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Wayne E. Sabbe
ARKANSAS
SOIL FERTILITY STUDIES
• 2007 •

Nathan A. Slaton, Editor

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WAYNE E. SABBE
ARKANSAS
SOIL FERTILITY STUDIES
– 2007 –

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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 2007 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 2006. 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.

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Soil Test and Fertilizer Sales Data: Summary for the 2006 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 during the period 1 January 2006 through 31 December 2006 were categorized according to geographic area, county, soil association number (SAN), and selected cropping systems. The soil analysis procedure was changed to a 1:10 soil:Mehlich-3 solution extraction ratio for soil nutrient concentrations beginning 1 January 2006. The geographic area 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 by inductively coupled plasma spectroscopy) 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 2006 and 31 December 2006, 95,325 soil samples were analyzed by the University of Arkansas Soil Testing and Research Laboratory in Marianna. After removing standard-check soils measured for quality assurance (7,953), the total number of client samples was 84,332. A total of 69,494 soil samples, representing a total of 1,581,985 acres averaging 23 acres/sample, had complete data for the total acres, soil pH, phosphorus (P), potassium (K), and zinc (Zn). The difference of 14,838 samples between the total samples and samples with reported acreage was designated as grid samples conducted on row crops. Soil samples from the Bottom Lands and Terraces and Loessial Plains, primarily row-crop areas, represented 49% of the total samples and 75% of the total acreage (Table 1). The average number of acres represented by each soil sample ranged from 2 to 70 acres/sample (Table 2). Clients from Washington (5178), Benton (4862), Arkansas (Stuttgart and DeWitt offices, 4807), Jackson (3980), and Craighead (3472) counties submitted the most soil samples for analyses. Sample numbers submitted by clients in Washington and Benton counties 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 4 (Captina-Nixa-Tonti), 22 (Foley-Jackport-Crowley), and 44 (Calloway-Henry-Grenada-Calhoun), and 45 (Crowley-Stuttgart). However, the soil associations representing the largest acreage were 44, 45, 24 (Sharkey-Alligator-Tunica), and 22, which represented 15, 14, 10, and 7% of the total sampled acreage, respectively. Crop codes indicate that land used for i) row crop production accounted for 72% of the sampled acreage and 40% of submitted samples, ii) hay and pasture production accounted for 21% of the sampled acreage and 22% of submitted samples, and iii) home lawns and gardens accounted for 1% of the sampled acreage and 20% of submitted samples (Table 4).

Soil Test Data

Information in Tables 5, 6, 7, and 8 pertains to the fertility status of Arkansas soils as categorized by geographic area, county, SAN, and the crop intended for production in 2006, 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 realistic 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 counties (Table 6), SAN (Table 7), and last crop produced (Table 8).

Table 8 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’, ‘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., grasses and ornamental) excluding vegetable. Fertilizer consumption by county (Table 9) and by fertilizer nutrient and formulation (Table 10) illustrates the wide use of inorganic fertilizer predominantly in row-crop production areas, however, it does not account for the use of animal manures or other by-products as a source of nutrients that may be applied to the land.

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 2006 through 31 December 2006.

Geographic area	Acres sampled	No. of samples	Acres/ sample
Ozark Highlands - Cherty Limestone and Dolomite	153,490	13,911	11
Ozark Highlands - Sandstone and Limestone	6,102	391	16
Boston Mountains	31,881	2,923	11
Arkansas Valley and Ridges	71,227	6,203	12
Ouachita Mountains	40,381	4,813	8
Bottom Lands and Terraces	696,526	22,194	31
Coastal Plain	57,910	4,218	14
Loessial Plains	449,021	11,027	41
Loessial Hills	21,461	1,411	15
Blackland Prairie	4,885	316	16

PRACTICAL APPLICATION

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.

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Financial support for routine soil testing services offered to Arkansas citizens from the Arkansas Fertilizer Tonnage Fee is appreciated.

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 2006 through 31 December 2006.

County	Acres sampled	No. of samples	Acres/ sample	County	Acres sampled	No. of samples	Acres/ sample
Arkansas, DeWitt	91,618	2,002	46	Lee	113,597	1,617	70
Arkansas, Stuttgart	113,172	2,805	40	Lincoln	3,195	123	26
Ashley	17,621	648	27	Little River	11,964	307	39
Baxter	2,037	476	4	Logan, Booneville	1,107	111	10
Benton	34,822	4,862	7	Logan, Paris	6,002	336	18
Boone	17,777	678	26	Lonoke	79,399	2,018	39
Bradley	394	147	3	Madison	12,881	724	18
Calhoun	314	42	8	Marion	3,754	281	13
Carroll	18,174	841	22	Miller	5,774	472	12
Chicot	35,838	747	48	Mississippi	34,953	1,788	20
Clark	3,715	314	12	Monroe	60,275	982	61
Clay, Corning	18,103	1,242	15	Montgomery	6,070	342	18
Clay, Piggott	22,525	961	23	Nevada	1,277	91	14
Cleburne	6,180	401	15	Newton	4,404	157	28
Cleveland	6,549	255	26	Ouachita	500	161	3
Columbia	1,764	199	9	Perry	3,325	272	12
Conway	9,820	406	24	Phillips	18,854	495	38
Craighead	104,679	3,472	30	Pike	4,498	252	18
Crawford	6,695	436	15	Poinsett	72,503	1,399	52
Crittenden	36,325	910	40	Polk	9,200	483	19
Cross	76,646	1,591	48	Pope	11,942	795	15
Dallas	1,134	67	17	Prairie, Des Arc	12,687	293	43
Desha	22,220	1,186	19	Prairie, De Valls Bluff	9,939	238	42
Drew	2,467	221	11	Pulaski	8,267	1,958	4
Faulkner	6,482	595	11	Randolph	34,630	1,718	20
Franklin, Charleston	295	19	16	Saline	1,704	387	4
Franklin, Ozark	3,751	219	17	Scott	5,573	284	20
Fulton	7,550	227	33	Searcy	6,987	370	19
Garland	2,876	1,526	2	Sebastian	7,595	1,819	4
Grant	1,892	255	7	Sevier	8,022	293	27
Greene	30,592	1,426	22	Sharp	4,678	281	17
Hempstead	7,442	410	18	St. Francis	19,232	511	38
Hot Spring	5,015	296	17	Stone	2,461	245	10
Howard	6,598	381	17	Union	2,331	344	7
Independence	10,271	547	19	Van Buren	6,787	504	14
Izard	4,423	273	16	Washington	44,145	5,178	9
Jackson	34,971	3,980	9	White	15,248	1,771	9
Jefferson	49,947	1,528	33	Woodruff	15,906	575	28
Johnson	10,057	476	21	Yell, Danville	6,800	381	18
Lafayette	9,077	290	31	Yell, Dardanelle	7,074	283	25
Lawrence	54,617	1,498	37				

Table 3. Sample number and total acreage by soil association number (SAN) for soil samples submitted to the University of Arkansas Soil Testing and Research Laboratory in Marianna from 1 January 2006 through 31 December 2006.

SAN	Soil association	Acres sampled	No. of samples	Acres/ sample
1.	Clarksville-Nixa-Noark	27,220	1,247	22
2.	Gepp-Doniphan-Gassville-Agnos	17,285	1,080	16
3.	Arkana-Moko	23,034	1,170	20
4.	Captina-Nixa-Tonti	80,017	10,060	8
5.	Captina-Doniphan-Gepp	2,526	138	18
6.	Eden-Newnata-Moko	3,408	216	16
7.	Estate-Portia-Moko	960	110	9
8.	Brockwell-Boden-Portia	5,142	281	18
9.	Linker-Mountainburg-Sidon	9,525	805	12
10.	Enders-Nella-Mountainburg-Steprock	22,356	2,118	11
11.	Falkner-Wrightsville	609	23	27
12.	Leadvale-Taft	30,055	3,332	9
13.	Enders-Mountainburg-Nella-Steprock	8,369	385	22
14.	Spadra-Guthrie-Pickwick	3,640	203	18
15.	Linker-Mountainburg	28,554	2,260	13
16.	Carnasaw-Pirum-Clebit	15,488	2,705	6
17.	Kenn-Ceda-Avilla	5,462	323	17
18.	Carnasaw-Sherwood-Bismarck	12,533	1,347	9
19.	Carnasaw-Bismarck	1,772	79	22
20.	Leadvale-Taft	1,430	65	22
21.	Spadra-Pickwick	3,696	294	13
22.	Foley-Jackport-Crowley	115,677	6,910	17
23.	Kobel	75,683	1,353	56
24.	Sharkey-Alligator-Tunica	153,865	2,287	67
25.	Dundee-Bosket-Dubbs	106,122	3,457	31
26.	Amagon-Dundee	44,808	2,383	19
27.	Sharkey-Steele	19,832	442	45
28.	Commerce-Sharkey-Crevasse-Robinsonville	24,162	624	39
29.	Perry-Portland	34,945	1,179	30
30.	Crevasse-Bruno-Oklared	155	13	12
31.	Roxana-Dardanelle-Bruno-Roellen	4,009	145	28
32.	Rilla-Hebert	103,524	2,960	35
33.	Billyhaw-Perry	4,679	139	34
34.	Severn-Oklared	6,585	186	35
35.	Adaton	65	3	22
36.	Wrightsville-Louin-Acadia	2,292	90	26
37.	Muskogee-Wrightsville-McKamie	123	23	5
38.	Amy-Smithton-Pheba	4,609	194	24
39.	Darco-Briley-Smithdale	161	21	8
40.	Pheba-Amy-Savannah	2,706	208	13
41.	Smithdale-Sacul-Savannah-Saffell	15,451	1,428	11
42.	Sacul-Smithdale-Sawyer	26,266	1,968	13
43.	Guyton-Ouachita-Sardis	8,717	399	22
44.	Calloway-Henry-Grenada-Calhoun	231,899	5,994	39
45.	Crowley-Stuttgart	217,122	5,033	43
46.	Loring	3,979	228	18
47.	Loring-Memphis	16,913	1,154	15
48.	Brandon	569	29	20
49.	Oktibbeha-Sumter	4,885	316	16

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 2006 through 31 December 2006.

Crop	Acres sampled	No. of samples	Acres/ sample
Corn	42,967	995	43
Cotton	280,084	8,058	35
Grain sorghum, non-irrigated	2,647	87	30
Grain sorghum, irrigated	24,568	187	131
Rice	194,710	4,931	40
Soybean	576,677	13,496	43
Wheat	10,944	351	31
Cool-season grass for hay	71,296	3,197	22
Native warm-season grass for hay	9,976	514	19
Warm-season grass for hay	87,462	4,057	22
Pasture, all Categories	163,943	7,547	22
Home garden	4,403	3,411	1
Home lawn	10,707	10,060	1
Small fruit	893	691	1
Ornamental	3,461	1,983	2

Table 5. Soil test data by geographic area for soil samples submitted to the University of Arkansas Soil Testing and Research Laboratory in Marianna from 1 January 2006 through 31 December 2006.

	pH[z]						P[y] (lb/acre)						K[y] (lb/acre)						Zn[y] (lb/acre)					
Geographic area	<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
	----------(Percentage of sampled acreage)----------																							
Ozark Highlands - Cherty Limestone and Dolomite	26	18	21	21	14	5.9	4	7	7	11	71	90	4	10	18	19	49	173	1	9	9	30	51	8.3
Ozark Highlands - Sandstone and Limestone	23	27	24	20	6	5.8	11	10	8	13	58	59	5	17	25	18	35	136	6	22	15	28	29	4.5
Boston Mountains	42	20	19	15	4	5.5	7	10	8	10	65	78	12	16	22	17	33	130	4	16	11	31	38	6.3
Arkansas Valley and Ridges	41	19	17	15	8	5.5	10	11	9	12	58	67	10	16	23	19	32	133	3	12	9	28	48	7.5
Ouachita Mountains	44	21	17	13	5	5.5	7	9	9	11	64	78	14	20	24	17	25	116	1	11	10	32	46	7.2
Bottom Lands and Terraces	19	18	27	26	10	6.0	7	13	15	21	44	47	5	13	23	20	39	150	3	21	18	42	16	4.5
Coastal Plain	49	18	16	11	6	5.4	13	10	9	10	58	68	19	19	20	15	27	114	6	18	10	26	40	6.2
Loessial Plains	17	13	21	26	23	6.2	12	23	21	19	25	32	5	23	33	17	22	115	5	26	17	35	17	4.2
Loessial Hills	30	18	21	20	11	5.8	13	19	14	13	41	40	7	17	25	21	30	134	3	21	15	35	26	5.0
Blackland Prairie	39	15	17	13	16	5.6	10	16	11	13	50	52	14	11	18	21	36	143	2	22	18	21	37	4.7
Average	33	19	20	18	10	5.7	9	13	11	13	54	61	10	16	23	18	33	134	3	18	13	31	35	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.

Table 6. Soil test data by county for soil samples submitted to the University of Arkansas Soil Testing and Research Laboratory in Marianna from 1 January 2006 through 31 December 2006.

	pH^z						P^y (lb/acre)						K^y (lb/acre)						Zn^y (lb/acre)					
County	<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
	(Percentage of sampled acreage)																							
Arkansas, DeWitt	9	8	16	27	40	6.7	13	34	26	17	10	27	3	27	40	16	14	108	3	19	15	47	16	4.8
Arkansas, Stuttgart	21	17	26	22	14	6.0	13	22	22	20	23	32	2	16	37	17	28	124	7	26	17	36	14	4.0
Ashley	14	10	22	35	19	6.4	8	9	7	15	61	58	9	14	20	25	32	143	7	35	17	29	12	3.6
Baxter	13	9	12	18	48	6.9	4	10	10	12	64	80	3	8	22	21	46	165	1	10	6	19	64	11.6
Benton	33	18	20	19	10	5.7	4	4	6	11	75	102	3	10	16	18	53	184	1	7	7	30	55	9.1
Boone	17	19	24	24	16	6.0	4	8	7	10	71	86	6	12	15	16	51	178	2	9	10	32	47	7.6
Bradley	35	10	24	20	11	5.9	8	6	7	8	71	124	20	15	15	12	38	129	5	11	5	26	53	9.6
Calhoun	67	14	19	0	0	5.1	14	14	7	14	51	47	29	19	24	21	7	98	17	24	0	24	35	5.0
Carroll	19	26	32	15	8	5.8	2	6	6	5	81	156	3	8	11	11	67	251	0	5	5	20	70	13.6
Chicot	11	12	24	33	20	6.3	5	15	16	20	44	45	7	10	12	13	58	221	3	16	15	34	32	5.4
Clark	59	17	9	9	6	5.1	9	21	14	17	39	40	25	20	19	14	22	101	8	29	18	23	22	3.7
Clay, Corning	26	28	27	15	4	5.7	11	21	21	23	24	34	9	28	39	18	6	101	2	19	16	43	20	4.8
Clay, Piggott	22	23	32	21	2	5.8	6	10	12	19	53	53	2	9	23	28	38	154	4	24	20	41	11	4.2
Cleburne	35	24	22	15	4	5.6	5	9	6	11	69	73	11	15	23	20	31	132	2	19	11	26	42	6.4
Cleveland	31	17	19	19	14	5.8	13	16	20	11	40	36	6	9	14	17	54	193	1	23	19	31	26	4.5
Columbia	51	17	17	10	5	5.3	14	6	6	10	64	79	21	30	24	14	11	89	4	20	8	30	38	5.8
Conway	50	19	14	11	6	5.4	16	11	11	11	51	53	17	19	20	13	31	113	13	20	12	21	34	4.9
Craighead	15	15	24	27	19	6.2	12	18	14	17	39	40	9	17	23	17	34	131	3	17	15	42	23	5.0
Crawford	28	17	20	25	10	5.9	5	7	8	9	71	89	6	12	20	18	44	161	1	9	10	32	48	7.8
Crittenden	15	19	31	27	8	6.0	1	6	15	29	49	50	0	1	10	25	64	203	1	19	22	49	9	4.4
Cross	9	9	20	31	31	6.5	12	23	24	23	18	31	9	22	25	11	33	117	4	24	16	40	16	4.5
Dallas	68	18	9	3	2	5.1	17	15	12	15	41	40	66	15	12	8	0	48	4	32	16	25	23	3.9
Desha	7	8	23	42	20	6.4	5	10	15	24	46	49	2	7	20	19	52	192	4	22	21	41	12	4.2
Drew	67	8	11	10	4	4.7	49	9	4	6	32	16	27	21	24	10	18	93	3	18	10	33	36	6.0
Faulkner	44	15	17	17	7	5.5	15	16	11	11	47	45	14	21	23	16	26	116	4	25	15	27	29	4.6
Franklin, Charleston	68	5	0	16	11	5.0	26	11	0	11	52	51	16	26	21	16	21	101	0	21	5	21	53	13.4
Franklin, Ozark	42	29	14	12	3	5.5	7	6	7	9	71	118	7	17	17	16	43	149	0	5	11	22	62	10.8
Fulton	38	30	16	10	6	5.5	13	18	15	16	38	38	11	19	29	22	19	115	13	26	16	23	22	3.7
Garland	38	21	19	15	7	5.6	4	8	10	14	64	72	12	22	24	17	25	116	1	8	10	36	45	7.3
Grant	66	17	10	6	1	5.1	20	13	11	15	41	39	23	28	19	16	14	89	6	36	9	26	23	4.0
Greene	33	21	24	15	7	5.7	13	24	21	18	24	32	12	21	29	21	17	115	4	31	23	31	11	3.7
Hempstead	34	25	18	15	8	5.6	6	7	6	7	74	120	10	14	20	17	39	143	3	11	7	21	58	10.6
Hot Spring	44	18	19	14	5	5.5	7	12	8	12	61	77	22	16	16	16	30	122	3	15	8	37	37	6.3
Howard	45	22	17	6	10	5.5	5	5	4	8	78	156	14	12	14	16	44	159	2	7	5	19	67	12.1
Independence	26	17	25	23	9	5.9	7	12	13	14	54	54	7	13	22	18	40	150	2	23	15	26	34	5.0
Izard	37	23	18	11	11	5.6	10	15	6	10	59	64	10	23	28	15	24	117	2	18	15	33	32	5.7
Jackson	30	22	25	19	4	5.7	5	14	17	21	43	46	7	19	32	20	22	119	4	22	18	35	21	4.5
Jefferson	22	14	23	30	11	6.1	4	9	12	26	49	50	4	11	23	23	39	153	4	26	20	33	17	4.0
Johnson	41	22	18	14	5	5.5	10	9	7	11	63	75	10	17	18	17	38	147	2	11	10	26	51	8.1
Lafayette	31	26	13	12	18	5.7	4	7	11	16	62	64	4	9	11	17	59	208	6	26	15	23	30	4.2
Lawrence	16	21	33	24	6	5.9	18	23	19	19	21	30	5	18	26	21	30	131	3	18	18	43	18	4.7
Lee	14	10	24	38	14	6.3	4	7	14	27	48	50	2	11	27	26	34	149	8	40	19	27	6	3.1
Lincoln	36	24	19	13	8	5.6	11	11	11	19	48	50	9	10	22	19	40	153	2	16	7	37	38	5.6
Little River	33	13	12	11	31	5.9	10	15	10	11	54	54	9	13	17	18	43	153	4	17	15	31	33	5.4

continued

Table 6. Continued.

