Total K	%	2.29	2.81
Total Ca	%	2.10	1.94
Total Mg	%	0.45	0.56
Total S	%	0.55	0.53
Total Fe	mg/kg	669	443
Total Mn	mg/kg	351	311
Total Zn	mg/kg	294	305
Total Cu	mg/kg	305	370
Total Na	mg/kg	4733	5816
Total B	mg/kg	34	44
Total Al	mg/kg	402	104

Table 3. Dates of selected wheat management practices initiated on research plots at two site-years.

Site-year	Planting	October litter	December litter	Inorganic N	Inorganic N	Plant sample	Harvest
	-----	-----	-----	(day / month)	-----	-----	-----
2006-2007	24 Oct	24 Oct	18 Dec	28 Feb	15 Mar	19 April	6 June
2007-2008	5 Nov	--	6 Dec	11 Feb	17 Mar	30 April	10 June

Table 4. Wheat dry matter and total N accumulation at Feekes stage 10.1 and grain yield as affected by inorganic-N fertilizer and poultry litter rate on a Loring silt loam following rice in rotation in 2006.

N source	N rate	Dry matter	Total N uptake	Grain yield
	(lb N/acre)	(lb/acre)	(lb N/acre)	(bu/acre)
None	0	964	14	13
Urea	30	2316	35	25
Urea	60	2516	40	38
Urea	90	3411	65	49
Urea	120	3765	74	59
Urea	150	3478	86	73
Litter-October	60	1145	15	15
Litter-October	120	1180	15	18
Litter-October	180	1773	22	23
Litter-October	240	2012	27	29
Litter-October	300	3011	38	31
Litter-December	60	1348	19	20
Litter-December	120	2204	32	23
Litter-December	180	1898	25	27
Litter-December	240	2466	33	34
Litter-December	300	3003	40	40
P-value		<0.0001	<0.0001	<0.0001
C.V., %		23.4	24.4	10.7
LSD(0.05)		692	11	4

Table 5. Wheat dry matter and total N accumulation at Feekes stage 10.5 and grain yield as affected by inorganic-N fertilizer and poultry litter rate on a Calloway silt loam following soybean in rotation in 2007.

N source	Total N rate	Dry matter	Total N uptake	Grain yield
	(lb N/acre)	(lb/acre)	(lb N/acre)	(bu/acre)
None	0	2062	26	23
Urea	40	2322	24	16
Urea	80	3927	38	40
Urea	120	5435	66	52
Urea	160	5177	60	69
Urea	200	7642	93	75
Litter-December	60	2720	29	33
Litter-December	120	2651	28	33
Litter-December	180	3497	37	43
Litter-December	240	3239	37	48
Litter-December	300	5239	60	54
P-value		<0.0001	<0.0001	<0.0001
C.V., %		23.4	36.6	14.2
LSD(0.05)		1341	22	9

Table 6. Regression coefficients for net N uptake at Feekes stage 10.1 (2006) or 10.5 (2007) and grain yield as affected by N rate for two trials conducted on silt loam soils at the Pine Tree Branch Station in 2006 and 2007 growing seasons.

Site-year	N source	Intercept	Linear	Quadratic
Net-N uptake[z]				
2006-2007	Litter-October	-7.6 (4.7)[y]	0.093 (0.024)	--
2006-2007	Litter-December	2.1 (4.7)[y]	0.075 (0.024)	--
2006-2007	Urea	5.2 (4.7)[y]	0.453 (0.047)	--
2007-2008	Litter-December	-9.1 (8.9)[y]	0.118 (0.045)	--
2007-2008	Urea	-17.8 (8.9)[y]	0.400 (0.067)	--
Net grain yield[x]				
2006-2007	Litter-October	-2.7 (1.33)[y]	0.072 (0.0067)	--
2006-2007	Litter-December	0.5 (1.33)[y]	0.085 (0.0067)	--
2006-2007	Urea	0.7 (1.33)[y]	0.39 (0.013)	--
2007-2008	Litter-December	5.6 (5.9)[y]	0.045 (0.075)[x]	0.00014 (0.00020)[x]
2007-2008	Urea	-32.2 (5.9)	0.700 (0.112)	-0.0014 (0.00046)

[z] Where Y = net N uptake (lb N/care) and x = N rate (lb N/acre). Units for the linear slope coefficient are lb net-N uptake/lb N applied.