	pH^z						P^y (lb/acre)						K^y (lb/acre)						Zn^y (lb/acre)					
County	<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
	(Percentage of sampled acreage)																							
Logan, Booneville	41	13	17	9	20	5.6	25	9	7	7	52	70	11	22	17	13	37	130	6	12	7	30	45	6.6
Logan, Paris	46	33	16	4	1	5.4	6	8	7	12	67	77	20	16	18	12	34	120	1	8	8	30	53	8.5
Lonoke	28	18	28	21	5	5.8	10	18	17	21	34	39	5	18	29	18	30	126	10	36	17	27	10	3.3
Madison	38	25	21	14	2	5.5	3	5	4	8	80	130	8	11	16	15	50	173	0	9	9	28	54	8.7
Marion	14	21	24	24	17	6.1	5	9	11	15	60	65	3	11	16	24	46	163	4	14	15	28	39	6.0
Miller	49	19	14	10	8	5.4	11	11	14	13	51	51	17	16	23	17	27	120	4	16	12	30	28	5.9
Mississippi	17	19	28	27	9	6.0	0	1	4	15	80	72	0	1	5	18	76	225	0	4	11	59	26	6.0
Monroe	7	14	27	34	18	6.3	16	24	16	19	25	31	5	23	35	18	19	112	2	26	23	39	10	4.0
Montgomery	39	21	20	18	2	5.5	3	6	7	9	75	135	15	17	19	17	32	115	1	14	10	30	45	6.9
Nevada	51	21	16	7	5	5.3	18	19	11	7	45	42	13	19	28	18	22	113	6	20	16	23	35	4.9
Newton	29	23	25	15	8	5.7	5	9	10	12	64	71	7	13	24	12	44	156	1	22	15	33	29	5.2
Ouachita	62	16	12	8	2	5.1	21	4	5	9	61	88	28	26	21	13	12	84	5	17	12	23	43	6.4
Perry	50	21	15	8	6	5.3	10	15	12	13	50	48	11	29	21	7	32	102	3	14	17	37	29	5.1
Phillips	14	14	27	26	19	6.1	2	6	9	22	61	56	2	7	15	26	50	174	3	27	27	31	12	3.8
Pike	57	25	11	6	1	5.2	11	6	3	5	75	125	23	25	21	12	19	94	7	19	11	25	38	6.0
Poinsett	8	8	20	33	31	6.5	10	18	16	17	39	41	5	20	32	16	27	121	1	15	14	43	27	5.4
Polk	65	15	10	8	2	5.1	4	8	7	10	71	96	21	21	16	16	26	108	3	16	10	29	42	6.8
Pope	40	19	22	14	5	5.6	8	10	6	9	67	91	11	16	18	17	38	142	3	13	10	26	48	7.7
Prairie, Des Arc	20	15	20	31	14	6.1	19	32	22	11	16	25	9	36	36	14	5	95	4	15	21	37	23	4.7
Prairie, De Valls Bluff	33	15	19	21	12	5.8	14	29	21	9	27	28	8	25	23	19	25	112	3	28	18	31	20	4.2
Pulaski	38	16	17	16	13	5.6	9	10	10	11	40	71	10	18	30	20	22	120	2	12	10	30	46	6.8
Randolph	21	19	26	26	8	5.9	23	22	17	15	23	28	9	20	29	16	26	117	3	26	20	34	17	4.2
Saline	42	18	17	12	11	5.5	8	9	11	12	60	72	18	19	20	18	25	113	2	13	13	30	42	6.3
Scott	48	21	13	14	4	5.4	31	12	6	9	42	39	34	17	16	10	23	85	8	23	10	26	33	5.0
Searcy	47	17	15	15	6	5.4	5	8	10	15	62	63	8	19	31	18	24	119	2	27	22	33	16	4.0
Sebastian	39	16	15	18	12	5.6	8	11	11	14	56	58	4	14	29	25	28	136	0	6	8	30	56	9.3
Sevier	63	18	14	5	0	5.2	10	10	5	6	69	127	24	14	18	10	34	117	3	13	8	27	49	8.0
Sharp	22	24	26	16	12	5.8	9	13	9	9	60	67	5	14	26	17	38	140	7	20	12	30	31	5.0
St. Francis	24	13	17	25	21	6.2	9	15	16	21	39	42	4	17	26	21	32	134	6	27	18	30	19	4.0
Stone	39	18	16	16	11	5.6	6	9	6	12	67	70	9	17	26	20	28	128	2	14	9	36	39	6.1
Union	47	19	19	12	3	5.4	15	5	7	7	66	92	26	26	19	11	18	87	7	11	9	20	53	8.9
Van Buren	47	25	16	9	3	5.4	12	12	9	12	55	60	15	20	20	14	31	119	10	23	13	26	28	4.5
Washington	19	16	20	26	19	6.1	4	7	8	11	70	88	4	8	18	22	48	171	1	7	8	33	51	8.4
White	39	18	23	17	3	5.6	9	13	13	12	53	53	14	18	24	18	26	121	7	19	14	29	31	5.2
Woodruff	19	14	20	25	22	6.2	19	20	15	22	24	33	5	19	37	26	13	118	5	18	14	36	27	4.9
Yell, Danville	49	33	13	5	0	5.4	10	9	8	11	62	79	10	19	20	18	33	133	0	9	8	34	45	8.0
Yell, Dardanelle	55	17	13	10	5	5.2	17	12	6	9	56	69	6	21	16	14	43	153	4	12	9	25	51	8.1
Average	35	18	19	17	11	5.7	11	12	11	14	52	64	12	17	22	17	32	134	4	18	13	31	34	6.1

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

[y] Analysis by ICAP in 1:7 soil weight:Mehlich-3 volume.

Table 7. Soil test data by soil association number (SAN) for soil samples submitted to the University of Arkansas Soil Testing and Research Laboratory in Marianna from 1 January 2006 through 31 December 2006.

		pH^z						P^y (lb/acre)						K^y (lb/acre)						Zn^y (lb/acre)					
SAN	Soil association	<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
		(Percentage of sampled acreage)																							
1.	Clarksville-Nixa-Noark	21	20	27	23	9	5.9	3	7	7	13	70	76	7	13	17	16	47	165	1	15	14	33	37	6.0
2.	Gepp-Doniphan-Gassville-Agnos	22	16	16	17	29	6.1	9	15	12	13	51	53	6	14	26	21	33	139	4	15	11	26	44	6.8
3.	Arkana-Moko	24	24	29	14	9	5.8	4	7	7	7	75	132	4	11	16	13	56	201	1	9	8	23	59	11.0
4.	Captina-Nixa-Tonti	26	17	20	23	14	5.9	4	6	7	11	72	94	3	9	17	20	51	176	1	7	7	31	54	8.7
5.	Captina-Doniphan-Gepp	22	17	28	20	13	6.0	12	11	14	12	51	52	3	21	17	22	37	144	6	17	15	31	31	5.1
6.	Eden-Newnata-Moko	51	16	16	13	4	5.3	5	11	9	10	65	72	9	13	32	19	27	125	2	26	23	30	19	4.0
7.	Estate-Portia-Moko	13	33	20	26	8	5.8	1	7	12	19	61	63	6	7	13	21	53	180	4	22	20	26	28	4.1
8.	Brockwell-Boden-Portia	27	24	26	17	6	5.7	15	11	7	10	57	57	4	20	29	17	30	123	7	22	13	28	30	4.7
9.	Linker- Mountainburg-Sidon	48	19	15	13	5	5.4	12	13	11	9	55	59	14	18	22	16	30	124	6	23	13	25	33	5.0
10.	Enders-Nella-Mountainburg-Steprock	40	20	20	16	4	5.5	6	9	7	10	68	83	11	16	23	18	32	131	3	13	11	34	39	6.5
11.	Falkner-Wrightsville	30	35	22	9	4	5.6	9	4	9	4	74	118	4	9	17	17	53	187	0	4	4	17	75	14.2
12.	Leadvale-Taft	42	17	16	16	9	5.5	9	11	10	13	57	61	7	16	25	21	31	136	2	10	9	29	50	8.1
13.	Enders-Mountainburg-Nella-Steprock	52	20	14	10	4	5.3	32	14	9	10	35	29	35	19	21	8	17	84	14	26	13	28	19	3.9
14.	Spadra-Guthrie-Pickwick	44	30	15	7	4	5.4	14	12	7	11	56	65	15	16	20	20	29	129	4	13	8	37	38	6.5
15.	Linker-Mountainburg	40	19	20	14	7	5.6	8	10	8	10	64	84	10	17	20	19	34	139	3	13	10	27	47	7.4
16.	Carnasaw-Pirum-Clebit	42	19	17	14	8	5.5	7	9	10	11	63	75	12	19	26	19	24	118	1	11	10	33	45	7.1
17.	Kenn-Ceda-Avilla	54	24	13	7	2	5.3	8	9	10	12	61	65	24	18	14	13	31	115	2	15	12	31	40	6.4
18.	Carnasaw-Sherwood-Bismarck	45	21	17	14	3	5.4	5	9	8	10	68	96	14	23	23	15	25	113	1	10	9	31	49	7.9
19.	Carnasaw-Bismarck	42	27	15	8	8	5.5	0	3	5	15	77	110	11	15	17	25	32	143	0	3	5	29	63	9.7
20.	Leadvale-Taft	45	39	14	3	0	5.4	14	8	2	12	64	4	12	22	25	15	26	119	0	20	9	28	43	7.2
21.	Spadra-Pickwick	50	21	16	8	5	5.3	11	17	11	13	48	46	13	28	20	7	32	102	3	14	17	35	31	5.1
22.	Foley-Jackport-Crowley	27	22	26	20	5	5.8	13	21	19	20	27	33	9	23	34	19	15	110	4	26	18	35	17	4.2
23.	Kobel	12	19	32	27	10	6.0	9	21	19	21	30	36	4	17	33	21	25	125	2	21	22	42	13	4.3
24.	Sharkey-Alligator-Tunica	17	14	27	28	14	6.1	1	9	15	27	48	49	1	4	11	15	69	253	2	16	17	50	15	4.9
25.	Dundee-Bosket-Dubbs	14	17	32	28	9	6.0	3	9	11	19	58	57	3	9	22	23	43	163	2	18	19	47	14	4.6
26.	Amagon-Dundee	18	21	30	26	5	5.9	3	8	7	15	67	64	1	7	15	21	56	185	0	9	16	56	19	5.3
27.	Sharkey-Steele	16	21	23	29	11	6.0	2	3	9	26	60	57	1	2	4	16	77	233	1	3	10	67	19	5.6
28.	Commerce-Sharkey-Crevasse-Robinsonville	10	13	25	34	18	6.3	3	8	14	18	57	58	7	11	11	13	58	199	3	9	14	49	25	5.5
29.	Perry-Portland	15	12	25	33	15	6.2	8	13	17	21	41	45	4	6	13	15	62	213	4	27	19	34	16	4.1
30.	Crevasse-Bruno-Oklared	23	8	39	31	0	6.0	0	0	15	15	70	65	0	8	8	15	69	262	8	0	0	31	61	12.0
31.	Roxana-Dardanelle-Bruno-Roellen	32	19	20	21	8	5.7	26	17	6	17	34	39	15	15	21	12	37	129	16	22	16	18	28	3.8
32.	Rilla-Hebert	14	13	26	35	12	6.2	2	8	13	25	52	51	2	10	25	25	38	154	5	31	20	24	10	3.7
33.	Billyhaw-Perry	20	17	14	22	27	6.2	7	14	19	25	35	42	2	3	9	9	77	289	4	29	27	28	12	3.5
34.	Severn-Oklared	25	18	12	8	37	6.0	3	7	8	13	69	67	9	11	13	18	49	173	7	16	10	40	27	5.3
35.	Adaton	67	33	0	0	0	5.3	0	67	33	0	0	25	0	33	0	0	67	202	0	33	0	67	0	5.0

continued

Table 7. Continued.

		pH^z						P^y (lb/acre)						K^y (lb/acre)						Zn^y (lb/acre)					
SAN	Soil association	<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
		(Percentage of sampled acreage)																							
36.	Wrightsville-Louin-Acadia	43	29	10	7	11	5.4	8	8	12	8	64	74	8	20	19	22	31	135	4	16	12	12	56	10.0
37.	Muskogee-Wrightsville-McKamie	35	22	26	13	4	5.7	26	9	4	4	57	99	4	13	22	22	39	147	0	9	17	13	61	9.7
38.	Amy-Smithton-Pheba	60	16	11	6	7	5.2	17	14	11	12	46	44	27	24	16	12	21	89	9	27	8	22	34	4.8
39.	Darco-Briley-Smithdale	29	24	19	14	14	5.7	5	0	10	10	75	108	5	10	33	14	38	162	0	5	10	19	66	13.0
40.	Pheba-Amy-Savannah	54	15	12	13	6	5.3	23	9	6	12	50	51	21	16	23	19	21	112	8	22	8	19	43	6.0
41.	Smithdale-Sacul-Savannah-Saffell	48	18	18	11	5	5.4	11	7	6	9	67	91	21	17	21	14	27	111	6	15	9	25	45	6.8
42.	Sacul-Smithdale-Sawyer	46	20	15	12	7	5.4	12	12	11	11	54	56	16	20	20	16	28	118	5	18	12	28	37	5.7
43.	Guyton-Ouachita-Sardis	60	17	15	8	0	5.2	16	14	8	8	54	67	22	20	20	11	27	103	6	20	10	25	39	6.2
44.	Calloway-Henry-Grenada-Calhoun	17	12	20	29	22	6.3	11	21	19	19	30	35	7	24	29	18	22	114	5	28	19	31	17	4.0
45.	Crowley-Stuttgart	17	14	23	24	22	6.2	13	27	23	18	19	29	3	22	39	16	20	115	5	24	16	40	15	4.3
46.	Loring	31	23	28	12	6	5.7	13	32	19	11	25	29	11	23	29	17	20	110	4	26	15	33	22	4.7
47.	Loring-Memphis	30	17	20	22	11	5.8	13	16	12	13	46	45	5	16	24	22	33	141	2	19	15	36	28	5.1
48.	Brandon	24	28	28	21	0	5.7	17	17	48	7	11	31	28	14	31	10	17	110	0	45	10	35	10	3.5
49.	Oktibbeha-Sumter	40	15	17	13	15	5.6	10	16	11	14	49	48	15	11	18	22	34	142	2	23	18	21	36	4.7
	Average	33	20	20	17	10	5.7	10	13	12	13	52	62	10	15	21	17	37	149	4	18	13	32	33	6.4

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

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

Table 8. Soil-test median (Md) values and percentage distribution for selected ranges by crop for soil samples submitted to the University of Arkansas Soil Testing and Research Laboratory in Marianna from 1 January 2006 through 31 December 2006.

	pH[y]						P[x] (lb/acre)						K[x] (lb/acre)						Zn[x] (lb/acre)					
Crop[z]	<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
	(Percentage of sampled acreage)																							
Corn	15	19	29	26	11	6.0	1	9	15	27	48	49	2	10	26	24	38	149	3	24	18	37	18	4.3
Cotton	13	16	31	31	9	6.1	1	3	7	18	71	65	1	3	13	25	58	188	3	21	19	46	11	4.4
Grain sorghum NI	44	26	13	10	7	5.4	5	16	31	17	31	34	14	21	28	13	24	109	7	35	22	24	12	3.5
Grain sorghum I	19	26	28	19	8	5.8	10	20	17	21	32	38	4	14	30	19	33	134	6	25	23	38	8	3.8
Rice	13	14	25	29	19	6.2	18	26	22	21	13	28	6	18	26	15	35	131	3	22	20	40	15	4.3
Soybean	17	16	23	26	18	6.1	11	24	23	22	20	32	5	22	34	17	22	114	5	25	19	38	13	4.1
Wheat	43	20	18	12	7	5.5	7	15	15	20	43	44	5	17	30	25	23	128	5	28	18	36	13	4.0
CS grass hay	34	25	25	14	2	5.6	3	6	5	9	77	130	7	13	18	15	47	161	1	9	7	21	62	11.5
NWS grass hay	59	20	13	5	3	5.2	24	17	11	12	36	34	20	24	26	12	18	99	4	27	13	31	25	4.6
WS grass hay	41	24	19	13	3	5.5	7	9	8	10	66	85	15	18	18	15	34	130	4	15	10	26	45	7.2
Pasture all	41	25	20	11	3	5.5	9	10	8	10	63	76	12	16	19	16	37	138	4	16	11	28	41	6.5
Home garden	18	12	16	26	28	6.4	4	4	4	6	82	169	4	9	14	16	57	200	1	7	6	18	68	14.1
Home lawn	35	15	17	20	13	5.8	5	9	11	15	60	65	4	13	24	24	35	147	1	9	10	39	41	7.0
Small fruit	64	11	7	11	7	5.0	12	12	11	11	54	61	14	20	28	17	21	114	5	26	15	26	28	4.5
Ornamental	21	11	16	26	26	6.3	6	7	7	8	72	106	7	15	24	17	37	138	1	5	4	21	69	13.1
Average	32	19	20	19	10	5.8	8	13	13	15	51	68	8	16	24	18	34	139	4	20	14	31	31	6.8

[z] NI = non-irrigated; I = irrigated; CS = cool-season; NWS = native warm-season; WS = warm-season, and All = All categories.

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

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

Table 9. Fertilizer consumption in Arkansas counties from 1 July 2006 through 30 June 2007^z.

County	Total	County	Total
	(tons)		(tons)
Arkansas	75,833	Lee	28,915
Arkansas	95,341	Lee	21,855
Ashley	20,283	Lincoln	13,998
Baxter	1,771	Little River	9,081
Benton	21,595	Logan	3,301
Boone	4,996	Lonoke	51,425
Bradley	2,243	Madison	4,540
Calhoun	223	Marion	1,973
Carroll	2,827	Miller	8,481
Chicot	35,945	Mississippi	86,923
Clark	1,792	Monroe	33,902
Clay	49,133	Montgomery	329
Cleburne	2,997	Nevada	4,411
Cleveland	314	Newton	1,223
Columbia	2,158	Ouachita	582
Conway	7,097	Perry	1,145
Craighead	57,738	Phillips	90,114
Crawford	6,288	Pike	2,788
Crittenden	27,993	Poinsett	79,664
Cross	41,677	Polk	1,286
Dallas	2,678	Pope	2,641
Desha	42,322	Prairie	30,443
Drew	10,991	Pulaski	10,999
Faulkner	5,461	Randolph	21,563
Franklin	2,892	Saline	2,668
Fulton	2,090	Scott	891
Garland	1,216	Searcy	2,131
Grant	703	Sebastian	2,461
Greene	33,808	Sevier	1,399
Hempstead	4,573	Sharp	910
Hot Spring	2,110	St. Francis	64,205
Howard	1,793	Stone	2,396
Independence	13,318	Union	5,912
Izard	2,564	Van Buren	9,228
Jackson	28,790	Washington	5,791
Jefferson	35,917	White	32,881
Johnson	1,660	Woodruff	39,591
Lafayette	8,921	Yell	1,582
Lawrence	25,181		

[z] Arkansas Distribution of Fertilizer Sales by County July 1, 2006 to June 30, 2007, Arkansas State Plant Board, Division of Feed and Fertilizer, Little Rock, Ark., and University of Arkansas AES, Fayetteville, Ark.

Table 10. Fertilizer nutrient and formulation consumed in Arkansas from 1 July 2006 through 30 June 2007^z.

Fertilizer	Bulk	Bagged	Fluid	Totals
	----------	---------- (tons)	----------	----------
Mixed	413,898	44,891	28,923	487,712
Nitrogen	528,538	3,176	135,148	666,862
Phosphate	956	2	0	958
Potash	74,340	335	4	74,679
Other	31,909	1,550	436	33,895
Totals	1,049,641	49,954	164,511	1,264,106

[z] Arkansas Distribution of Fertilizer Sales By Counties 1 July 2006-30 June 2007, Arkansas State Plant Board, Division of Feed and Fertilizer, Little Rock, Ark., and University of Arkansas Agricultural Experiment Station, Fayetteville, Ark.

Yield Response of Canola to Varying Nitrogen Rates

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

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Canola *(Brassica napus* L.) is a relatively new crop in Arkansas. There is an increased interest in canola production due to its potential use for biofuel production. Previous research conducted in states where canola is traditionally produced has shown that the nutritional requirements of canola are similar to those of wheat, with the exception that canola may require larger amounts of nitrogen (N) and sulfur (S), and may grow better at higher soil pH than wheat to maximize yield (Harris, 2007). The objective of this study was to assess the yield response of three canola varieties to varying N rates.