[y] Coefficient not different than zero.

[x] Where Y = net grain yield (bu grain/care) and x = N rate (lb N/acre). Units for the linear slope coefficient are bu net grain/lb N applied.

Predicting Soil Phosphorus Saturation using Mehlich-3 Extractable Nutrients

N.A. Wolf and N.A. Slaton

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Soil phosphorus (P) and its relationship to water quality is a major agronomic and environmental issue. Transport of P from soil, fertilizer, and/or manure into surface and ground water degrades water quality. The potential for P transport in soil is dependent upon many land use factors and soil chemical and physical properties. An important soil property to estimate the extent to which soil P sorption sites are filled is soil P saturation and degree of P saturation (DPS; Breeuwsma and Reijerink, 1999). If soil-solution P is present at greater concentrations than available soil P sorption sites, the potential for P transport increases. One method of determining P saturation calculates the DPS from the P, Fe, and Al concentrations extracted by ammonium oxalate over a specific soil depth; a DPS over 25% is considered too high (Schoumans, 2000). The laboratory method for directly measuring P saturation by soil adsorption isotherms requires a 24-hour equilibration with increasing P standards, which is not a feasible method for routine soil testing laboratories.

Ammonium oxalate extractable P, Fe, and Al have been established as the basis for calculating soil DPS (Breeuwsma and Reijerink, 1992, Schoumans, 2000), but P sorption indices (PSI) have been proposed using other extractants including Mehlich-3. The Mehlich 3 extract is more commonly used by soil-test laboratories for routine soil analysis than is ammonium oxalate. Therefore, it would be beneficial to relate the directly analyzed P sorption maxima (S_{MAX}) to the Mehlich 3 PSI (PSI_{M3}). The main research objective was to perform soil P adsorption isotherm batch studies on the soils to analytically determine the P sorption maxima and correlate the P sorption maxima to other more easily attained P saturation indices.

PROCEDURES

Soil characteristics and taxonomic information for the 16 soils used in this study were reported by Wolf and Slaton (2008) and selected soil properties are listed in Table 1. Soil texture analysis was performed in duplicate by the hydrometer method with hydrometer readings taken at 40 seconds and 6 hours (WCC-103, 2003). Phosphorus adsorption isotherms were performed according to the procedure described by Graetz and Nair (2000). Briefly, 25 mL of 0.01 *M* $CaCl_2$ solution containing 0.0, 0.5, 1.0, 5.0,10.0, 15.0, or 20.0 mg P/L were added to 1 g of soil in a 50 mL centrifuge tube. The tubes were shaken for 24 hours on an Eberbach reciprocating shaker at 185 rpms at ambient temperature. After shaking, the soil was allowed to settle and the supernatant was filtered through a 0.45 µm syringe filter. The P in solution was measured with a Spectro CIROS inductively coupled plasma spectrophotometer (ICPS) at wavelengths of 178 and 213 nm. A blank consisting of only the P solution was included and analyzed to ensure that the added P concentrations were correct. Because there was high variation in the ICPS measurements at the 0, 0.5, and 1.0 mg P/L levels for many of the soils, the P adsorption isotherm batch study was repeated using a higher range of P concentrations (0 - 100.0 mg P/L). Phosphorus sorption calculations were performed following procedures described in the *Western States Laboratory Plant, Soil and Water Analysis Manual (WCC-103, 2003).* Phosphorus adsorption isotherms were determined with the linearized Langmuir equation $[C / S = (1 / k S_{MAX}) + (C / S_{MAX})]$ where S = the total amount of P retained, mg P/kg; C = the concentration of P after a 24-hour equilibrium, mg P/L; S_{MAX} = the P sorption maximum, mg P/kg; and k = a constant related to the bonding energy. The S_{MAX} value is the reciprocal of the slope of C regressed against C/S where C is the equilibrium solution P concentration and S is adsorbed P (Olsen and Watanabe, 1957). Regression analysis was performed using PROC REG in SAS v9.1 to determine S_{MAX} values and the relationships between soil properties (e.g., S_{MAX} and % clay content).

RESULTS AND DISCUSSION

Adsorption Isotherm P Equilibrium Solution Analyses

Obtaining consistent solution P concentrations when low rates of P (<1.0 mg P/L) were added to 1 g soil proved to be a difficult task (Table 2). For most soils, soil solution P equilibrium concentration usually increases as the rate of P added increases, but several soils, mostly those with high clay content, continued to adsorb the added P, resulting in very low solution P concentrations. The low and high range P data were used separately with the P adsorption calculations and the Langmuir equation. Adsorption studies by Kleinman and Sharpley (2002) and Zhang et al. (2005) used the Murphy-Riley ascorbic acid colorimetric method to measure the solution P. Although ICPS or colorimetric methods may be used to quantify solution P concentrations, ICPS is best used only when the P concentration is >10 mg P/L (WCC-103, 2003). Graetz and Nair (2000) recommended an initial P addition range from 0 to 10 mg P/L, but suggested that the P range could vary from 0 to 100 mg P/L. The second adsorption batch study used higher solution P addition concentrations of 0 to 100 mg P/L to overcome the analytical problems with the ICPS (Table 2). The added P concentrations common to both batch trials, 10 and 20 mg P/L, showed consistent results for all soils. The 1.0 mg P/L addition for analysis performed with the 0-100 mg P/L (high) range showed more consistent results than analysis conducted with the low range of solution P concentrations. However, at additions of up to 100 mg P/L, adsorption sites may have been saturated for the Amy, Carnasaw, Leadvale, and Moutainburg soils as indicated by the P sorbed decreasing with increasing P added. Example P sorption curves for the Alligator clay and Dundee silt loam, as determined with the low and high range of solution P concentrations, are shown in Fig. 1. Adsorption calculations, with the Langmuir equation, were performed separately for the low and high solution P concentration ranges.

Langmuir Equation to Describe Adsorption Isotherms

The linearized Langmuir equation described P adsorption data adequately with r^2 values ranging from 0.80 to 0.99 for all soils in the low and high batches (Table 3). The initial P concentration ranges (low or high) affected the predicted S_{MAX}, which was numerically lower for the low P range for all soils. For soils showing P saturation (Carnasaw, Leadvale, Mountainburg, and Amy), the S_{MAX} values were numerically similar when the saturated data points were excluded from the Langmuir equation. The S_{MAX} value for the Mountainburg soil (High P addition range) was not statistically significant. Although the blank (0.0 mg P/L) in the high P range batch contained some P in the sample, the fit to the Langmuir equation did not improve greatly when the blank P concentration was subtracted from each sample receiving P solution. Graetz and Nair (2000) summarized studies that have used a number of different methods to determine native P, including ammonium oxalate, Mehlich 1, anion-impregnated membrane technology, and the least squares fit method. They concluded that "at this point, it appears that selection of the method for determination of native sorbed P would depend on the nature of the soils in the study and the reproducibility of the results." For this study with Arkansas soils, no corrections for native P were made to improve the fit of the Langmuir equation.

Nair et al. (1984) and Graetz and Nair (2000) indicated that the range of initial P concentration was likely to influence P equilibration. The concentration range should be high enough to saturate adsorption sites if it is being utilized to determine the soil's capacity to adsorb P. The S_{MAX} values of Arkansas soils ranged from 70 to 962 mg P/kg soil (Table 3), which is comparable to values reported by Zhang et al. (2005) and Kleinman and Sharpley (2002), who used the same initial P concentrations or concentrations up to 300 mg P/L, respectively. The greatest S_{MAX} values were found in the Perry, Sharkey, Linker, and Alligator soils, which also contained the highest clay contents (Table 1), and are consistent with results reported by Zhang et al. (2005) for Oklahoma soils. Linear regression of soil S_{MAX} values (Table 3) against soil % clay content (Table 1) showed that S_{MAX} increased as soil clay content increased, with r^2 values of 0.42 for the low P range and 0.69 for the high P range (Fig. 2).