PROCEDURES

A study consisting of three canola varieties and six N-fertilizer rates was established at the Lon Mann Cotton Branch Station (LMCBS) near Marianna, on a soil mapped as a Memphis silt loam. Soil samples were collected at the 0- to 6- and 6- to 12-inch depths prior to planting and were extracted using the Mehlich-3 procedure. Nitrate-N was analyzed with an ion-selective electrode and pH was determined in a 1:2 soil: water mixture (Table 1). Soil phosphorus and potassium levels were considered 'Optimum' for winter wheat and therefore were not applied. Sulfur (90% elemental sulfur) was applied at a rate of 25 lb S/acre. Canola varieties Summer, Wichita, and AR377 were seeded at the rate of 7 lb/acre on a field previously cropped to wheat. Canola was seeded in 7.5-inch wide rows on 23 October 2006 with a research plot drill (Hege-Wintersteiger, Colwich, Kan.) equipped with a seed distributor.

Ammonium nitrate was applied at rates equivalent to 0, 40, 80, 120, 160, and 200 lb N/acre. Fertilizer was applied in a 2-way split, except for the 40 and 80 lb N/acre treatments. which received a single application. The first N application (50% of the total rate) was done on 26 January with the remainder applied on 15 February 2007. Treatments were replicated five times and were arranged as a randomized complete block design with plots being 5-ft wide by 25-ft long. The height of five plants in each plot was measured at the pod-fill stage (150 days after planting). Plots were harvested with a plot combine equipped with a weigh-system and moisture meter. Percent relative yields for all varieties were calculated, with a regression model fit to the data. The N rate at which 95% of relative yield intercepted the regression line was used to identify the fertilizer rate at which yields were maximized.

The experiment was a randomized complete block design with a 3 (canola varieties) × 6 (N rates) factorial treatment arrangement. The PROC GLM procedure of SAS (SAS Institute, Inc., Cary, N.C.) was used for analysis of variance and the Fisher's Protected Least Significance Difference method at a significance level of 0.10 was used to test differences among treatments.

RESULTS AND DISCUSSION

The variety by N-rate interaction was not significant during the first year of this study. Yield differences among varieties, averaged across N rates, were not statistically different at the 0.10 probability level. Canola variety Wichita showed a positive linear response to N rate, and produced the highest numerical yields. Yield response for the other varieties appeared non-linear and tended to peak at 160 lb N/acre (Fig. 1). There was no lodging at any N rate applied in this study, which is always a concern in canola production. Percent relative yields for all varieties were calculated, and a regression model was fit to the resultant data (Fig. 2). The N rate at which 95% of relative yield intercepted the regression line (optimum yield) was 150 lb N/acre. There was a trend (non-significant) for average plant height to increase with N rate up to 120 lb N/acre. Average plant height for variety AR377 was greater than the other varieties at all N rates (Fig. 3), but it was not correlated to yield response as Wichita was the highest yielding variety in this study.

PRACTICAL APPLICATION

Preliminary results suggest that canola yields were maximized by application of 150 lb N/acre when averaged across varieties. The yield response of canola variety Wichita appeared to be linear, with yields increasing with increasing N rate. More data are necessary to characterize canola varietal response to N fertilization and develop N fertilizer recommendations for this crop.

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Table 1. Selected soil chemical properties before N-fertilizer treatment application to canola at the Lon Mann Cotton Branch Experiment Station.

Soil depth	Soil pH	Soil NO_3-N	P	K	Ca	SO_4-S
(inches)		---------------------(ppm)------------------------				
0-6	6.1	11	44	210	1176	16
6-12	5.8	9	39	190	1267	14

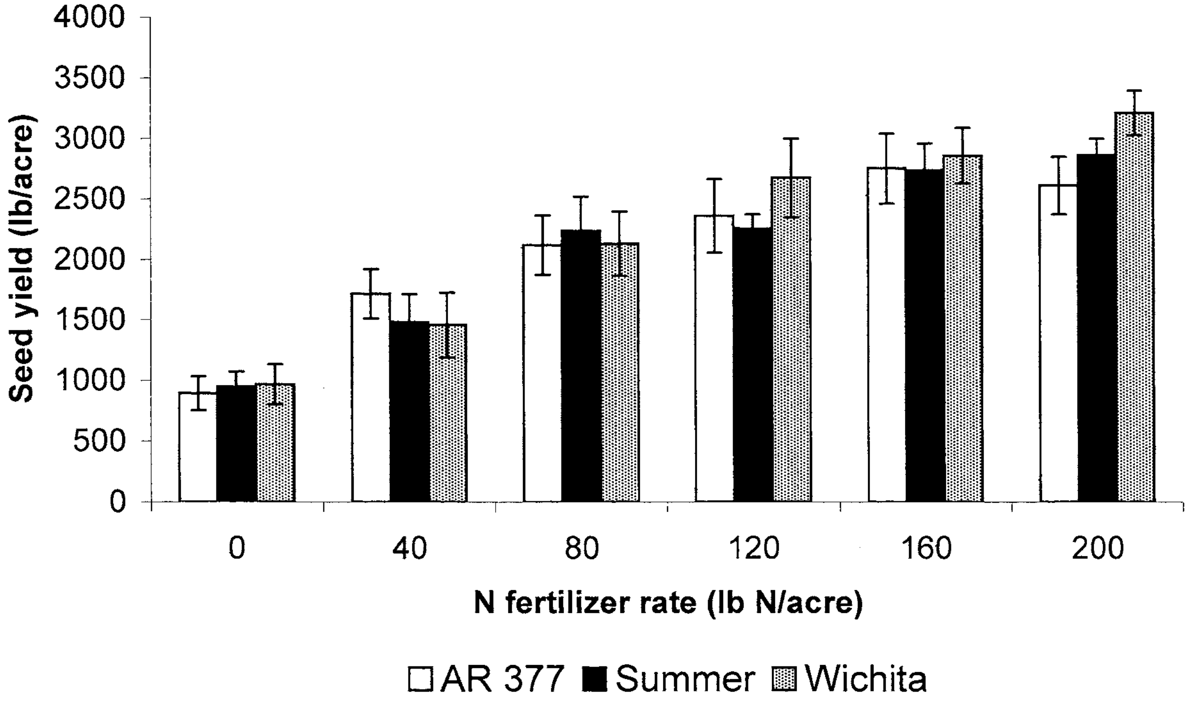

Fig. 1. Average yield response of three canola varieties grown under varying N rates. Bars represent ± one standard deviation.

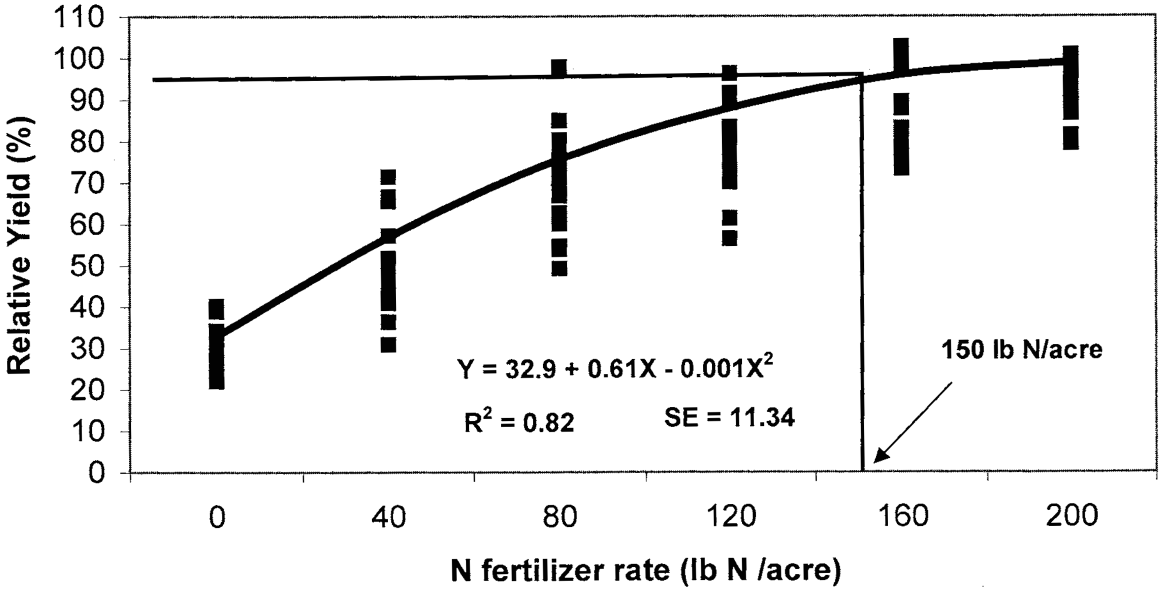

Fig. 2. Percent relative yield of three canola varieties grown under varying N rates.

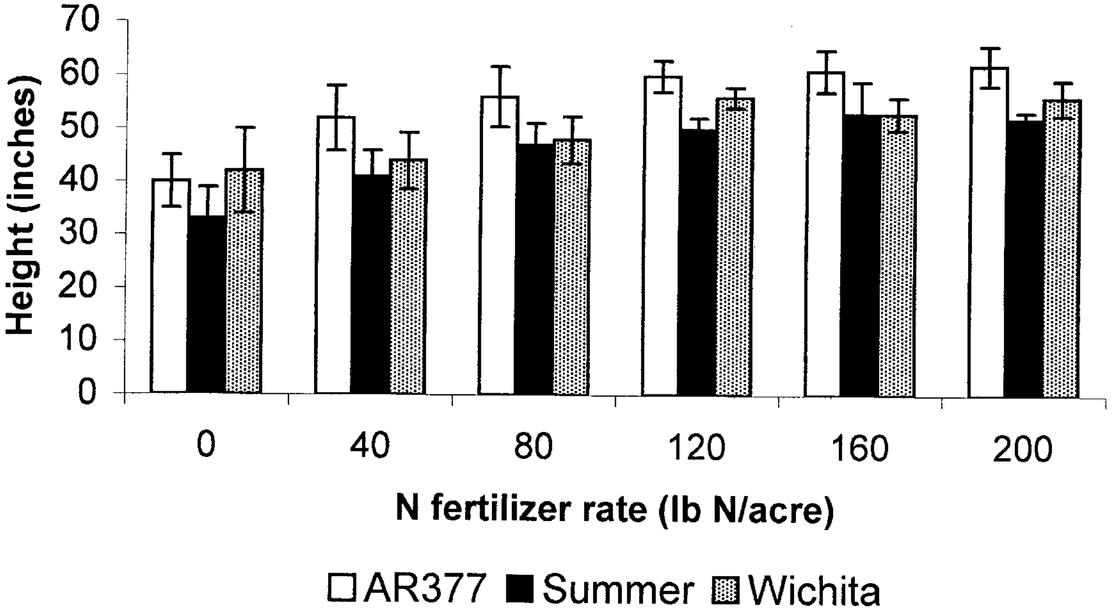

Fig. 3. Average plant height and associated standard deviations for three canola varieties grown under varying N rates.

Enhancement of Early Loblolly Pine Production Through Inorganic Fertilizer and Pelletized Poultry Litter Application

H.O. Liechty, R.L. Ficklin, and C. Stuhlinger

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Nitrogen and phosphorus (P) inorganic fertilizers are commonly applied to loblolly pine stands in the southern United States to increase wood and fiber production. Fertilization of newly established plantations accounts for approximately 20% of the 1.3 million acres of southern pine fertilized annually (Dickens et al., 2003) in the United States. It is expected that the area of pine plantations in Arkansas will increase from 800,000 to 1,600,000 acres by 2040 (Prestemon and Abt, 2002) and thus increase the number of acres and sites that need to be fertilized at or soon after plantation establishment. Currently there are no well established P-fertilizer recommendations for young loblolly pine plantations based on Mehlich-3 extractable P. This lack of data could limit the ability of land managers to maximize the growth of these young plantations.

Nutrient deficiencies of loblolly pine stands are almost exclusively ameliorated with inorganic fertilizers. Poultry litter, which is commonly used in Arkansas to increase forage production, has also been shown to increase yields of crops such as cotton (Nyakatawa et al., 2000; Mozaffari et al., 2005a) and wheat (Mozaffari et al., 2005b). Few studies have evaluated whether poultry litter additions can increase loblolly pine growth. Given that Arkansas produces more than 1.2 million tons of poultry litter annually (Reiter et al., 2004), the application of poultry litter to pine plantations could be an economically attractive method of increasing timber yields. Consequently, this study will provide landowners and forest managers with information to evaluate the potential for increasing pine production through the addition of common inorganic fertilizers and/or poultry litter. The specific objectives of this study are to quantify the effects of different rates of N and P additions on early loblolly pine growth in soils with inherently different levels of soil-P availability, to determine if soil P guidelines developed in other areas of the southern U.S. provide accurate fertilizer recommendations for soils commonly planted to loblolly pine in Arkansas, and to compare loblolly pine growth responses from the addition of N and P as pelletized poultry litter to those obtained with additions of inorganic fertilizer.

PROCEDURES

This study is being conducted at five locations in Arkansas. Research sites were located at the Pine Tree Branch Station (PTBS) in Colt, Ark., the Livestock and Forestry Branch Station (LFBS) near Batesville, Ark., the Southwest Research and Extension Center (SWREC) in Hope, Ark., and two sites on lands owned by Plum Creek Timber Co. (PCC 1 and PCC 2) near Monticello, Ark. Soils at the five sites represent a wide range of textures and soil P availabilities. Each study site consisted of a 1- to 2-year old loblolly pine plantation at the time of plot establishment.

Three replicate plots of each of five treatments were established during January or February at the PTBS in 2005, SWREC in 2006, PCC1 in 2007 and PCC2 in 2007. At LFBS, plots will be established in 2008. The plots at the PTBS and SWREC were established prior to those at PCC1, PCC2, and LFBS as part of a companion study. Plots were approximately 0.20 to 0.25 acres in size. Treatments include three primary nutrient amendments: 1) diammonium phosphate (DAP) + Urea, 2) pelletized poultry litter, and 3) a control without any nutrient amendment. Two separate application levels of pelletized poultry litter and DAP+Urea were utilized to provide two levels of N and P (43 lb N/acre + 57 P_2O_5 lb P/acre; 86 lb N/acre + 114 lb P_2O_5/acre) for a total of five treatments. The application levels of P were based on the general range of recommendations for loblolly pine plantation establishment in the southern United States. Application levels of N assumed pelletized poultry litter has an analysis of 3-4-3 to provide the two levels of P amendment. However, nutrient content of the pelletized litter to be applied at each site was analytically quantified to make site-specific adjustments to litter and supplemental urea application rates. Fertilizer was applied between February and March during 2005 at the PTBS, 2006 at the SWREC, 2007 at the PCC1, and 2007 at the PCC2 sites. Treatments will be applied at the LFBS site in February or March of 2008.

Basal diameter and height of approximately 30 trees located within a central portion of each plot were measured prior to nutrient amendment and annually each dormant season following amendment. At the end of the study (four years after treatment application) diameter at breast height will be measured and used with tree height to determine volume growth response. First-flush, current-year foliage is collected during January the first two years following nutrient amendment from five trees in each plot to assess nutrient deficiencies and nutrient responses to each treatment. Foliage N concentrations were determined using an Elementar Vario Max CN combustion analyzer. Foliage P, K, Ca, Mg, and S concentrations were determined by inductively coupled plasma analysis after perchloric acid digestion.

Mineral soil was collected from each plot to a depth of 6 inches at each site during the dormant season prior to treatment application and annually for two years following treatment application. A total of three subsamples from each plot was analyzed following each collection period. Soils were analyzed for P, K, Ca, Mg, S, and B following the Mehlich-3 (1:10 soil:solution ratio) extraction procedure. Soil samples taken prior to treatment application were also analyzed for P using Bray-Kurtz P-1 and Mehlich-1 extraction methods. Soil C and N were determined with an Elementar Vario Max CN combustion analyzer.

The experimental design for the study is a randomized complete block with subsampling. Each site is a block and each treatment replicate is a subsample. Differences among treatments were or will be determined using analysis of variance. If the analysis of variance determines that differences are significant, a Tukey's HSD means separation test will be used to make paired treatment comparisons. All tests will be performed at $\alpha=0.05$.

RESULTS AND DISCUSSION

Currently research plots have been established at four of the five sites. The plantation at the LFBS was planted during February 2007 and plots will be established in 2008. Taxonomic classification and surface textures for the dominant soils at each of the five research sites are presented in Table 1. Initial soil sampling was done prior to plot establishment to evaluate the variability in P concentrations among sites. Average soil-test P was 23, 9, 7, 5, and 3 ppm for the PTBS, LFBS, SWREC, PCC1, and PCC2 sites, respectively. These soils provide a wide range of P availability as well as characteristics to assess loblolly pine growth responses to nutrient additions.

To date, two-year growth responses and one-year growth responses have been summarized for the PTBS and SWREC sites, respectively (Table 2). Nutrient amendments did not significantly increase either basal diameter or height at either of the two sites. The failure of poultry litter and inorganic fertilizer to increase tree growth at the PTBS site is not surprising given the high levels of soil-test P. In addition, foliar concentrations of N and P in the control plots averaged 1.72 and 0.14%, respectively, well above critical concentrations (1.20 and 0.12%) summarized by Ngono and Fischer (2001) for loblolly pine. Thus, it is unlikely that N and P are deficient and limiting loblolly pine growth at PTBS site.

Growth rates at the SWREC were also not affected by nutrient additions. The low growth rates and lack of nutrient responses at the SWREC site may have been related to drought conditions at this site. Precipitation from December 2005, just prior to planting, through November 2006 was 18.02 inches below normal. Mortality rates during this year were relatively high (18 to 31%), reflecting the stress from drought, and were not related to any of the treatments. It is likely that any potential growth responses to nutrient additions will occur when precipitation levels are at or near long-term norms.

PRACTICAL APPLICATION

At this time there has not been a significant response to any nutrient amendment. However, only two of the five sites are old enough to show a growth response to fertilizer and poultry litter application. At one of these sites N and P did not appear to be limiting loblolly pine growth and at the other a severe drought may have limited growth responses. Tree responses to fertilization frequently occur over a 2- to 3-year time span. Thus, future measurements will likely provide a better understanding of the impact of these nutrient additions on loblolly pine growth.

ACKNOWLEDGMENTS

Support for this research was provided by the Arkansas Fertilizer Tonnage Fees, Weyerhaeuser Co., USDA Agricultural Research Services, and Plum Creek Timber Company. The authors also thank the staff of the Pine Tree Branch Station, Southwest Research and Extension Center, Livestock and Forestry Branch Station, and University of Arkansas Soil Testing and Research Laboratory in Marianna for assistance in field work and laboratory analysis.

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Table 1. Classification and surface soil texture for dominant soils at five research site locations.

Site	Soil series	Classification	Surface texture
PTBS	Arkbutla	Fine-silty, mixed, active, acid, thermic Fluvenitc Endoaquepts	Silt loam
	Calloway	Fine-silty, mixed, active, thermic Aquic Fraglossudalfs	Silty clay loam
	Longing	Fine-silty, mixed, active, thermic Oxyaquic Fragiudalfs	Silt loam
LFBS	Noark	Clayey-skeletal, mixed, semiactive, mesic Typic Paleudults	Very gravelly silt loam
SREC	Sacul	Fine, mixed, active, thermic Aquic Hapludults	Very fine sandy loam, Clay
	Sawyer	Fine-silty, siliceous, semiactive, thermic Aquic Paleudults	Silt loam, Silty clay loam
PCC1	Amy	Fine-silty, siliceous, semiactive, thermic Typic Endoaquults	Silt loam
PCC2	Guyton	Fine-silty, siliceous, active, thermic Typic Glossaqualfs	Silt loam, Silty clay loam

Table 2. Loblolly pine average annual basal diameter and height growth response to inorganic and poultry litter additions.