The relationship between S_{MAX} and soil clay content could be helpful to predict P sorption maxima, but textural analysis is not routinely analyzed for by most soil test laboratories. Soil adsorption isotherms would also be difficult to perform on the large number of soils received by most soil testing laboratories. Therefore, the ability to predict S_{MAX} values from routinely analyzed soil parameters rather than by P adsorption isotherms would be useful. Kleinman and Sharpley (2002) correlated a reference P sorption index based upon S_{MAX}, referred to as P_{SAT} and defined as bicarbonate P/ S_{MAX} + bicarbonate P to PSI indices, determined from ammonium oxalate and Mehlich 3 extractions. They concluded that PSI_{M3} could be used to predict reference P_{SAT} in acidic soils. More recently, Zhang et al. (2005) correlated a number of soil parameters to S_{MAX} and developed multiple regression models using soil clay, organic carbon, and Mehlich-3 aluminum to seven parameters of pH, clay, organic carbon, and Mehlich-3 Al, Fe, Ca, and Mg ($R^2 = 0.89$ to 0.90) for 28 Oklahoma soils. Another P index was calculated similar to the reference P_{SAT} of Kleinman and Sharpley (2002) except that it was defined as Mehlich-3 P/S_{MAX} and called $\%P_{SAT}$. For 26 Oklahoma soils with pH< 7.0, $\%P_{SAT}$ was highly correlated to PSI_{M3} with $r = 0.85$. The relationship between $\%P_{SAT}$ and PSI_{M3} for both the low and high P ranges in which S_{MAX} was calculated was also very good for Arkansas soils (Fig. 3). The PSI_{M3} may be useful to predict P sorption maxima without having to determine P adsorption isotherms for Arkansas soils.

PRACTICAL APPLICATION

Knowledge of soil P sorption capacity may aid in developing best nutrient management practices and interpreting routine soil-test data to assess the risk of P transport from soils of agronomic and environmental importance. The PSI_{M3} could be determined by evaluating Mehlich-3 extracts for P, Fe, and Al and used to assess the extent of P saturation of top soils submitted for routine analysis. The relationships described for the 16 Arkansas soils should be considered as preliminary results. Additional research is warranted and required to better define the relationships between soil P saturation and chemical properties as determined with routine soil analysis.

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Table 1. Selected soil chemical properties and clay content of the 16 Arkansas soils.

				Mehlich-3			Ammonium oxalate		
Soil series	pH	Total C	Clay	P	Fe	Al	P	Fe	Al
		------------(%)----------		---(mg/kg) --------------------------------------					
Alligator	8.1	1.1	44.5	9	155	449	61	2543	891
Dundee	6.6	1.4	13.7	43	238	242	181	1884	313
Perry	5.7	2.1	68.3	54	201	713	566	7195	1667
Sharkey	5.9	1.3	56.4	17	208	719	278	7665	1536
Calloway	6.9	0.8	10.2	9	241	265	169	1962	544
Dewitt	6.0	1.1	18.5	11	227	602	118	4430	1108
Henry	7.4	1.2	11.1	25	346	183	109	1904	262
Hillemann	7.4	1.1	12.0	31	336	220	151	2613	468
Enders	6.1	3.4	18.5	24	86	547	102	1541	921
Fayetteville	5.5	1.6	15.2	13	100	635	95	1282	874
Linker	5.9	1.7	30.2	3	67	761	29	1002	996
Clarksville	6.0	2.2	11.7	12	144	451	327	1280	683
Carnasaw	5.3	2.1	12.4	11	99	765	79	1274	1207
Leadvale	6.7	2.3	16.7	6	130	477	123	3342	1030
Mountainburg	5.6	2.1	13.3	51	175	481	237	1662	708
Amy	4.6	0.8	13.1	7	236	669	38	2267	907

Table 2. Phosphorus solution equilibrium concentrations of 16 soils using two sets of solution P concentrations.

	Solution P concentration added to soil (mg P/L)												
	Low range (first run)							High range (second run)					
Soil series	0.0	0.5	1.0	5.0	10.0	15.0	20.0	0.0	1.0	10.0	20.0	40.0	60.0	100.0
	[solution P concentration (mg P/L)]													
Soil series	0.0	0.5	1.0	5.0	10.0	15.0	20.0	0.0	1.0	10.0	20.0	40.0	60.0	100.0
No Soil	0.03	0.53	1.03	5.13	10.2	15.0	20.0	0.44	0.96	9.9	19.9	39.6	61.0	99.6
Alligator	0.02	0.03	0.03	0.56	2.5	5.2	8.5	0.39	0.11	2.1	8.1	22.5	38.8	74.1
Dundee	0.10	0.16	0.28	2.49	6.4	10.9	15.7	0.51	0.31	5.9	14.2	32.5	49.7	87.0
Perry	0.12	0.07	0.10	0.41	1.4	3.2	5.4	0.19	0.06	1.2	1.5	15.4	29.1	60.6
Sharkey	0.03	<0.02	<0.02	0.17	1.1	2.3	4.6	0.52	0.14	0.8	1.1	16.2	30.4	64.2
Calloway	<0.02	0.08	0.11	1.81	5.4	9.6	14.0	0.46	0.15	1.9	7.0	23.1	29.6	77.5
Dewitt	0.27	0.09	0.06	0.47	2.2	4.9	8.3	0.56	0.17	2.1	7.5	24.2	40.4	76.6
Henry	0.07	0.12	0.19	2.14	5.8	10.0	14.5	0.64	0.21	5.4	13.6	32.2	50.7	88.8
Hillemann	0.06	0.12	0.19	1.88	5.4	9.3	13.7	0.54	0.27	4.5	12.8	30.0	48.9	87.6
Enders	0.07	0.11	0.09	0.69	2.5	5.1	7.7	0.60	0.22	2.5	7.4	22.6	38.6	78.0
Fayetteville	0.13	0.10	0.09	0.91	3.4	6.7	10.4	0.59	0.18	3.4	10.0	27.0	44.5	84.9
Linker	<0.03	0.04	0.05	0.21	1.2	3.1	5.9	0.48	0.11	1.0	4.8	18.7	34.8	73.9
Clarksville	0.54	0.65	<0.02	3.46	7.9	12.3	17.0	0.37	1.07	7.4	16.0	33.2	53.0	91.9
Carnasaw	0.06	0.09	0.08	0.70	3.0	6.1	9.9	0.46	0.24	2.5	10.2	33.3	58.1	93.3
Leadvale	0.04	0.03	0.06	0.67	2.5	5.5	8.9	0.38	0.19	3.8	11.2	28.2	65.1	95.7
Mountainburg	0.16	0.26	0.36	2.43	6.0	9.8	14.3	0.30	0.62	5.8	15.2	21.6	58.1	98.6
Amy	0.07	0.05	0.12	0.27	1.2	3.5	6.5	0.36	0.17	1.3	6.6	24.4	44.2	101.3

Table 3. Phosphorus sorption indices of 16 soils collected in Arkansas.

	Langmuir S_{MAX}[z]				P_{SAT}[y]		P saturation index	
Soil	Low P range		High P range		Low P	High P	PSI_{M3}[x]	PSI_{OX}[w]
	(mg/kg)	r^2[v]	(mg/kg)	r^2[v]	(%)			
Alligator	287	0.97	643	0.97	3.1	1.4	1.5	2.5
Dundee	114	0.98	310	0.91	37.7	13.9	10.6	12.9
Perry	384	0.80	962	0.97	14.1	5.6	5.8	9.6
Sharkey	393	0.96	888	0.98	4.3	1.9	1.8	4.6
Calloway	151	0.98	575	0.96	6.0	1.6	2.1	10.0
Dewitt	300	0.91	582	0.97	3.7	1.9	1.3	3.2
Henry	142	0.98	274	0.97	17.6	9.1	6.3	8.1
Hillemann	164	0.97	316	0.99	18.9	9.8	7.3	7.6
Enders	309	0.83	575	0.99	7.8	4.2	3.5	5.3
Fayetteville	249	0.95	391	0.99	5.2	3.3	1.7	5.6
Linker	372	0.96	667	0.99	0.8	0.5	0.4	1.7
Clarksville	70	0.93	213	0.95	29.3	5.6	20.8	21.9
Carnasaw	264	0.96	253	0.85	4.2	4.4	1.2	3.8
Leadvale	282	0.98	302	0.96	2.1	2.0	0.9	4.1
Mountainburg	154	0.83	115[u]	0.61	33.1	44.4	7.8	13.7
Amy	361	0.92	406	0.99	1.9	1.7	0.7	1.7

[z] P sorption maxima calculated from Linearized Langmuir Equation.