			PTBS		SREC	
Nutrient source	N rate	P rate	Basal diameter	Total height	Basal diameter	Total height
	(lb N/acre)	(lb P_2O_5/acre)	(inches)	(feet)	(inches)	(feet)
Control	0	0	0.74	1.78	0.37	0.77
Poultry litter	43	57	0.83	2.15	0.42	0.59
Poultry litter	86	114	0.73	1.94	0.25	0.55
DAP + Urea	43	57	0.83	2.13	0.43	0.62
DAP + Urea	86	114	0.75	1.93	0.46	0.75

Bermudagrass Forage Response to Nitrogen Fertilization

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

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Beef and dairy cattle producers in Arkansas are dependent on hay and forage crops for feed to maintain steady livestock production. Bermudagrass [*Cynodon dactylon* (L. Pers.)] is grown on approximately 2 million acres in Arkansas (University of Arkansas, 2006), where poultry litter [*Gallus domesticus*] has been the primary fertilizer source for many years. However, high soil-test phosphorus (P) can limit or prohibit litter application in western Arkansas and many growers must begin using inorganic fertilizers such as ammonium nitrate (NH_4NO_3), ammonium sulfate [$(NH_4)_2SO_4$], or urea to supplement forage-N requirements.

Ammonium nitrate has long been an affordable and efficient inorganic N-fertilizer in agriculture. However, the availability of NH_4NO_3 has declined because of national security and public safety concerns regarding the fertilizer's explosive characteristics. Alternative sources to poultry litter and NH_4NO_3 must be evaluated to provide sound recommendations to forage growers to produce high yields.

Use of inorganic fertilizers to maintain soil productivity for forages is a relatively new management practice and represents an economic hardship for many growers. Research investigating yield response to N fertilizer is essential to develop cost-effective and environmentally sound nutrient management practices that continue to produce adequate forage yields. The goal of this research is to develop (or refine) existing University of Arkansas yield-goal based, N-rate recommendations for bermudagrass hay production. Specific research objectives were to evaluate the i) effects of three inorganic N fertilizers treatments, NH_4NO_3, urea, and urea+Agrotain (urease inhibitor), applied across a range of N rates on bermudagrass yields, ii) fertilizer value of pelleted poultry litter (PPL), and iii) total N uptake, NH_3 volatilization, and fertilizer-N recovery by bermudagrass among three inorganic N fertilizer treatments and pelleted poultry litter applied at 120 lb N acre^{-1} application.

MATERIALS AND METHODS

A N fertilizer experiment was initiated in April 2006 and continued in 2007 on an established field of common bermudagrass on a Captina (fine-silty, siliceous, active, mesic Typic Fragiudult) silt loam at the Main Agricultural Experiment Station (MAES) located in Fayetteville, Ark. The field had a history of manure application, was used for hay production and grazing, and has no irrigation capability. Each plot was 5-ft wide × 20-ft long. Composite soil samples were collected in February 2007 before initial fertilization to a depth of 4 inches from each unfertilized control ($n = 10$) with all plots receiving 360 lb total N/acre in 2006 (Slaton et al., 2007). 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. Soils were also analyzed for total C and N by combustion (Elementar Americas, Inc., Mt. Laurel, N.J.), and NO_3-N and NH_4-N concentrations were determined by extraction with KCl. Selected soil chemical property means are listed in Table 1.

The experiment evaluated four N sources including pelleted poultry litter (4.15% total-N, 1.40% total-P, 3.0% total-K, pH = 7.2, % Moisture = 11.5%, NH_4-N = 4982 ppm, NO_3-N = 2209 ppm), NH_4NO_3, urea, and urea treated with Agrotain [a urease inhibitor applied at 3.6 to 4.0 quart/ton urea] applied at 0, 90, 180, 270, 360, and 450 lb N/acre/season. Fertilizer was applied in two or three equal split applications with the exception of the 90 lb N/acre rate, which was applied in two applications (45 lb N acre × 2) at green-up and following the first harvest to simulate a relatively low yield goal. All other season-total N rates were applied in three equal split applications of 60, 90, 120, and 150 lb N/acre/application.

Forage was harvested by cutting an 18-ft long x 3.8-ft wide swath in the middle of each plot with a self-propelled cycle-bar mower at a height of 2.0 to 2.5 inches. All harvested (freshly cut) biomass from each plot was weighed in the field and adjusted to a total dry weight yield expressed as lb dry forage/acre by recording the weight (~500-g) of a sub-sample of fresh forage, which was subsequently dried to a constant weight in a forced draft oven at 140°F and weighed again for dry weight. A shrink factor was calculated to adjust total fresh forage weight to a dry-weight basis. Forage was harvested on 7 June, 17 July, and 18 September to approximate ~30-35 d between fertilization and harvest events. Poor growth resulting from dry, hot weather delayed the third cutting from occurring within the planned harvest interval.

Nitrogen concentration was determined for forage receiving 120 lb N/acre/application (360 lb N/acre/year) at each harvest. The dried tissue was ground to pass a 1-mm sieve and analyzed for N using combustion. Total N uptake was calculated and used to estimate N uptake efficiency for each source by difference.

The experiment was a randomized complete block design with a 4 (N source) × 5 (N rate) factorial treatment structure plus two unfertilized controls and 5 replicates per treatment. Analysis of variance was performed with the PROC GLM procedure in SAS (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. Season-total yields were initially regressed on N-rate with linear and non-linear terms with coefficients depending on N source. Non-significant model terms were omitted and the model was refit until the simplest significant model was obtained. Nitrogen uptake among sources was analyzed as a randomized complete block design with 5 replicates and analyzed as previously described.

RESULTS AND DISCUSSION

Precipitation was slightly above normal during fall and winter 2006 and was slightly below normal for the 2007 growing season. However, below-normal rainfall did not seem to inhibit normal forage growth significantly. Precipitation measured from Drake Field (Fayetteville, Ark.) totaled 30.01 inches from September 2006 through April 2007 compared to the normal amount of 27.15 inches. During the growing season (May to September 2007), rainfall data for each harvest interval measured 2.6 inches for the first harvest, 5.4 inches for the second harvest, and 7.9 inches for the third harvest.

Soil samples collected in February 2007 after receiving N-fertilizer treatments in 2006 showed low, but significantly different, concentrations of NO_3-N in the top 4 inches of soil (Table 1). Soil receiving no N in 2006 contained the lowest amounts of NO_3-N, which were different from those of NH_4NO_3, Urea, and PPL. Soil NH_4-N concentrations were similar among all N treatments (all four N sources and the unfertilized control). Total inorganic N concentrations were not different among treatments since NH_4-N was the primary form of inorganic N present in soil from all treatments. Soil receiving PPL often contained greater soil-test concentrations of other nutrients, which is not surprising since PPL contains other nutrients and all plots received uniform rates of P and K inorganic fertilizers in 2006.

Bermudagrass yields as affected by the main effects of N source and N rate for each harvest and the season total are listed in Tables 2 and 3, respectively. For brevity, only the statistical analysis of season-total yields will be discussed in detail. Forage yield was significantly affected by N source and N rate at each harvest and the sum of the first three harvests. The interaction between N source and N rate was also significant for the second harvest yield (P=0.0005, data not shown) and the season-total yield (P=0.0209, Table 4). The unfertilized control produced the lowest yield (4617 lb/acre) and NH_4NO_3 applied at 450 lb N/acre produced the greatest yield (12583 lb/acre). Within each source, yields generally increased numerically as N rate increased. When applied at the greatest N rate, all N sources except urea produced statistically similar yields as 450 lb NH_4NO_3-N/acre. Within each N rate the greatest numerical yields were always produced by forage receiving NH_4NO_3, but the yields were not always greater than other N sources applied at the same N rate.

Forage yields followed a quadratic trend across N rates for each source with the rate of yield increase per unit of N being similar across all N sources [i.e., same linear (20.33) and nonlinear (-0.0152) coefficients among N sources (Fig. 1)]. Only the intercept differed among N sources suggesting differences in uptake efficiency or agronomic efficiency exist among N sources. The intercept values were statistically similar among inorganic N sources and greater than the intercept for PPL. Based on the intercept values, PPL produced 79 to 89% of the yields produced by inorganic N fertilizers indicating that about 80% of the total-N is plant-available during the growing season of PPL application assuming that residual N from 2006 fertilization was similar among N sources. Likewise, urea and urea + Agrotain-fertilized forage produced 89% of the forage as NH_4NO_3. Such differences could be attributed in part to the influence of N source on soil acidity, forage yield enhancement when NO_3 and NH_4 are supplied, or N loss differences among sources.

Nitrogen uptake by forage receiving 120 lb N/acre/application was significantly affected by N source (Table 5). Total-N uptake was similar among inorganic N sources for the season total and all harvests except the third harvest (September) with total-N uptake from inorganic N sources always being significantly greater than N uptake from PPL. On average, the season-total, fertilizer-N recovered by forage was 52% for PPL, 67% for urea, 69% for urea + Agrotain, and 70% for NH_4NO_3. These data suggest that N from PPL was taken up at 75% of the efficiency as inorganic N fertilizers.

PRACTICAL APPLICATION

Yield results from a N-fertilizer trial conducted in 2007 showed a slight yield advantage for forage fertilized with NH_4NO_3 compared to urea or urea + Agrotain, which produced similar yields that were, on average, 89% of the a yield produced with benefit to fertilization with NH_4NO_3. However, N uptake data showed similar total N uptake among these inorganic N sources applied at 360 lb N/acre/year. Adding Agrotain, a urease inhibitor, with urea had no beneficial influence on yield or season-total N uptake compared with urea applied alone. Although fertilizer NH_3 loss results were not described in this report, we found that Agrotain significantly reduced NH_3 volatilization losses of urea for 15 days following fertilizer application, which may explain why urea had a lower N uptake for the third harvest than urea + Agrotain and NH_4NO_3. Forage fertilized with pelleted poultry litter produced only 79 to 89% of the yield and contained only 75% as much total N as forage receiving inorganic N sources. Data from the first two years of this study suggest urea is a suitable alternative to NH_4NO_3 for warm-season grass production in northwest Arkansas with the advantages of higher N concentration, lower price per unit of N, and greater availability. Furthermore, the risk of NH_3 loss from applied urea may be significantly reduced with Agrotain, especially in situations where timely rainfall or irrigation cannot be used to incorporate urea following application. Although Agrotain provided no benefit for forage yield production in 2007, Agrotain should be considered as a best management practice for reducing agricultural NH_3 emissions. Additional data on yield, forage quality, and nutrient uptake are necessary to determine optimal fertilizer strategies across years and soils with different climatic conditions and management levels before recommendations can be changed.

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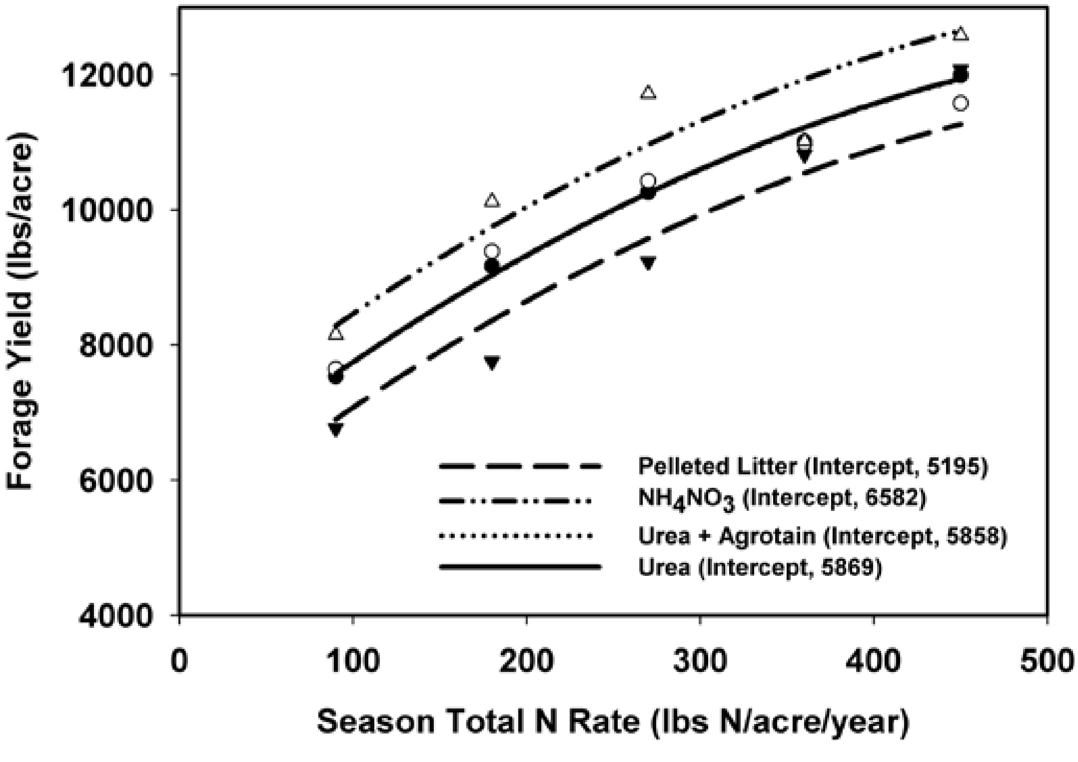

Fig. 1. Season total forage yield as affected by N rate and source for a trial conducted on a Captina silt loam in 2007. (Symbol Legend: ●, Urea + Agrotain; ▼, Pelleted Litter; , NH_4NO_3; and ○, Urea).

Table 1. Selected soil chemical property means for plots receiving no N (the unfertilized control) and 360 lb N/acre from each N source (applied) in 2006 for samples (0- to 4-inches) collected in February 2007.

	Soil	Soil nitrogen		Mehlich-3 extractable soil nutrients								
N source	pH	NO_3-N	NH_4-N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
		(mg/kg)										
Control	5.3	2.8	27	75	186	700	95	18	197	83	5.4	1.4
NH_4NO_3	5.0	4.8	22	74	164	513	75	20	205	95	5.2	1.4
Urea	5.0	4.6	26	83	156	589	84	20	202	88	5.4	1.4
Urea+UA[z]	5.1	3.6	27	70	167	695	79	19	196	94	5.5	1.4
PPL[y]	5.3	5.6	30	130	231	809	121	20	190	81	8.9	2.7
LSD0.10	0.27	1.3	NS[x]	9	26	134	16	NS	NS	NS	0.9	0.2

[z] Urea+UA = urea + the urease inhibitor Agrotain.

[y] PPL = pelleted poultry litter.

[x] NS = not significant.

Table 2. Bermudagrass forage yields as affected by N source, averaged across N rates, for a trial conducted on a Captina silt loam in Fayetteville, Ark., during 2007.

	Forage yield (by harvest)			
N Source	Season	June	July	September
	(lb/acre)			
None	4617	1998	1624	996
Poultry litter	9331	3772	3347	2211
Urea	10005	3810	3761	2434
Urea + Agrotain	9994	3803	3562	2629
Ammonium nitrate	10718	4123	3714	2881
LSD(0.10)	391	219	222	176
p-value	<0.0001	0.01	0.005	0.0007
C.V., %	7.6	7.9	7.3	8.14

Table 3. Bermudagrass forage yields as affected by N rate, averaged across N sources, for a trial conducted on a Captina silt loam in Fayetteville, Ark., during 2007.

Total N	N rate % application	Forage yield (by harvest)			
rate	number	Season	June	July	September
(lb N/acre)		(lb/acre)			
0	--	4617	1998	1624	996
90	45 % 2	7525	3273	3114	1138
180	60 % 3	9109	3606	3278	2224
270	90 % 3	10411	3996	3711	2700
360	120 % 3	10958	4163	3715	3084
450	150 % 3	12057	4348	4162	3548
LSD(0.10)		414	232	235	187
p-value		<0.0001	0.01	0.005	0.0007

Table 4. Season total bermudagrass yield as affected by the N source by rate interaction for the second year of a trial conducted on a Captina silt loam.

Total N rate	N Rate % application number	Nitrogen source			
		NH_4NO_3	Urea	Urea + Agrotain	Pelleted litter
(lb N/acre)		(lb/acre)			
0	--	4617			
90	45 % 2	8151	7647	7537	6764
180	60 % 3	10120	9389	9168	7758
270	90 % 3	11718	10429	10259	9235
360	120 % 3	11017	10983	11012	10821
450	150 % 3	12582	11578	11994	12076
LSD(0.10)		766			
p-value		0.0209			
C.V., %		7.7			

Table 5. Nitogen uptake by forage receiving 120 lb N/acre/application for each N source and the unfertilized control for a N fertilization trial conducted on a Captina silt loam in 2007.

N Source	Total nitrogen uptake (by harvest)			
	Season	June	July	September
	(lb N/acre)			
None	78	36	26	17
Poultry litter	266	103	97	66
Urea	320	115	125	80
Urea + Agrotain	328	123	113	91
Ammonium nitrate	329	118	113	98
LSD(0.10)	22	15	13	8
p-value	<0.0001	<0.0001	<0.0001	<0.0001
C.V., %	7.6	5.3	12.8	10.7

Evaluation of Urea and Baled Poultry Litter as Nutrient Sources for Cotton Production

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Arkansas' poultry industry, concentrated in the northwestern part of the state, makes a significant contribution to the state economy. Poultry manure is a byproduct of poultry production and contains plant-essential nutrients that can be utilized as a fertilizer. Land application has been the predominant practice for disposal of poultry manure. Intensification of the poultry industry has resulted in application of manure near the points of poultry production well in excess of the quantities removed by crops. Continuous application of manure has resulted in accumulation of soil P in many agricultural soils in northwestern Arkansas and these high P soils have been implicated as a potential water-quality problem. Transport of poultry litter from nutrient-rich poultry production areas of northwest Arkansas to areas of high demand for nutrients such as the row-crop producing areas in eastern Arkansas will reduce the rate of P buildup in northwest Arkansas soils. Poultry litter is currently being baled to increase the economic feasibility of transporting it from northwest Arkansas to eastern Arkansas. Field studies to evaluate cotton response to baled poultry litter (BPL) are needed to provide information to growers who might be interested in utilizing BPL as a source of N and other nutrients. The specific objective of this project was to evaluate the effect of inorganic-N fertilizer and BPL application rate on seedcotton yield on soils commonly used for cotton production in the Mississippi River Delta Region of Arkansas (MRDRA).

PROCEDURES

Replicated field experiments were conducted at three locations in MRDRA on soils representing those commonly used for cotton production. The experimental sites were on University of Arkansas Agricultural Experiment Station facilities in Desha (DEG71), Lee (LEG71), and Mississippi (MSG71) counties. These sites represent a range of latitude from southeast to northeast Arkansas. Each study was arranged as a randomized complete block design with a factorial arrangement of N-fertilizer sources and rates. There were two sources of N (urea and BPL) and six rates of N within each source corresponding to 0, 30, 60, 90, 120, and 150 lb N/acre from urea or BPL (Table 1). At all three sites each experimental treatment was replicated four times. Each experimental plot was 40-ft long and 25- (LEG71 and MSG71) or 12.6-ft wide (DEG71) allowing for eight or four rows of cotton with 38-inch wide row spacings.

Baled poultry litter used in this study was provided by the same entity that is working on commercial-scale baling and shipping of the poultry litter to eastern Arkansas, thus it represents the type of BPL that eventually will be used by cotton producers in eastern Arkansas. Sub-samples of BPL were analyzed by the University of Arkansas Agricultural Diagnostic Laboratory by standard methods (Peters et al., 2003). The results of chemical analysis of six subsamples are reported in Table 2.

Prior to application of BPL or urea a composite soil sample was collected from the 0- to 6-inch depth of each replication. Soil samples were oven-dried, crushed, extracted with Mehlich-3 solution, and the concentration of elements in the soil extracts were measured by inductively coupled plasma atomic emission spectroscopy (Dahlquist and Knoll, 1978). Soil nitrate was extracted with 0.025 *M* aluminum sulfate and measured with a specific-ion electrode (Donahue, 1992). Soil pH was measured in a 1:2 (weight:volume) soil-water mixture (Donahue, 1983). Particle size analysis was performed by the hydrometer method (Arshad et al., 1996). Selected soil properties for each site are listed in Table 3. Nutrients other than N were applied when needed according to the current University of Arkansas recommendations for cotton production.

Baled poultry litter (BPL) and urea treatments were hand-applied to the soil surface and incorporated with a rotary hoe or Do-All before planting (Table 2). Cotton ('Delta PineLand 117') was planted between 4 and 17 May at various sites and emerged within 7 days after planting. Detailed information on important agronomic dates is listed in Table 4. Conventional tillage and pest management practices were followed and irrigation was managed according to the University of Arkansas Cooperative Extension Service Irrigation Scheduler Program. Analysis of variance (ANOVA) 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) or Least significant Difference test (LSD) at a significance level of 0.05 and 0.10.