[y] P saturation calculated from Mehlich-3 P / S_{MAX}.

[x] Single point P sorption index calculated from Mehlich-3 P/ Mehlich-3 Fe + Mehlich-3 Al.

[w] Single point P sorption index calculated from Oxalate P/ Oxalate Fe + Oxalate Al.

[v] Coefficient of determination.

[u] Not significant (slope coefficient P=0.1394).

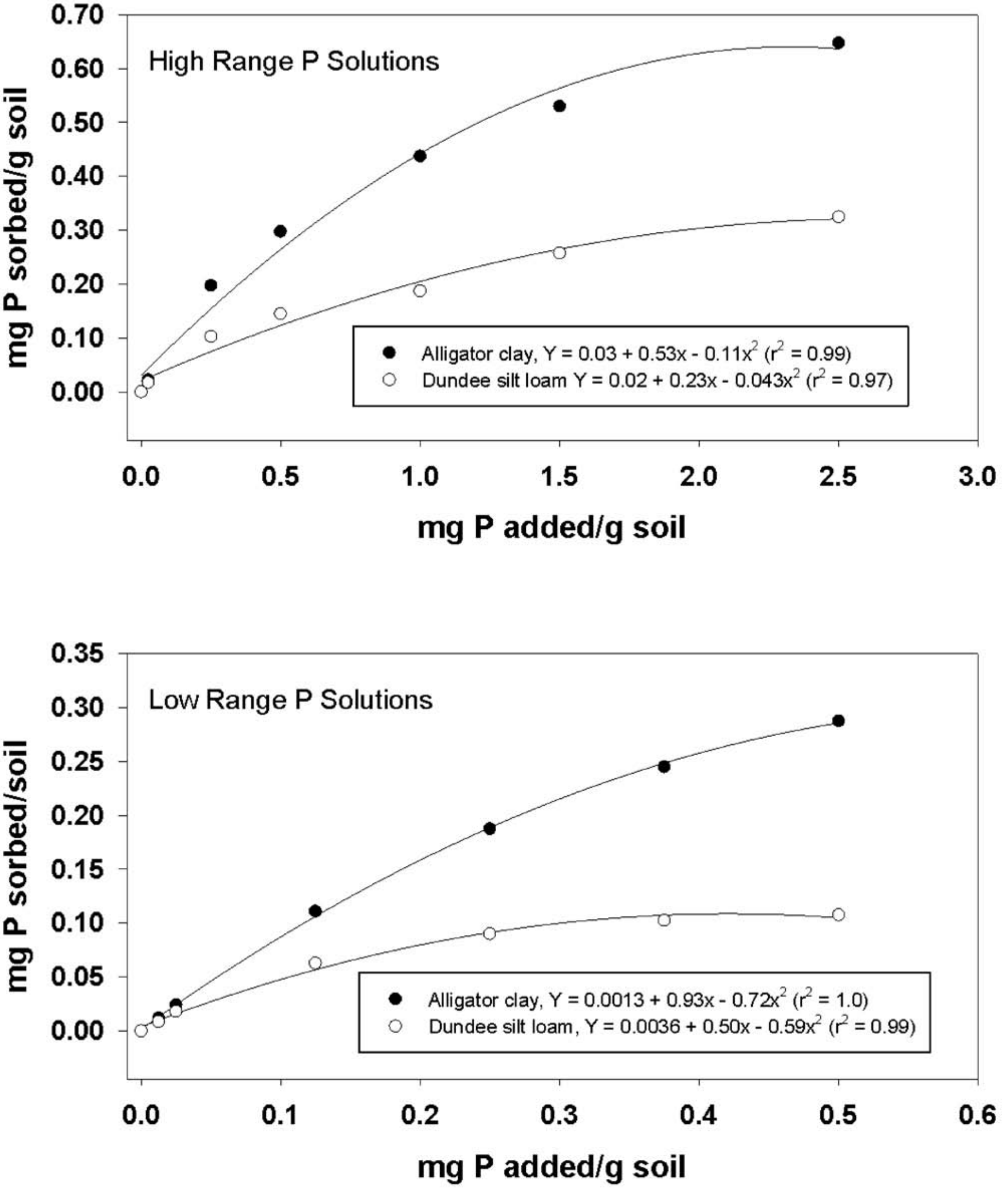

Figure 1. Example P sorption curves for the Alligator clay and Dundee silt loam soils as determined with the low and high range of solution P concentrations (Table 2).