RESULTS AND DISCUSSION

Properties of BPL and Soil

Baled poultry litter contained on the average (n=6) 3.06% N, 1.27% P, and 2.31% K (Table 3). Organic N was the predominant form of N and NH_4-N was the predominant form of inorganic N. The manure data suggest that in addition to N, the BPL can potentially be used as a low-grade K or P fertilizer.

Analysis of soil samples collected before application of treatments indicated that the average soil pH ranged from 6.4 to 7.1, and P and K were 'Optimum' or 'Above Optimum' (Table 4). Soil NO_3-N was 3 to 5 ppm, thus a yield response to N application was expected. Surface horizon soil texture ranged from silt loam to clay loam, depending on site.

Seedcotton Yield

The N source × N rate interaction did not have any significant effect ($P \geq 0.1446$) on seedcotton yield. Nitrogen source, averaged across N rates, significantly ($P \leq 0.0748$) affected seedcotton yield (Table 5) with seedcotton yields ranging from 1699 to 2685 lb/acre for cotton receiving urea and 1519 to 2273 lb/acre for cotton receiving BPL. On average, cotton fertilized with urea produced greater overall yields.

Averaged across both N sources seedcotton yields receiving no N or BPL ranged from 1021 to 1760 lb/acre and 1926 to 2784 lb/acre for cotton fertilized with 150 lb N/acre (Table 6). Application of >30 lb N/acre produced significantly (P=0.10) higher yields than the no N control. Application of 120 lb N/acre increased yields 841 to 1219 lb/acre as compared to cotton receiving no N and in general maximum seedcotton yields were produced with application of 120 lb N/acre. However, the yields at 150 lb N/acre were not significantly (P=0.1) different than cotton receiving 120 lb N/acre.

PRACTICAL APPLICATION

Application of N increased seedcotton yield, regardless of the N source. Seedcotton yield was increased 50 to 90% by application of 120 lb N/acre. This single year of data from three sites suggests that BPL is a good N source for cotton production in silt loam and clay loam soils of MRDRA. Use of BPL to supply the recommended or maintenance rates of P and K and a portion of the recommended N rate appears to be a feasible nutrient management strategy for cotton. Additional field studies are needed to generate a more robust data base for developing reliable N availability recommendations for utilization of BPL in cotton production in Arkansas.

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Table 1. Nitrogen sources and rates for the three experiments conducted at three locations in Arkansas in 2007 to evaluate the effect of urea and baled poultry litter (BPL) on seedcotton yield.

N source	BPL rate	Total N rate
	(lb/acre)	(lb N/acre)
Urea-control	0	0
Urea	0	30
Urea	0	60
Urea	0	90
Urea	0	120
Urea	0	150
BPL-control	0	0
BPL	1,000	30
BPL	2,000	60
BPL	3,000	90
BPL	4,000	120
BPL	5,000	150

Table 2. Selected agronomic information for the experiments on evaluating nitrogen (N) availability from urea and baled poultry litter (BPL) for cotton at three locations in Arkansas in 2007.

Site ID	Previous crop	Urea and BPL application date	Planting	Predicted 1st square[z]	Predicted bloom[y]	Predicted 1st open boll[x]	Harvest date
DEG71	Cotton	17 May	17 May	15 June	2 July	12 Aug	11 Oct
LEG71	Corn	30 April	4 May	6 June	23 June	5 Aug	5 Oct
MSG71	Cotton	8 May	9 May	9 June	26 June	6 Aug	2 Oct

[z, y, x] 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, 1992.

Table 3. Selected chemical properties of the baled poultry litter (BPL, n=6) used in the three experiments evaluating nitrogen (N) availability of BPL for cotton production in 2007.

Total N	Total C	Total P	Total K	NO_3-N	NH_4-N	Zn	As	Cr	Pb	Cd
(%)				(ppm)						
3.06	22.61	1.27	2.31	19	5415	294	24.5	4.5	0.6	0.6

Table 4. Selected chemical and physical properties of soil samples collected (0- to 6-inch depth) from the experimental sites in the spring of 2007 before the application of treatments for the experiments evaluating nitrogen (N) availability of BPL at three locations in Arkansas in 2007.

		Soil	Soil Mehlich-3-extractable nutrients							Soil physical properties			
Site ID	Soil pH	NO_3-N	P	K	Ca	Mg	Mn	Cu	Zn	Sand	Silt	Clay	Texture
		(ppm)								(%)			
DEG71	6.7	3	75	147	943	127	131	1.1	2.6	33	50	16	Silt loam
LEG71	7.1	4	60	167	2046	428	120	2.2	2.5	4	56	40	Silty clay
MSG71	6.4	5	47	235	3292	623	60	3.9	4.0	44	21	35	Clay loam

Table 5. Effect of N source, averaged across N rates, on seedcotton yields at three locations in Arkansas during 2007.

N source	DEG71	LEG71	MSG71
	Seedcotton yield (lb/acre)		
BPL	2071	1519	2273
Urea	2346	1699	2685
LSD at 0.05[z]	235	250	232
LSD at 0.10[y]	195	208	192
p value	0.0273	0.0748	0.0008

[z, y] LSD = least significant difference at *P*=0.05 and 0.10.

Table 6. Effect of urea and baled poultry litter (BPL) and the mean of N sources applied at six N rates on seedcotton yield at three locations in Arkansas in 2007.

	DEG71			LEG71			MSG71		
	N source		Mean of	N source		Mean of	N source		Mean of
Total-N rate	BPL	Urea	N sources	BPL	Urea	N sources	BPL	Urea	N sources
(lb N/acre)	Seedcotton yield (lb/acre)								
0	1717	1601	1659	947	1096	1021	1687	1857	1760
30	1755	2055	1927	1299	1465	1393	1840	2053	1946
60	1787	2428	2108	1558	1467	1512	2524	2863	2693
90	2292	2569	2430	1443	2381	1845	2465	2785	2648
120	2474	2520	2500	1810	2118	1964	2740	3217	2979
150	2537	2902	2745	2009	1844	1926	2434	3133	2784
MSD 0.05[z]	interaction was NS		392	interaction was NS		426	interaction was NS		377
MSD 0.10[y]	interaction was NS		334	interaction was NS		363	interaction was NS		322
p value	interaction =0.4856		0.0001	interaction =0.1446		0.0003	interaction =0.8464		<0.0001

[z, y] Minimum Significant Difference (MSD) as determined by Waller-Duncan Test at *P* = 0.05 or *P*= 0.10, respectively.

Cotton Response to Potassium Fertilization at Multiple Locations

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Potassium (K) performs many important metabolic functions in cotton growth and development. Potassium deficiency can limit cotton yield and negatively impact lint quality. Modern cotton cultivars grow rapidly (e.g., short growing season), have high yield potential, and may require more nutrients than older, obsolete cultivars. Information on cotton response to K fertilization under current production practices will aid in developing agronomically sound K-fertilizer recommendations.

Improving soil-test-based K-fertilizer recommendations for cotton will ensure that Arkansas growers receive a sound return on their fertilizer investment and aid in securing long-term sustainability of agriculture in the region. The research objective was to evaluate the effect of K-fertilization rate on seedcotton yield of modern cotton cultivars under the production practices common to Arkansas.

PROCEDURES

In 2007, four replicated field experiments were conducted on soils commonly used for cotton production in Arkansas (Table 1). The experimental sites were located on the University of Arkansas Agricultural Experiment Station facilities in Desha (DEG73), Lee (LEG79), Mississippi (MSG73), and Poinsett counties (POG72). Information on the soil series, previous crop, cotton cultivar(s), and agronomically important dates of each site-year are provided in Table 1. The study at site LEG79 was the second year of a continuous cotton K-fertilization experiment where the same K rates were applied to the same plots in 2006.

Prior to application of any soil amendments a composite soil sample consisting of 10 to 12 soil cores was collected from the 0- to 6-inch soil depth of alternating replications at all sites except site LEG79 where composite soil samples were collected from each plot. Soil samples 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 (weight:volume) soil-water mixture (Donahue, 1983). Soil particle size analysis was determined by the hydrometer method (Arshad et al., 1996).

Potassium fertilizer (KCl) was applied in one single application at rates of 0, 30, 60, 90, 120, and 150 lb K_2O/acre at all sites. Each experimental treatment was replicated four times for LEG79, six times for DEG72, and eight times at the other two sites. Ammonium sulfate was surface-applied at 30 lb N/acre before or at planting and an additional 60 lb N/acre were surface-applied at first square as urea and incorporated by irrigation. Individual plots were 40-ft long and 12.5-ft wide allowing for four rows of cotton with 38-inch wide row spacings. All other cultural practices including fertilization closely followed the University of Arkansas recommendations for irrigated-cotton production. Irrigation timing was managed by using the University of Arkansas Cooperative Extension Service Irrigation Scheduler program.

At all sites, the two center rows of each plot were harvested with a plot picker. At LEG79 (Table 1), the experimental design was a randomized complete block with a split-plot treatment structure where cultivar was the main-plot factor and K rate was the subplot factor. All other sites included only one cultivar and the experimental design was a randomized complete block. Analysis of variance (ANOVA) was performed using the GLM procedure of SAS. Sites were analyzed separately. Mean separations were performed by the Waller Duncan minimum significant difference (MSD) test at significance levels of 0.05 and 0.10.

RESULTS AND DISCUSSION

Significant and positive yield increases from K fertilization were expected at DEG73 and LEG79 because soil-test K was 88 and 90 ppm, respectively, which are considered ‘Low’ levels of K by current University of Arkansas recommendations and would each receive a recommendation for 95 lb K_2O/acre. The POG72 site had an ‘Optimum’ soil-test K, suggesting little or no yield increase would occur from K fertilization, although this soil would receive a recommendation for 40 lb K_2O/acre to replace K removed by harvested cotton. The MSG72 site, a clay soil, had an ‘Above Optimum’ soil-test K level and no positive yield response to K fertilization was expected (Table 2).

At LEG79, seedcotton yields were not affected by cultivar or the cultivar × K-rate interaction, but were significantly affected by K rate, averaged across cultivars (Table 3). Compared to cotton receiving no K fertilizer, seedcotton yields were significantly increased by 13 to 26% from K fertilization at the three sites having loam or silt loam textures (Table 3). In general, cotton receiving >30 lb K_2O/acre produced significantly (P = 0.10) higher yields than the unfertilized control and maximum yields were produced with application of 90 to 150 lb K_2O/acre. The significant yield increase at POG72 was surprising since the soil contained an 'Optimum' level of K. Potassium fertilization did not significantly influence seedcotton yield on the clay soil at MSG73 (Table 3).

PRACTICAL APPLICATION

Potassium fertilizer rates significantly increased seedcotton yields at three sites having silt loam or loam textured soils. Soil at one responsive site, POG72, contained an Optimum level of K suggesting that soil-test K levels used for K fertilization recommendations may need to be reevaluated. However, previous K-fertilization trials have generally shown no significant yield response to K fertilization for soils having >130 ppm soil-test K. Soil at the POG72 site contained appreciably more sand than the other sites which suggests that sandy soils may require greater levels of soil and/or fertilizer K to produce maximal yields than do silt loam soils. On the responsive soils, near maximum seedcotton yields were produced by application of 90 to 150 lb K_2O/acre which approximates the amount of K that would have been recommended.

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Table 1. Selected agronomic information for cotton K fertilization experiments conducted in Arkansas during 2007.

Site ID	Soil series	Previous crop	Cultivar(s)	K_2O applied	Planting date	Harvest date
				------------------------------- (day month) ---------------------------		
DEG73	Herber silt loam	corn	DPL117	7 June	17 May	11 Oct
LEG79	Loring silt loam	cotton	DPL143 DPL117	1 May	3 May	6 Oct
MSG73	Sharkey silty clay	corn	DPL143	29 May	9 May	4 Oct
POG72	Dundee silt loam	cotton	DPL117	10 May	10 May	9 Oct

Table 2. Selected soil chemical and physical property means (0- to 6-inch depth) of four cotton K-fertilization trials conducted in Arkansas during 2007.

		Soil	Soil Mehlich-3-extractable nutrients							Soil physical properties			
Site ID	Soil pH[z]	NO_3-N[y]	P	K	Ca	Mg	Mn	Cu	Zn	Sand	Silt	Clay	Texture
		--- (mg/kg) --								--------------------(%)-----------------------			
DEG73	6.1	41	47	88	916	153	164	1.1	2.5	23	59	18	silt loam
LEG79	7.0	19	59	90	1181	273	109	1.1	2.4	15	67	19	silt loam
MSG73	6.2	21	47	272	3383	649	68	4.3	5.1	22	26	53	clay
POG72	5.5	31	73	137	1217	201	87	1.3	5.3	45	33	22	loam

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

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

Table 3. Effect of K-fertilizer rate on seedcotton yield in four trials conducted in Arkansas during 2007.

	Seedcotton yield			
K_2O rate	DEG73	LEG79	MSG73	POG73
(lb/acre)	--- (lb/acre) ---			
0	2437	2553	2572	3456
30	2653	2876	2636	3484
60	2812	2850	2626	3820
90	2753	2948	2808	3931
120	2525	2948	2673	4100
150	2990	3215	2701	4116
P value	0.0051	0.0050	0.3522	0.0146
MSD at 0.05[z]	286	294	NS	486
MSD at 0.10[y]	249	249	NS	410

[z, y] Minimum significant difference at *P*=0.05 and *P*=0.10 as determined by Waller-Duncan Test.

Residual Effect of Pelleted Poultry Litter and Freshly Applied Inorganic Nitrogen Fertilizer on Corn in Arkansas

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

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Nitrogen (N) is the essential plant nutrient that is usually most limiting to corn (*Zea mays* L.) yield. Pelleted poultry litter (PPL) is currently being marketed in Arkansas as an N source. Rising cost of synthetic fertilizers and the increasing number of acres under corn production have renewed Arkansas corn producers' interest in PPL. The PPL that is currently marketed in Arkansas is produced in Delaware and very little information is available about N availability of PPL in soil and cropping conditions of Arkansas. In response to the need for such information for Arkansas growers, we started a long-term experiment to evaluate immediate and residual availability of N from PPL in Arkansas in 2005 (Mozaffari et al., 2005; 2006). This report describes the third year of results. The research objective was to evaluate the residual N-fertilizer value of PPL applied two years ago on corn growth and yield.

PROCEDURES

In 2007 a replicated field experiment was continued at the Lon Mann Cotton Research Station (LMCRS) in Marianna, Ark., on a Loring silt loam. The experimental treatments included annual (2005-2007) applications of total-N rates of 50, 100, 150, 200, 250, and 300 lb N/acre as inorganic N fertilizer (INF) to the same plots every year and a one-time PPL application at rates of 2660, 5320, 7980, 10,640, and 13,300 lb/acre in 2005 only, with approximate total-N rates of 80, 160, 240, 320, and 400 lb total-N/acre. The PPL N rates were based on the minimum guaranteed analysis of PPL (3.0% total-N) provided by the manufacturer. A no N (0 lb N/acre) control was also included in the study. In early April of 2007, before planting, composite soil samples were collected from the 0- to 6-inch depth of each plot. Soil samples were dried, crushed, extracted with Mehlich-3 solution, and the concentrations of elements in the extracts were measured by inductively coupled plasma atomic emission spectroscopy. Soil nitrate was extracted with 0.025 *M* aluminum sulfate and measured with an ion-specific electrode. Soil pH was measured in a 1:2 (weight:volume) soil-water mixture.

Corn cultivar Pioneer 33B54 was planted on 9 April 2007 and seedlings emerged on 16 April. Corn management closely followed University of Arkansas Cooperative Extension Service recommendations for irrigated-corn production. Each plot was 40-ft long and 12.6-ft wide allowing for four rows of corn planted in 38-inch wide rows. No additional PPL or inorganic N fertilizer was applied to plots that received PPL in 2005. However, plots designated for INF received the same rates of INF each year including 50, 100, 150, 200, 250, and 300 lb N/acre. In 2007, INF N was applied in two split applications. A preplant application of 20 lb N/acre was made on 9 April as ammonium sulfate and the balance of INF was applied 38 days after emergence (24 May) by broadcasting urea to the soil surface. About the same time, 100 lb Sol-Po-Mag™/acre (potassium-magnesium sulfate, 0-0-22-22) was surface applied to supply 22 lb/acre of K_2O and S to all plots. No P fertilizer was applied, since Mehlich-3-extractable soil test-P was 'Above Optimum'. When corn plants were at the 5 to 6 leaf stage (18 May), the aboveground portion of five plants was collected from the no N control and residual PPL plots by cutting plants 2 inches above the soil. Plant samples were dried overnight at 70°C, ground to pass a 1-mm sieve, and analyzed for N by the Kjeldahl procedure. Plant dry weights were recorded and used to calculate and compare total-N uptake. Ear-leaf samples were collected at early-silk stage (22 June) from 10 plants/plot and analyzed as described previously. The middle two rows of each plot were harvested with a plot combine on 28 August 2007. Grain yields were adjusted to 15.5% moisture content for statistical comparison of yield data.

The experiment was a randomized complete block with four replications of each treatment. Analysis of variance was performed using the GLM procedure of SAS to evaluate the effect of inorganic-N fertilizer and residual PPL on corn growth responses. Significant treatment means were separated by the Waller-Duncan Minimum Significant Difference (MSD) test (*P*=0.05 and 0.10) when appropriate.

RESULTS AND DISCUSSION

The preplant soil pH and nitrate ranged from 6.2 to 6.6 and 18 to 28 ppm, respectively, and were not affected by N source or rate applied in 2005 and 2006 (Table 1). Mehlich-3-extractable Ca, Mg, and Mn soil concentrations were not affected by the treatments (data not shown). Soil-test concentrations of P, K, Zn, and Cu were significantly different among treatments

(Table 1). As expected, Mehlich-3-extractable P, K, Cu, and Zn were usually similar among INF treatments (Table 1). However, application of ≥240 lb N/acre as PPL significantly increased soil concentrations of Mehlich-3-extractable P, K, and Cu.

Nitrogen uptake by corn seedlings in residual PPL plots was not significantly (*P*=0.2447) different than the no N control (Table 2). Nitrogen concentration in corn ear-leaves differed significantly among treatments, but was similar among all PPL rates and the unfertilized control. Ear-leaf N concentrations in treatments that received ≥50 lb N/acre as INF were significantly greater than the unfertilized control and tended to increase numerically as N rate increased (Table 2).

Experimental treatments significantly (*P* <0.0001) affected corn grain yields (Table 2). Corn yields increased numerically and significantly as INF-N rate increased until maximum yields were produced with 250 to 300 lb N/acre (Table 2). The maximum yields for INF-treated and residual-PPL plots were 203 and 94 bu/acre, respectively. In 2007, corn yields receiving all rates of PPL in 2005 were significantly (*P*=0.10) higher by 10 to 23 bu/acre than the no N control, but were significantly lower than plots treated with ≥50 lb N/acre as INF. This suggests that the residual benefit of a single PPL application lasts for at least two growing seasons beyond the year of application and the magnitude of residual benefit increases as PPL rate increases. In 2006, corn yields receiving PPL in 2005 were 7 to 25 bu/acre greater than the no N control with a trend for yield differences to increase as PPL rate increased (Mozaffari et al., 2007).

PRACTICAL APPLICATIONS

Application of INF in 2007 and residual N from PPL (applied in 2005) significantly increased corn yields. Maximum grain yields were produced with application of 250 lb N/acre of INF. Application of ≥80 lb N/acre from PPL produced corn yields that were significantly higher than when no N was applied. However, the yields from residual PPL-N applied in 2005 were less than 50 lb N/acre of INF applied annually. The study shows that in a typical eastern Arkansas silt loam the residual benefit of PPL-N in the third year after application is significant but very small and cannot sustain maximum corn yield without inorganic-N fertilizer. Although the residual benefit of INF was not studied, one-time applications of INF may also show similar residual benefits as PPL. Data from this 3-year study indicate that PPL cannot be used as a sole source of N for crop production, but can be used with INF to supply a portion of the N as well as other essential nutrients such as P, K, and Zn that are routinely recommended for corn production. Additional research on other soils (i.e., multiple sites) is needed to provide a comprehensive assessment of the immediate (year 1) and residual availability of N and other nutrients from PPL.