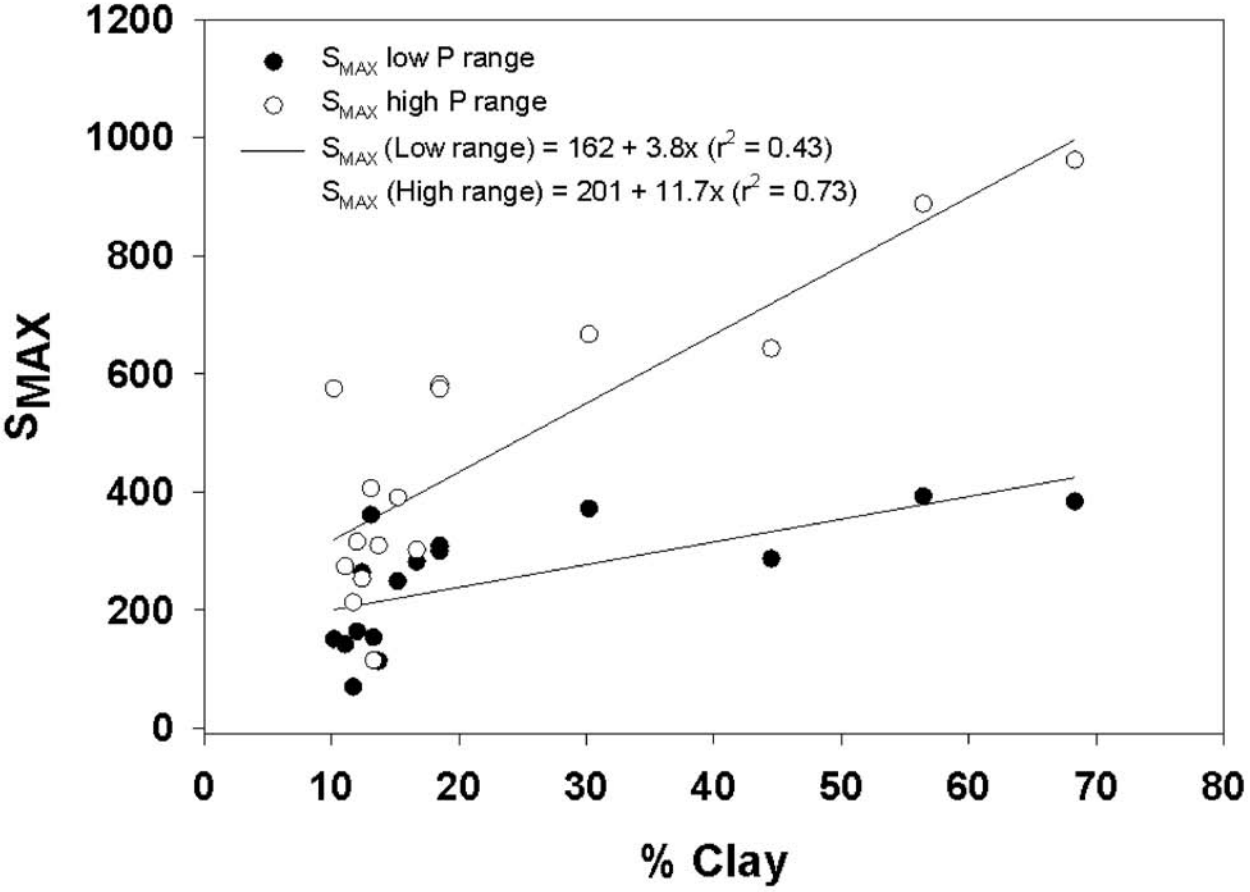

Figure 2. Relationship between S_{MAX} as determined with the low and high P solution ranges and percentage soil clay content (Table 3) for 16 Arkansas soils.