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Table 1. Selected chemical properties of the soil samples collected in spring 2007 before planting from plots (0- to 6-inch depth) that received inorganic N fertilizer (INF) in 2005 and 2006 and pelleted poultry litter (PPL) in 2005.

	N rate		Soil					
N source	2005	2006	pH^z	NO_3-N^y	P	K	Cu	Zn
	-------(lb N/acre) ------			---------- (ppm) ----------				
None	0	0	6.5	23	65	181	2.0	4.6
INF	50	50	6.2	24	63	175	1.8	3.4
INF	100	100	6.3	20	63	177	2.0	4.0
INF	150	150	6.3	23	56	167	1.9	3.6
INF	200	200	6.4	28	63	193	2.2	3.9
INF	250	250	6.2	26	53	165	1.7	3.3
INF	300	300	6.5	21	65	180	2.0	5.3
PPL	80	0	6.4	20	79	218	2.3	4.3
PPL	160	0	6.3	20	77	216	2.3	4.6
PPL	240	0	6.6	24	79	210	2.4	4.7
PPL	320	0	6.6	27	111	256	3.1	5.9
PPL	400	0	6.5	18	96	231	2.9	5.7
MSD at *P* = 0.05^x			0.5	30	18	40	0.4	1.9
MSD at *P* = 0.1^w			0.4	24	15	24	0.3	1.6
P value			0.186	0.9566	<0.0001	0	<0.0001	0.026

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

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

[x, w] Minimum Significant Difference as determined by Waller-Duncan Test at P=0.05 and P=0.1, respectively.

Table 2. Effect of inorganic-N fertilizer (INF) rate applied in 2007 and residual effect of pelleted poultry litter (PPL) rate (applied in 2005) on corn grain yields at the Lonn Man Cotton Research Station (LMCRS) in 2007.

N	Application rate			N uptake by		
source	2005	2006	2007	seedlings	Leaf N	Corn yield
	--------------- (lb N/acre) ----------------			(g/5 seedlings)	(%)	(bu/acre)
Control	0	0	0	1.24	2.15	71
INF	50	50	50	--	2.82	115
INF	100	100	100	--	3.37	163
INF	150	150	150	--	3.44	185
INF	200	200	200	--	3.88	186
INF	250	250	250	--	3.71	203
INF	300	300	300	--	3.84	203
PPL	80	0	0	1.51	1.99	81
PPL	160	0	0	1.29	2.02	82
PPL	240	0	0	1.11	2.10	90
PPL	320	0	0	1.75	2.10	94
PPL	400	0	0	1.40	2.11	84
P value				0.2447	<0.0001	<0.0001
MSD at 0.05^z				--	0.36	10
MSD at 0.10^y				--	0.3	9

[z, y] Minimum Significant Difference as determined by Waller-Duncan Test at *P*=0.05 and *P*=0.1, respectively.

Effect of Urea and Urea Treated with Agrotain™ on Corn Grain Yield in Arkansas

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Corn (*Zea mays* L.) yield is usually limited by nitrogen (N) more than any other nutrient in agricultural soils. Thus, N fertilization is widely practiced to optimize corn grain yields. Acreage under corn production in Arkansas has increased since the late 1990s due to favorable prices and interest in ethanol production. In 2007 more than 600,000 acres of corn were harvested in Arkansas. Increasing N-use efficiency has become an important concern to corn producers due to escalating N fertilizer prices and environmental concerns. Surface application of urea-N has become the predominant means of N application for corn in Arkansas. However, a significant amount of surface-applied urea N can be lost to the atmosphere by ammonia volatilization, a reaction mediated by the activity of the urease enzyme (Christenson, 2000). A commercial urease inhibitor was introduced in the late 1990s under the trade name Agrotain™. According to the manufacturer, its inhibitory effect on urease will last for up to 14 days, depending on application rate, which allows additional time for urea incorporation by tillage, rain, or irrigation. Agrotain is relatively inexpensive ($0.02 to 0.04/lb of urea) and can be an economically feasible option for corn growers if research proves its effectiveness for corn production under Arkansas environmental and soil conditions. Our research objective was to compare corn grain yields when fertilized with urea or urea treated with Agrotain applied across a range of N rates.

PROCEDURES

Five replicated field experiments were conducted on soils commonly used for corn production in Arkansas. Three of the sites were on commercial farms in Clay (CLZ71), Cross (CRZ71), and Jackson (JAZ71) counties. The other two sites were located on University of Arkansas Agricultural Experiment Station Research Stations in Lee (LEZ71) and Mississippi (MSZ61) counties. Information on previous crop, corn cultivar, and agronomically important dates is listed in Table 1. Soil samples were collected from the 0- to 6-inch depth at each site and composited by replicate prior to planting and fertilization. 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. Soil nitrate was extracted with aluminum sulfate and measured with an ion-specific electrode (Donahue, 1992). Soil pH was measured in a 1:2 (weight:volume) soil-water mixture (Donahue, 1983). Soil particle size analysis was performed by the hydrometer method (Arshad et al., 1996). When needed, P, K, S, and Zn fertilizers were applied to each site following University of Arkansas Cooperative Extension Service soil-test recommendations for corn. All sites were irrigated and irrigation timing was managed by the cooperating grower or using the University of Arkansas Cooperative Extension Service Irrigation Scheduler program at LEZ71 and MSZ61.

Plots were 25-ft long and 4 rows wide. The experimental treatments were arranged in a factorial design of two N sources (urea and urea plus Agrotain) and six total N rates of 0, 60, 120, 180, 240, and 300 lb N/acre. Nitrogen fertilizer was applied in split applications with 20 lb N/acre applied as ammonium sulfate before or at planting to all plots except the no N control and the balance of each N rate was sidedressed when plants were at the 5- to 9-leaf stage. At CRZ71 it rained two days after N treatments were applied. Rainfall and irrigation information was not available for JAZ71. At the other three sites (CLZ71, LEZ71, MSZ71) there was no rain or irrigation 5 or 6 days after N treatments were applied. At LEZ71 and MSZ61, the two center rows of each plot were harvested with a plot combine. At commercial farm sites, 15-ft long sections from the two center rows of each plot were hand-harvested. Grain weight and moisture values from each plot were recorded and used to calculate corn yield, which was adjusted to 15.5% moisture for statistical analysis and reporting

Each experiment was a randomized complete block with four or five replications of each N rate. Analysis of variance (ANOVA) was performed using the GLM procedure of SAS. Sites were analyzed separately. When appropriate, the least significant difference (LSD) test was used to separate significant means at significance levels of 0.10.

RESULTS AND DISCUSSION

In the 0- to 6-inch depth the soil texture ranged from sandy loam to clay loam (14 to 47% clay), soil pH ranged from 5.6 to 6.6, and preplant soil NO_3-N ranged from 18 to 73 ppm (Table 2). Corn grain yield response as affected by the N source by rate interaction was not significant (*P*≥0.2695) at any of the sites (Table 3). However, N rate, averaged across N sources, significantly (*P* <0.0001) increased corn grain yield at all sites except CRZ71 (*P*=0.4047). The lack of response to N fertilization at CRZ71 can be attributed to high residual N in the top 6 inches of soil (Table 2). At N-responsive sites corn grain yields ranged from 16 to 168 bu/acre for the unfertilized controls and 105 to 241 bu/acre for the highest N rate of 300 lb N/acre (Table 3). The N rates required to produce near maximal yields varied from 60 to 300 lb N/acre among N-responsive sites and were consistent with results from N-rate trials studies conducted in previous years (Mozaffari et al., 2006; 2007).

Nitrogen source, averaged across N rates, significantly (*P*≤0.024) affected corn grain yield at JAZ71 and MSZ71, but had no significant effect (*P*≥ 0.2805) on corn grain yield at LEZ71, CRZ71, and CLZ71 (Table 4). Averaged across all N rates, application of urea plus Agrotain increased corn grain yield by 21 and 15 bu/acre at JAZ71 and MSZ71, respectively.

PRACTICAL APPLICATIONS

Averaged across two N sources, N fertilization significantly increased corn grain yield at four of five sites with maximum grain yield achieved by application of 60 to 300 lb N/acre. Averaged across all N rates, Agrotain-amended urea increased corn grain yield by 15 to 21 bu/acre at two sites. This one-year study indicated that Arkansas corn producers may increase N use efficiency by using the urease inhibitor Agrotain in some Arkansas soils. Additional research is needed to provide a better assessment of potential benefits of utilization of Agrotain for Arkansas corn producers.

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Table 1. Selected agronomic information for corn N-fertilization experiments conducted at Agricultural Experiment Stations and commercial fields in Arkansas during 2007.

Site ID	Previous crop	Cultivar	Planting date^z	N application dates 1st	N application dates 2nd	Harvest date
CLZ71	soybean	Pioneer 33P67	4 April	10 May	30 May	27 Aug
CRZ71	soybean	Pioneer G17BTRR	21 April	22 May	5 June	28 Aug
JAZ71	corn	Pioneer G17BTRR	21 April	8 May	25 May	30 Aug
LEZ71	corn	Pioneer 32B32	13 April	6 May	4 June	16 Aug
MSZ71	corn	Pioneer 32B32	23 April	9 May	29 May	17 Aug

[z] Seedling emergence occurred 7-10 days after planting.

Table 2. Selected soil chemical property means (0- to 6-inch depth) of samples taken before planting corn N-fertilization trials conducted at five sites in Arkansas during 2007.

		Soil	Mehlich-3-extractable nutrients							Soil physical properties			
Site ID	Soil pH[z]	NO_3-N[y]	P	K	Ca	Mg	Mn	Cu	Zn	Sand	Silt	Clay	Texture
		(ppm)								(%)			
CLZ71	5.7	50	70	152	1126	270	383	1.3	8.6	2	71	27	Silt loam
CRZ71	5.7	73	38	98	1438	279	159	1.2	5.0	2	72	26	Silt loam
JAZ71	6.1	29	103	185	656	86	169	0.7	4.9	74	13	14	Sandy loam
LEZ71	6.6	26	51	104	1007	932	135	1.1	1.6	30	56	14	Silt loam
MSZ71	5.6	18	73	263	3154	659	112	4.0	5.9	31	22	47	Clay

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

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

Table 3. Effect of N-fertilizer source (urea or urea plus Agrotain) and rates on corn grain yield in five trials conducted in Arkansas during 2007.

Site &	N-fertilizer rate (lb N/acre)						
N Source	0	60	120	180	240	300	LSD0.10[z]
CLZ71	Grain yield (bu/acre)						
Urea	174	204	225	230	237	242	NS^{I}
Agrotain	160	216	233	241	258	240	
Mean	168	210	228	235	247	241	13
CRZ71							
Urea	151	150	143	168	151	156	NS^{I}
Agrotain	120	159	146	141	160	150	
Mea	135	154	144	154	155	152	NS^{NR}
JAZ71							
Urea	107	186	197	188	210	202	NS^{I}
Agrotain	131	208	221	221	212	226	
Mean	119	195	208	204	210	213	20
LEZZ71							
Urea	45	67	101	83	101	101	NS^{I}
Agrotain	43	81	82	85	91	115	
Mean	44	73	91	84	95	105	13
MSZ71							
Urea	15	74	106	139	142	162	NS^{I}
Agrotain	19	103	118	142	159	170	
Mean	16	86	111	140	151	166	15

[z] NS = not significant at *P*=0.10. Superscripted letters on NS indicate whether it is for the interaction (NS^{I}) or the main effect of N rate (NS^{NR}) (For each site, the 2-way interaction between N-source and N rate was not significant.)

Table 4. Effect of N-fertilizer source (urea or urea plus Agrotain) on corn grain yield averaged across all N rates in five trials conducted in Arkansas during 2007.

	Study site				
Nitrogen source	CLZ71	CRZ71	JAZ71	LEZ71	MSZ71
	Grain yield (bu/acre)				
Urea	218	152	181	84	104
Urea plus Agrotain	228	145	202	79	119
LSD at *P*=0.1[z]	--	--	12	--	9
P value for N source	0.1849	0.2805	0.004	0.702	0.0244

[z] Least significance difference at *P*=0.1.

Phosphorus Fertilization Increases Seedcotton Yield in Arkansas

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Phosphorus (P) is an important plant-essential nutrient that is needed for energy transfer reactions in cotton (*Gossypium hirsutum* L.). Phosphorus deficiency will limit cotton yield and excessive buildup of P in soil will increase the potential for transport of P from agricultural fields and may enhance the risk of eutrophication of surfacewaters. Therefore, accurate P fertility recommendations will benefit the cotton growers and aid in protecting the environment.

Cotton-production practices in Arkansas have dramatically changed during the last three decades, consequently yields have improved and nutrient requirements have changed. Therefore, there is a need for updated information on cotton response to P fertilization with the current soil and cropping conditions in Arkansas. The objective of this study was to evaluate the effect of P-fertilizer rate on seedcotton yield on a soil commonly used for cotton production in Arkansas.

PROCEDURES

A replicated field experiment was conducted in a commercial farm in Crittenden County Arkansas in 2007. Soil at the experimental site is mapped as a Commerce silt loam and the previous crop was cotton. Prior to application of any soil amendments, 10 to 12 soil cores were collected and composited from the 0- to 6-inch soil depth of each replication. Soil samples 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 (Table 1). Soil pH was measured in a 1:2 (weight:volume) soil-water mixture (Donahue, 1983). Soil particle size was determined on each composite sample using the hydrometer method (Arshad et al., 1996).

Cotton cultivar Stoneville5590 was planted by the cooperating grower on 5 May 2007 into a conventionally tilled seedbed. Phosphorus fertilizer (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 14 May. Potassium was blanket applied to the experimental plots at the rate of 60 lb K_2O/acre as potassium chloride (0-0-60) on the same date. Urea was applied by the grower to supply 100 lb N/acre in mid-May. Individual experimental plots were 40-ft long and 12.5-ft wide allowing for four rows of cotton with 38-inch-wide row spacings. All other cultural practices including fertilization closely followed the University of Arkansas recommendations for irrigated-cotton production. Irrigation timing was managed by the cooperating grower. Plants in one 10-ft-long section of one center row were hand picked on 3 October.

The experiment was a randomized complete block design with four replications. Analysis of variance (ANOVA) was performed using the GLM procedure of SAS to determine the effect of P fertilizer application rate on seedcotton yield. Mean separations were performed by the Waller Duncan minimum significant difference (MSD) test at significance levels of 0.05 and 0.10.

RESULTS AND DISCUSSION

Soil pH was 7.4 and soil contained 30, 46, and 24% sand, silt, and clay, respectively (Table 1). Before fertilizer application, Mehlich-3 extractable P was 17 ppm, thus the soil-test P was classified as 'Low' and would have received a recommendation for 70 lb P_2O_5/acre to aid in building soil-test P and maximize cotton yields.

During the season, plants in the control plots were stunted and by maturity were shorter than cotton receiving P fertilizer. Seedcotton yield ranged from 1881 to 2674 lb/acre and was significantly (P=0.0217) affected by P fertilizer rate (Table 2). Seedcotton yield was maximized from application of 30 lb P_2O_5/acre, which increased yields by 42% compared with the no P control. Application of P rates >30 lb P_2O_5/acre had no additional positive influence on yield.

PRACTICAL APPLICATION

Seedcotton yield was significantly increased by P fertilization of a Commerce silt loam having a soil-test (0- to 6-inch depth) P of 17 ppm. University of Arkansas soil-test-based fertilizer recommendations correctly identified this soil as P deficient. The P-fertilizer rate needed to maximize seedcotton yield was only 30 lb P_2O_5/acre compared with the recommended rate of 70 lb P_2O_5/acre. Additional research is needed to properly calibrate the P-fertilizer rate needed to maximize cotton yield on P-deficient soils. Results from this experiment will be added to a database on cotton response to P fertilization so that recommendations can be verified or revised in the future if needed.

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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 for a cotton P fertilization trial conducted on a commercial farm in Crittenden County, Ark., in 2007.

		Soil	Mehlich-3-extractable nutrients							Soil physical properties			
Site ID	Soil pH[z]	NO_3-N[y]	P	K	Ca	Mg	Mn	Cu	Zn	Sand	Silt	Clay	Texture
		(ppm)								(%)			
CRIG71	7.4	69	17	125	2230	460	112	2.2	3.4	30	46	24	loam

[z] Soil pH was measured in a 1:2 (weight: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 in a commercial farm in Crittenden County, Ark., in 2007.

P rate	Seedcotton yield
(lb P_2O_5 /acre)	(lb/acre)
0	1881
30	2674
60	2660
90	2468
120	2570
P value	0.0217
MSD at 0.05[z]	555
MSD at 0.10[y]	461

[z, y] Minimum significant difference at *P*=0.05 and *P*=0.1 as determined by Waller-Duncan Test.

Effect of Soil-Applied Nitrogen Fertilizer Rate on the Nitrogen Content of Cotton Flowers

D.M. Oosterhuis, M.A. Okuba, and M. Mozaffari

BACKGROUND INFORMATION AND RESEARCH PROBLEM

The flower represents the central point of the cotton (*Gossypium hirsutum* L.) plant's reproductive growth in which anthesis, pollination, fertilization, and seed set occur. However, these critical processes for successful seed and fiber (yield) development are sensitive to plant nutrition and environmental stress. It has been speculated that the effect of imbalances in plant nutrition in the flower may be the cause of lowered yield and unpredictable year-to-year yield variability. The objective of this preliminary study was to determine the nutrient content of cotton flowers as influenced by soil nitrogen (N) rate.

The nitrogen requirements of the cotton plant have been well documented (Bassett et al., 1970; Oosterhuis et al., 1983). Nitrogen plays a crucial role in cotton plant growth and development, leaf photosynthesis, boll retention, and yield development. The growth and yield of cotton depend strongly upon the availability of N during the season, and management of this input has received much attention (McConnell et al., 2005). Nitrogen demand by a cotton plant is high, especially during the reproductive phase when bolls import large amounts of N from the leaves (Zhu and Oosterhuis, 1992). Nitrogen fertilization is a critical practice in cotton production because soils on which cotton is grown are more often deficient in N than any other plant nutrient, and N fertilization represents a significant cost in cotton production. A major concern of cotton producers is the extreme year-to-year yield variability experienced in cotton yields during the last decade. These variable yields have been linked to environmental stress, high temperature, and drought stress in particular. However, it is possible that poor plant nutrition, particularly N during flowering and boll development, may result in inadequate reproductive development and therefore in low and more variable yields.

PROCEDURES

Cotton cultivar DPL117 was planted at the Cotton Branch Station in Marianna, Ark., on 10 May 2007. Treatments consisted of three levels of soil applied N fertilizer; 0, 60 and 120 lb N/acre arranged in a randomized block design with four replications. Plot size was 43 feet by 4 rows. Nitrogen was applied as ammonium sulfate and urea where the first 20 lb N/acre were surface-applied as ammonium sulfate and the balance of each N rate was applied as urea at first square. All plots received 60 lb K_2O/acre according to soil tests taken 3 May 2007. The experiment was furrow-irrigated using the University of Arkansas Irrigation Scheduler program.

Flowers were sampled during peak boll development three weeks after the start of flowering. Only first-position sympodial flowers were selected from main-stem nodes 10 to 14. The flowers were dried, ground, and analyzed for nutrient content in the University of Arkansas Soil and Tissue testing laboratory located in Fayetteville. Nitrogen was analyzed by combustion using an elementar VarioMax CN analyzer (Elementar Americas Inc, Mt. Laurel, N.J.) and the remaining mineral elements were determined by digestion in concentrated HNO_3 and elemental concentrations determined by inductively coupled plasma spectrophotometry (Spectro Analytical Instruments Inc, Marlborough, Mass.).

RESULTS AND DISCUSSION

Increasing soil-applied N rate resulted in a corresponding increase in the N content of cotton flowers (Table 1). This increase did not appear to be associated with flower size. The effect of N rate on the flower content of phosphorus, potassium, and boron was opposite to that of N with a decrease as fertilizer-N rate increased. This negative correlation with increased N is difficult to explain but may be related to a dilution effect due to the influence of N on vegetative growth. There was little or no effect of N rate on the remaining essential mineral elements (Table 2).

Nitrogen plays a critical role in reproductive growth, especially in the formation of proteins, DNA, and growth-promoting polyamines, all necessary for successful fertilization and seed set. Polyamines have been shown to be intimately involved in successful seed set in cotton ovaries (Bibi et al., 2007). Therefore, any decrease in available N would be expected to lower the efficiency of reproductive development. Furthermore, it is generally accepted that shedding of young bolls is due to nutritional stress, usually predicated on environmental stress such as drought, through the action of plant hormones. However, nutritional stresses have not been associated with lowered nutrient content in the flowers prior to the development of bolls. Shedding rate was not measured in this preliminary study. Future research will investigate the effect of soil-N status on the N content and polyamine concentration of cotton flowers in relation to successful fertilization and seed set. In addition, the growing importance of global warming and climate change strongly indicates that planned research should include the effect of high temperature on flower N content and polyamine concentration.

PRACTICAL APPLICATIONS

Flower N content increased with increasing N-fertilizer rate, as was hypothesized, because N plays such a critical role in reproductive growth. However the negative correlation of flower P, K, and B content was unexpected. Future studies will address the effect of N with high temperature and/or drought stress on flower N content, polyamines, and the resulting seed set efficiency.

ACKNOWLEDGMENTS

The authors thank Nancy Wolf for conducting the tissue nutrient analyses.

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Table 1. Effect of soil-applied, nitrogen-fertilizer rate on mineral macronutrient composition of cotton flowers.

	Mineral element concentration					
Treatments	N	P	K	Ca	Mg	S
(lb N/acre)	(%)					
0	1.85 b[z]	0.55 a	2.10 a	1.99 a	0.65 a	0.50 a
60	2.02 b	0.50 b	1.90 ab	1.62 a	0.67 a	0.40 ab
120	2.27 a	0.43 c	1.78 b	1.45 a	0.64 a	0.36 b

[z] Columns with the same letter not significantly different (P=0.05)

Table 2. Effect of soil-applied, nitrogen-fertilizer rate on mineral micronutrient composition of cotton flowers.

	Mineral element concentration					
Treatments	Na	Fe	Mn	Zn	Cu	B
(lb N/acre)	(mg/kg)					
0	89.5 a[z]	43.9 a	81.7 a	30.4 a	5.9 a	22.1 a
60	116.0 a	36.6 a	70.5 a	37.2 a	5.9 a	13.7 b
120	134.8 a	34.1 a	76.2 a	27.7 a	6.2 a	7.8 c

[z] Columns with the same letter not significantly different (P=0.05)

Runoff Water Quality from Turfgrass Applications of Nitrogen-Fortified Poultry Litter and Biosolids Fertilizers Using Simulated Rainfall

M.S. Reiter, T.C. Daniel, R.G. Hinkle, and M.D. Richardson

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Over 0.6 million tons of poultry litter (PL) is land-applied yearly in northwest Arkansas (NWA) (National Agricultural Statistics Service, 2006) with significant applications to soils with soil-test P concentrations above the agronomic optimum. Due to high soil-test P concentrations and water quality concerns, the 226 tons of wet biosolids (BS) produced daily from the five major NWA municipalities are disposed in landfills versus land-applied where nutrients would be recycled (Northwest Arkansas Conservation Authority, 2003). Granulation of organic materials, such as PL and BS, allows for additions of value-added items and transforms the fresh product into a material easier to store, transport, and apply than PL and BS in the unprocessed forms. Additives may also reduce nutrient loss when fertilizers are exposed to rainfall events.

Applying excessive amounts of PL in regional areas contributes to water quality concerns. In two such watersheds in NWA, court action was used to limit PL applications in an attempt to reduce phosphorus (P) in overland flow (DeLaune et al., 2006). The objective of our study was to evaluate the effect of three binding agents, a nitrification inhibitor, urea, and dried biosolids (BS) on runoff water quality from PL granular fertilizers. We also evaluated the nitrogen (N) and P losses of N-fortified granulated PL and BS fertilizers compared to unprocessed materials and inorganic fertilizers.

PROCEDURES

Research was conducted on a Captina silt loam (Fine-silty, siliceous, active, mesic Typic Fragiudult) that had a 4% slope and was seeded with bermudagrass (*Cynodon dactylon*) manicured as a golf-course fairway. Background soil characteristics taken before rainfall simulations are listed in Table 1. Soil concentrations were calculated using 1,831,100 lb soil/acre furrow slice (4-inch depth) to express nutrient concentrations as pounds per acre. For fertilizer and soil, inorganic N and dissolved reactive P (DRP) were extracted on a 1:10 ratio of 2 *M* KCl and deionized water, respectively. Total N (TN) was analyzed by dry combustion and organic N determined by subtracting inorganic N from TN. Total P was quantified by a concentrated HNO_3 and H_2O_2 digest. Nitrogen-fortified PL and BS granular fertilizers, BS, Milorganite, fresh PL, and urea + triple superphosphate (TSP) treatments were applied on a total P (TP) basis at a rate of 18 lb P/acre (41 lb P_2O_5/acre). The rates of inorganic N, organic N, TN, DRP, and total solids applied are presented in Table 1. All fertilizer applications were applied on the morning of rainfall simulations.

Rainfall simulation plots were established according to the National Phosphorus Project Protocol (http://www.sera17.ext.vt.edu/Documents/National_P_protocol.pdf) using a portable rainfall simulator from 10 to 12 August 2006. Rainfall was simulated at an intensity of 2.6 inches/hour and a composite runoff sample was collected for 30 minutes from the beginning of the runoff event. A non-acidified runoff sub-sample was filtered through 0.45 µm pore filter paper for DRP analysis. An unfiltered sub-sample was acidified and quantified for inorganic N and TN. The remaining unfiltered and non-acidified sample was digested and analyzed for TP.

Rainfall simulations were established as a randomized complete block design with 3 replications. Initially, just the 12 N-fortified PL and BS fertilizers were analyzed in a 2 × 2 × 3 factorial arrangement of fertilizers with and without BS, with and without DCD, and bound with one of three binding agents (lignosulfonate, urea formaldehyde, or water) totaling 12 different fertilizer combinations. Secondly, the 12 N-fortified PL and BS fertilizers, fresh PL, dried municipal BS, Milorganite, urea + TSP, and a no-fertilizer control were compared. Data were analyzed using analysis of variance (PROC GLM) with SAS software. Means were separated using Fisher's protected least significant difference tests (LSD) using a significance level of $p \leq 0.10$ that was established *a priori*.

RESULTS AND DISCUSSION

Comparison Among PL and BS Formulations

Additions of BS to formulations generally decreased TP loss, runoff load, and runoff concentrations by 50% (Table 2), with the exception of water-bound treatments. Metal salt additions to BS during the waste-water treatment process reduced granule DRP concentrations by 50% (formulations were 50% BS and 50% PL, Table 1) and was likely responsible for reducing overall TP loss (Table 2). Binding agents had little influence on TP or DRP loss. We expected lower runoff nutrient concentrations in formulations bound with urea formaldehyde or lignosulfonate since granulation produced physically stronger granules with these binding agents (data not shown); however, all granules were generally equal in water solubility during rainfall simulations regardless of binding agent and no strong treatment effect was observed (Table 2).

Granular fertilizer formulations containing DCD had more TN lost in runoff than treatments without DCD (4.9 vs. 3.6% TN lost, respectively). Dicyandiamide is water soluble and may have been carried in runoff as granules dissolved during the rainfall simulation. However, DCD may still reduce overall N loss by inhibition of nitrification. Similar to DRP and TP findings, no strong trend was shown regarding various binding agents with TN loss (data not shown).

Comparison to Inorganic and Organic Fertilizers

Fertilizing turfgrass with different organic and inorganic fertilizer treatments resulted in significantly different TP concentrations, loads, and percentage fertilizer TP lost in runoff (Table 3). The urea + TSP treatment had higher runoff water P concentration (29 ppm), load (4 lb P/acre), and percentage of TP applied lost (24.7% TP loss) than any N-fortified PL and BS granular fertilizer or organic fertilizer treatment (Table 3). Fresh PL generally had similar TP runoff water concentration (9.7 ppm), load (1.9 lb P/acre) and P loss (10.4%) as the N-fortified granular fertilizer treatment without BS (Table 3). Dissolved reactive P runoff water concentrations were higher from inorganic TSP treatments (4.2 ppm) than any other fertilizer treatment used in this study (Table 3). Granular fertilizer (containing PL and/or BS) DRP runoff concentrations were similar to or less than fresh PL (3.0 ppm, Table 3). Therefore, P loss via runoff was not significantly increased over fresh PL even though granules had higher DRP concentrations.

Fertilizer treatments were applied on a P basis; therefore, N data are only discussed as a percentage since different amounts of N were applied among treatments (Table 1). Total N lost as a percentage of TN applied ranged from 0.0 (no-fertilizer added) to 7.6% (PLUBDCD-W) (Table 4). Granulated PL and BS fertilizers generally had similar TN losses as urea (3.9%) and Milorganite (3.2%). Generally, PL, Milorganite, urea, and N-fortified PL and BS granule treatments had similar proportions of NH_4-N, NO_3-N and organic N represented as TN load (Table 4). Most N was present as NH_4-N and organic N while NO_3-N concentrations were generally an inconsequential factor in this experiment.

PRACTICAL APPLICATION

Using tap water compared to more expensive lignosulfonate and urea formaldehyde binders generally worked equally well in retarding N and P loss in runoff water. Additions of DCD to formulations may increase N loss while BS additions retard P loss. Processing PL (grinding and heating) did not generally accentuate runoff nutrient concentrations over fresh PL.

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Table 1. Soil background and nutrient concentrations applied from N-fortified poultry litter and biosolid granular fertilizers, commercial fertilizers, and organic fertilizers. Fertilizer sources applied at 18 lb P/acre rate on a bermudagrass golf fairway.

Formulation - binder	NH_4-N	NO_3-N	Organic N	Total N	Dissolved reactive P	Total solids
	(lb/acre)					
Soil background[z]	87.8	3.8	3379	3471	32.1	1831100[y]
PLU – LS[x]	4.0	0.3	196	201	2.1	1094
PLUDCD – LS	3.3	0.2	196	199	2.8	1078
PLUB – LS	2.6	0.2	181	183	1.6	1105
PLUBDCD – LS	2.7	0.2	184	187	1.5	1143
PLU – UF	4.5	0.2	209	214	2.2	1123
PLUDCD – UF	3.7	0.3	225	229	3.2	1241
PLUB – UF	1.6	0.1	205	206	1.4	1178
PLUBDCD – UF	2.3	0.2	202	204	1.3	1252
PLU – W	3.6	0.2	172	176	2.8	1078
PLUDCD – W	2.8	0.2	183	186	3.6	1086
PLUB – W	3.0	0.2	173	176	1.6	1070
PLUBDCD – W	2.7	0.2	172	174	1.7	1057
Biosolids	0.4	0.0	19	20	0.1	626
Milorganite	1.3	0.0	62	63	0.1	929
No-fertilizer control	0.0	0.0	0	0	0.0	0
Poultry litter	5.9	0.2	36	42	0.5	879
Urea + TSP	0.2	0.0	218	218	17.8	942

[z] pH = 6.6, electrical conductivity (1:2, soil:water ratio) = 176 μS cm^{-1}, Mehlich-3 P = 247 lb P/acre, and total P = 1053 lb P/acre.

[y] For 4-inch deep furrow slice calculated from bulk density.

[x] Poultry litter + urea (PLU), PLU + dicyandiamide (DCD) (PLUDCD), PLU + biosolids (PLUB), PLUB + DCD (PLUBDCD), lignosulfonate (LS), urea formaldehyde (UF), water (W), and triple super phosphate (TSP).

Table 2. Percentage of applied total P (TP) lost, runoff water loads, and runoff water concentrations for N-fortified poultry litter and biosolids granular fertilizers on a bermudagrass golf fairway in a biosolids × dicyandiamide (DCD) × binding agent interaction.

	Biosolids		No biosolids	
Binding agent	DCD	No DCD	DCD	No DCD
	Applied TP lost (%)			
Lignosulfonate	5.5 ef[z]	3.8 f	12.4 bc	16.9 a
Urea formaldehyde	8.5 de	6.2 ef	10.4 cd	15.5 ab
Water	8.1 de	9.1 cde	11.9 bcd	8.3 de
	TP runoff water load (lb/acre)			
Lignosulfonate	1.0 ef	0.7 f	2.2 bc	3.0 a
Urea formaldehyde	1.5 de	1.2 ef	1.9 cd	2.8 ab
Water	1.4 de	1.6 cde	2.1 bcd	1.5 de
	TP runoff concentration (ppm)			
Lignosulfonate	5.9 fg	5.5 g	10.5 c	15.0 a
Urea formaldehyde	7.4ef	6.4 fg	11.4 bc	12.8 b
Water	6.8 efg	8.3 de	10.8 c	9.8 cd

[z] Means followed by the same letter are not significantly different at $p<0.10$ within each interaction.

Table 3. Dissolved reactive P (DRP) and total P (TP) runoff water concentrations; loads; the percentage DRP fraction of TP load; and percentage of TP applied lost from N-fortified poultry litter and biosolids granular fertilizer, commercial fertilizer, and organic fertilizer applications on a bermudagrass golf fairway.

	Concentration		Load		DRP fraction	Applied
Formulation - Binder	DRP	TP	DRP	TP	of TP load	TP lost
	------------ (ppm)	-----------	----------- (lb/acre)	----------	------------------- (%)	---------------
PLU – LS[z]	3.0 bc[y]	15.0 b	0.6 a	2.7 b	20.5 hi	16.9 b
PLUDCD – LS	2.9 bcde	10.5 d	0.6 a	2.0 cd	27.4 fgh	12.4 cd
PLUB – LS	2.6 fg	5.5 gh	0.4 a	0.6 hij	46.7 b	3.8 hi
PLUBDCD – LS	2.4 gh	5.9 g	0.4 a	0.9 ghij	40.9 bc	5.5 ghi
PLU – UF	2.7 def	12.8 c	0.6 a	2.5 bc	21.7 ghi	15.5 bc
PLUDCD – UF	3.1 b	11.4 cd	0.5 a	1.7 def	27.6 fgh	10.4 def
PLUB – UF	2.6 efg	6.4 fg	0.4 a	1.1 ghi	41.1 bc	6.2 gh
PLUBDCD – UF	2.7 cdef	7.4 fg	0.5 a	1.3 efg	37.0 cde	8.5 efg
PLU – W	3.1 b	9.8 de	0.4 a	1.3 efg	31.3 def	8.3 efg
PLUDCD – W	2.9 bcd	10.8 d	0.5 a	1.9 cde	27.3 fgh	11.9 cde
PLUB – W	2.9 bcd	8.3 ef	0.4 a	1.2 fgh	36.2 cdef	7.4 fgh
PLUBDCD – W	2.7 cdef	6.8 fg	0.6 a	1.3 fg	40.1 bcd	8.1 fg
Biosolids	1.8 j	2.7 l	0.3 a	0.4 j	67.2 a	2.4 ij
No-fertilizer control	2.1 ij	3.5 l	0.4 a	0.5 ij	63.4 a	0.0 j
Milorganite	2.3 hi	3.7 hi	0.4 a	0.6 hij	62.2 a	4.0 hi
Poultry Litter	3.0 bcd	9.7 de	0.5 a	1.7 def	30.7 efg	10.4 def
Urea + TSP	4.2 a	28.8 a	0.6 a	3.9 a	14.6 l	24.7 a

[z] Poultry litter + urea (PLU), PLU + dicyandiamide (DCD) (PLUDCD), PLU + biosolids (PLUB), PLUB + DCD (PLUBDCD), lignosulfonate (LS), urea formaldehyde (UF), water (W), and triple super phosphate (TSP).

[y] Means followed by the same letter are not significantly different at *p*<0.10 within each column.

Table 4. Percent of total N (TN), inorganic N, and organic N lost as a function of the amount applied. Fractions of TN load presented as inorganic and organic N from applications of N-fortified poultry litter and biosolids granular fertilizers, commercial fertilizers, and organic fertilizers on a bermudagrass golf fairway.

	Percent applied lost[z]	Percent fraction of TN load[y]		
Formulation - binder	TN	NH_4-N	NO_3-N	Organic N
	------------------------	------------------------ (%)	------------------------	------------------------
PLU – LS[x]	4.4 cdef[w]	43.0 bcd	0.1 b	56.9 bcd
PLUDCD – LS	5.6 abcd	29.8 defg	0.1 b	70.1 ab
PLUB – LS	3.3 defg	29.7 defg	0.2 b	70.1 ab
PLUBDCD – LS	5.9 abc	20.6 efg	0.1 b	79.3 a
PLU – UF	3.4 defg	51.8 ab	0.1 b	48.1 de
PLUDCD – UF	2.7 fg	49.0 abc	0.1 b	50.9 cde
PLUB – UF	3.7 cdefg	37.9 bcde	0.4 b	61.7 bcd
PLUBDCD – UF	4.6 cdef	33.3 cdef	0.1 b	66.6 abc
PLU – W	3.8 cdef	41.8 bcd	0.1 b	58.1 bcd
PLUDCD – W	5.2 bcde	43.8 bcd	0.1 b	56.1 bcd
PLUB – W	4.2 cdef	40.1 bcd	0.1 b	59.8 bcd
PLUBDCD – W	7.6 a	18.1 fg	0.1 b	81.8 a
Biosolids	1.4 gh	61.0 a	1.8 a	37.2 e
Milorganite	3.2 efg	42.0 bcd	0.1 b	57.9 bcd
No-fertilizer control	0.0 h	15.5 g	2.3 a	82.2 a
Poultry litter	7.3 ab	46.7 abcd	0.2 b	53.1 bcde
Urea + TSP	3.9 cdef	31.6 cdefg	0.1 b	68.3 abc

[z] Percent lost of amount applied = (TN load/TN applied) × 100.

[y] Percent of TN load = (NH_4-N load/TN load) × 100; substitute NO_3-N and organic N when appropriate.

[x] Poultry litter + urea (PLU), PLU + dicyandiamide (DCD) (PLUDCD), PLU + biosolids (PLUB), PLUB + DCD (PLUBDCD), lignosulfonate (LS), urea formaldehyde (UF), water (W), and triple super phosphate (TSP).

[w] Means followed by the same letter are not significantly different at *p*<0.10 within each column.

Rice Yield and Nitrogen Recovery from Nitrogen-Fortified Poultry Litter Granular Fertilizers

M.S. Reiter, T.C. Daniel, N.A. Slaton, and R.J. Norman

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Extensive row-crop agriculture in Arkansas uses more than 1,074,717 tons of inorganic fertilizer per year (Arkansas State Plant Board, 2005). Approximately 1.2 billion broilers (*Gallus gallus domesticus*) are produced in Arkansas annually resulting in over 1.9 million tons of poultry litter (PL, excreta plus bedding material) containing appreciable inorganic and organic nutrients (National Agricultural Statistics Service, 2006). Physical alteration of PL allows for production of a uniform product with additions of value-added nutrients and nitrification inhibitors.

Moving surplus PL nutrients from northwest Arkansas to the row-crop production areas in eastern Arkansas is an ideal scenario. However, based on PL fertilizer value, fresh PL transport over 25 miles without industry or government subsidies is not economically feasible (Govindasamy and Cochran, 1995). The primary objective of this research was to demonstrate the efficiency of granular fertilizers composed of PL and urea for rice production. A secondary objective was to demonstrate the effectiveness of dicyandiamide (DCD) for increasing N recovery efficiency when incorporated with PL.