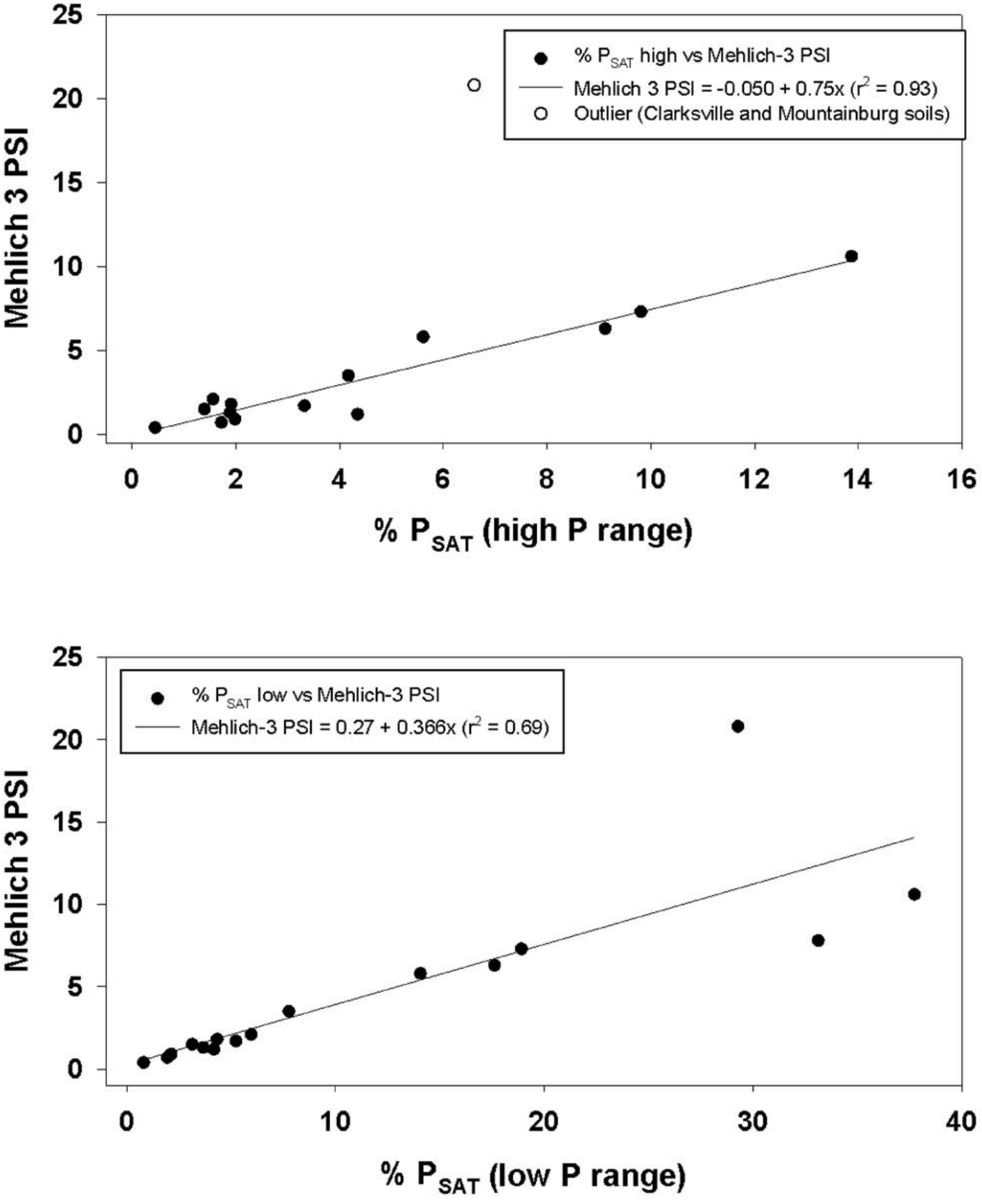

Figure 3. Relationship between percentage soil P saturation [% P_{SAT} = Mehlich-3 P (ppm)/S_{MAX}] with high (*n*=14) and low (*n*=16) P solution ranges and Mehlich-3 P saturation index [PSI_{M3} = (((Mehlich-3 P)/(Mehlich-3 Fe + Al)) × 100; with concentrations expressed as mmol/kg]. Note the different range for x-axis between low and high range.

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