PROCEDURES

Research plots were established from 2004 to 2006 at the Rice Research and Extension Center near Stuttgart, Ark., (34°27'N; 91°33'W) to test flood-irrigated rice response to N fertilizers developed from PL. Plots were situated on a Dewitt silt loam (fine, smectitic, thermic Typic Albaqualfs) previously cropped to soybean [*Glycine max* (L.) Merr]. Fertilizer treatments were fresh PL, PL + urea (PLU), PLU + DCD (PLUDCD), and urea. Fresh poultry litter, PLU, and PLUDCD treatments were applied preplant to dry soil and incorporated using a rotary tiller (Table 1). 'Wells' rice was immediately planted after fertilizer incorporation at 100 lb seed/acre. In 2004, preflood urea treatments were applied to moist soil at the 5-leaf growth stage and a permanent 10-cm flood was established within 3 d (Table 1). In 2005 and 2006, preflood urea treatments were applied to dry soil and the permanent flood was established within 24 h (Table 1). All N sources were applied on a total N basis at 60, 100, 140, and 180 lb N/acre. A no-N control was also included. The aboveground portion of rice was collected from 3 ft of row at early heading to determine total-N uptake. Grain yield was determined by harvesting the middle 7 rows from each plot. Grain yields were adjusted to 13.5% moisture prior to statistical analysis. Nitrogen fertilizer recovery efficiency (FRE) was calculated by subtracting N uptake from the unfertilized control from each treatment receiving N and dividing by the total applied N rate. Likewise, agronomic efficiency, grain produced per unit of applied N, was calculated by subtracting the yield of the unfertilized control from the yield of each treatment receiving N and dividing by the applied N rate.

The experiment was arranged in a factorial arrangement of 4 N sources × 5 N rates using a randomized complete block design with 4 replications. Rice grain yield and total aboveground N uptake were analyzed using simple linear and non-linear regression procedures using SAS v. 9.1. Regression equations for the highest order (quadratic or linear) significant model were used. For rice yields, confidence intervals were used to compare linear to non-linear relationships at the lowest N rate that provided maximal yields for preflood urea treatments. For N recovery, linear slopes were used to estimate plant N uptake per lb N applied. An alpha level of 0.10 was used for all statistical analysis and was chosen *a priori*.

RESULTS AND DISCUSSION

Rice Plant Fertilizer Recovery

In 2004, preflood urea treatments were delayed due to frequent rainfall and eventually had to be applied to a moist soil, which led to the lowest plant N uptake for urea among years (58% N FRE, Fig. 1 and Table 2). The PLU and PLUDCD granular fertilizers had numerically lower, but statistically similar, N FRE as preflood-applied urea (46 and 48% vs. 58%, respectively). Poultry litter had the lowest N FRE (22%) out of all N sources. Rice receiving preflood urea treatments in 2005 had 79% N FRE which was greatest among N sources (Fig. 1 and Table 2). Dicyandiamide, a nitrification inhibitor, successfully increased rice N uptake in PLUDCD treatments compared to PLU (56 vs. 21%, respectively), but N FRE for PLUDCD was still not as great as preflood urea. The DCD likely reduced nitrification of NH_4-N, which reduced N loss from denitrification after flooding. Granulated PLU and fresh PL treatments had the lowest N FRE with only 16 and 21% of TN applied, respectively (Table 2). Rice plant N uptake in 2006 generally showed similar trends as reported for 2005 (Fig. 1 and Table 2). Preflood urea had the highest N FRE with 98% of applied N being assimilated by plants (Table 2). Dicyandiamide addition again increased N FRE from 25% for PLU to 49% for PLUDCD. Fresh PL and PLU had the lowest FRE efficiency out of all N sources (17 and 25%, respectively).

Rice Yield

Rice receiving urea preflood produced 5,658 lb rice/acre and had an agronomic efficiency of 18 lb rice/lb N when 80 lb N/acre were applied in 2004 (Table 3 and Fig. 2). The PLU and PLUDCD granules (18 and 20 lb rice/lb N, respectively) had similar N agronomic efficiencies for like N rates as urea applied preflood to the moist soil. Fresh PL had lowest agronomic efficiencies (12 lb rice/lb N) of all N sources. Rice yields in 2005 were compared at preflood urea applications of 135 lb N/acre (Fig. 2 and Table 3). Preflood urea treatments produced 10,071 lb rice/acre, resulting in 53 lb rice/lb N applied. Granular PLUDCD had the second highest yields but produced half as much rice grain per lb N applied (28 lb rice/lb N) compared to preflood applied urea. Fresh PL and PLU granules had similar N agronomic efficiencies producing only 15 and 18 lb rice/lb N. Similar rice yield trends among N rate and N sources were observed in 2006 as in 2005 (Fig. 2 and Table 3). Preflood N rates of 140 lb N/acre were used to compare N sources in 2006 and urea had an agronomic efficiency of 41 lb rice/lb N applied. Granular PLUDCD treatments produced 29 lb rice/lb N applied (Fig. 2 and Table 3). Fresh PL and PLU had similar linear yield responses producing only 12 and 16 lb rice/lb N applied, respectively.

PRACTICAL APPLICATIONS

Data from 2004 should generally be disregarded due to abnormally wet soil conditions prior to permanent rice flooding. Both plant N uptake and rice yield results indicated that N efficiency generally increased among N sources in the following manner: fresh PL ≤ PLU < PLUDCD < preflood urea. Averaged across years, plant recovery of N in PL, PLU, PLUDCD, and preflood urea averaged 17, 23, 53, and 89% of applied total N and produced 14, 17, 29, and 47 lb rice/lb N applied, respectively. Addition of the DCD nitrification inhibitor significantly improved N uptake and yields of rice receiving PLU, but PLUDCD applied preplant was not as efficient an N source as urea applied preflood

ACKNOWLEDGMENTS

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Table 1. Selected dates for rice plot sampling and management at the Rice Research and Extension Center near Stuttgart, Ark.

	Year		
Management event	2004	2005	2006
Applied PL fertilizers	20 May	18 April	15 May
Planted rice	21 May	18 April	15 May
Applied preflood urea	28 June	6 June	13 June
Established permanent flood	30 June	7 June	14 June
Early heading samples collected	3 August	26 July	8 August
Drained permanent flood	17 September	26 August	12 September
Harvested rice	28 September	8 September	25 September

Table 2. Rice N uptake when fertilized with poultry litter, N-fortified poultry litter fertilizers with and without dicyandiamide (DCD), and preflood urea on a Dewitt silt loam.

N Source	Equation[z]	R^2	N Fertilizer recovery efficiency[y]	Urea basis[x]
			------------------------- (%) -------------------------	
2004				
Poultry litter	60.9 + 0.22N	0.32	22	38
PLU[w]	65.1 + 0.46N	0.51	46	79
PLUDCD[w]	62.6 + 0.48N	0.60	48	83
Preflood urea	57.3 + 0.58N	0.68	58	100
Standard error			12	21
2005				
Poultry litter	31.5 + 0.16N	0.71	16	20
PLU	30.3 + 0.21N	0.60	21	27
PLUDCD	21.1 + 0.56N	0.68	56	71
Preflood urea	25.2 + 0.79N	0.85	79	100
Standard error			9	11
2006				
Poultry litter	41.3 + 0.17N	0.29	17	17
PLU	40.0 + 0.25N	0.38	25	26
PLUDCD	47.7 + 0.49N	0.35	49	50
Preflood urea	35.2 + 0.98N	0.83	98	100
Standard error			15	15

[z] Highest order that was significant presented (quadratic or linear) where Y = [Interecept + (linear slope coefficient × N rate)] with units of lb fertilizer-N/acre.

[y] N fertilizer recovery efficiency (FRE) = linear slope coefficient*100.

[x] Urea basis = N Source FRE/urea N FRE*100.

[w] Poultry litter + urea (PLU) and PLU + DCD (PLUDCD).

Table 3. Rice grain yield agronomic efficiency from applications of poultry litter, N-fortified poultry litter fertilizers with and without dicyandiamide (DCD), and preflood urea on Dewitt silt loam.

N Source	Yield response[z]	R^2	Urea N rate[y]	Predicted yield	Predicted yield confidence interval	N agronomic efficiency[x]	Urea basis[w]
			----------------------- (lb/acre) -----------------------			(lb rice/lb N)	(%)
2004							
Poultry litter	4199 + 12.4N	0.82	80	5191	5052 – 5330	12	71
PLU[v]	$4207 + 22.1N – 0.051N^2$	0.84	80	5649	5459 – 5839	18	100
PLUDCD[v]	$4187 + 24.4N – 0.054N^2$	0.94	80	5793	5603 – 5983	20	111
Preflood urea	$4183 + 26.2N – 0.097N^2$	0.76	80	5658	5474 – 5842	18	100
2005							
Poultry litter	2570 + 14.7N	0.52	135	4555	4213 – 4897	15	28
PLU	2479 + 18.4N	0.82	135	4963	4621 – 5305	18	34
PLUDCD	2484 + 27.6N	0.89	135	6210	5862 – 6558	28	52
Preflood urea	$2390 + 84.3N – 0.203N^2$	0.95	135	10071	9737 – 10405	53	100
2006							
Poultry litter	3268 + 12.2N	0.56	104	4537	4252 – 4822	12	29
PLU	3170 + 16.0N	0.64	104	4834	4549 – 5119	16	39
PLUDCD	$3225 + 40.2N – 0.092N^2$	0.81	104	6411	6017 – 6805	29	71
Preflood urea	$3200 + 65.5N – 0.206N^2$	0.94	104	7784	7409 – 8159	41	100

[z] Highest order that was significant presented (quadratic or linear).

[y] Statistically lowest N rate for maximum yield in preflood urea treatments.

[x] Nitrogen agronomic efficiency = (predicted yield – y-intercept)/preflood urea N rate.

[w] Urea basis = Source N agronomic efficiency/preflood urea N agronomic efficiency*100.

[v] Poultry litter + urea (PLU) and PLU + DCD (PLUDCD).

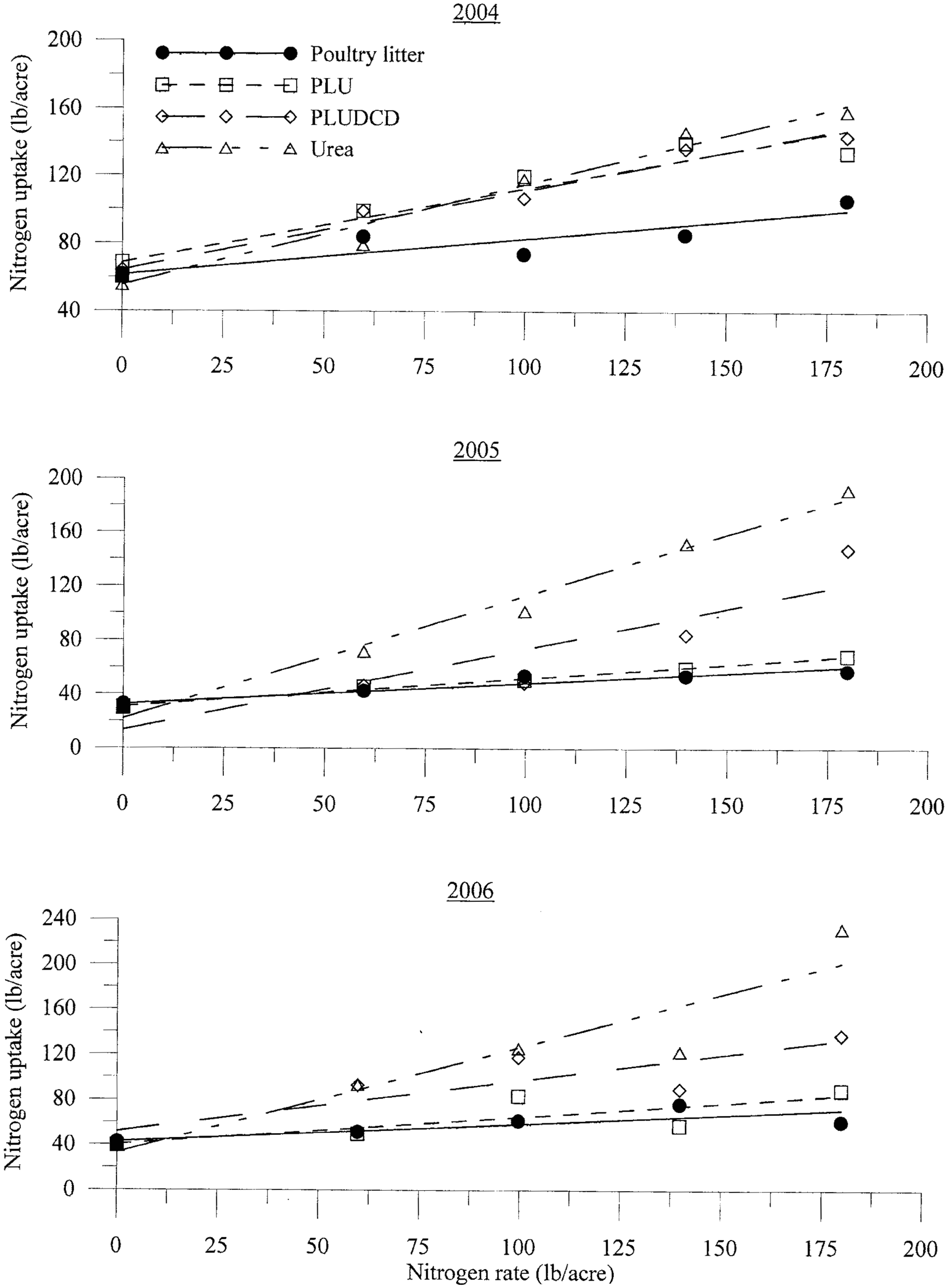

Fig. 1. Rice plant N uptake for fresh poultry litter (PL). granular PL fortified with urea (PLU), PLU fortified with a nitrification inhibitor (PLUDCD), and preflood-applied urea for 2004, 2005, and 2006 on a Dewitt silt loam.

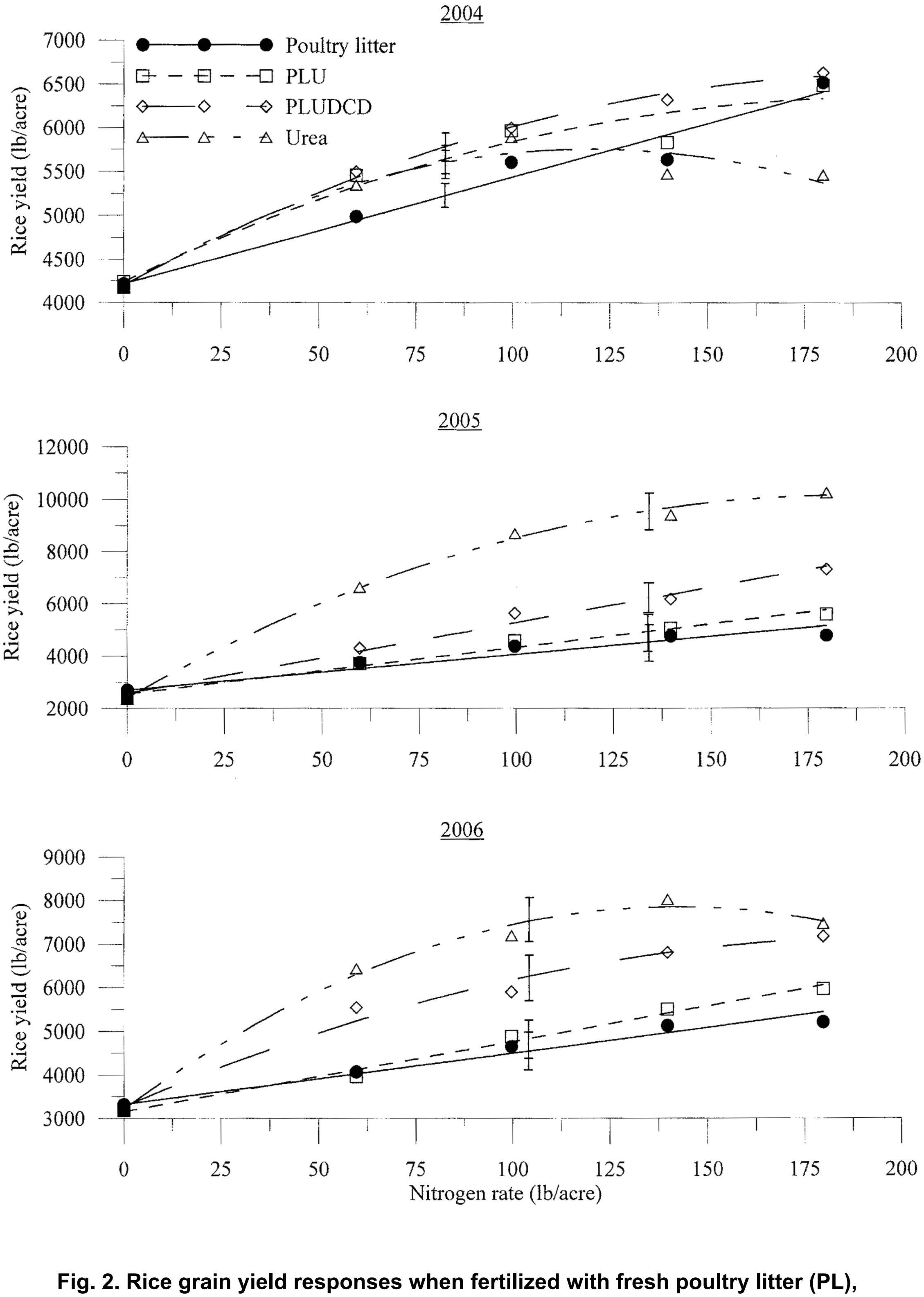

Fig. 2. Rice grain yield responses when fertilized with fresh poultry litter (PL), granular PL fortified with urea (PLU), PLU fortified with a nitrification inhibitor (PLUDCD), and preflood-applied urea for 2004, 2005, and 2006 on a Dewitt silt loam.

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

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

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 the 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. The most common question asked is whether to apply the recommended P and K for both crops to wheat in the fall or to split the recommended fertilizer rate 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 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 24 October 2006 into a conventionally tilled seedbed at the Pine Tree Branch Station (PTBS) on a Calloway silt loam following soybean. 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, 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 2007 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, 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, 100, 150, and 200 lb P_2O_5/acre) before seeding wheat and the second strategy was to apply one-half (0, 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 (June 13). 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, and 180 lb K_2O/acre in one or two split applications to simulate two fertilization strategies for wheat followed by double-cropped soybean. The first fertilization strategy involved application of the entire K rate (0, 60, 120, and 180 lb K_2O/acre) before seeding wheat and the second strategy was to apply one-half (0, 30, 60, and 90 lb K_2O/acre) the total K rate to wheat in the fall and the remaining one-half following wheat harvest. 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. The experimental design and soil sample collection for the K-fertilization trial was the same as described for the P-fertilization trial.

'Beretta' wheat was drill-seeded (7.5-inch row spacing) on 24 October at a rate of 120 lb/acre into a conventionally tilled seedbed. Nitrogen fertilizer was applied in two split applications on 21 February 2007 [100 lb $(NH_4)_2SO_4$/acre + 100 lb urea/acre] and again on 15 March 2007 [100 lb urea/acre]. Freezing temperatures (~24-28°F) occurred on two consecutive nights (6 and 7 April) when wheat was at Feekes stage 9-10, which damaged the developing spikes and reduced wheat yield potential.

Whole, aboveground plant samples were taken at Feekes stages 10.1 (early 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 plants were harvested and straw was clipped to a height of 6 inches and scattered within the test area. Soybean ('Armor 52U2') was planted no-till in 15-inch-wide rows on 11 June 2007 with emergence occurring between 16 and 23 June. The second split application of P and K fertilizer treatments was broadcast onto the soil surface on 13 June. Dry soil conditions following planting resulted in poor stand and erratic emergence in some plots.

Trifoliate leaf samples (15) were collected from the middle of each plot at the R1 to R2 growth stage (15 August). Trifoliate leaf samples were processed and analyzed as described for wheat tissue samples. At maturity, the six 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 the fall of 2006, the average Mehlich-3-extractable P in the P fertilization trial was considered 'Very Low' (<16 ppm, Table 1). Soil-test K was 'Optimum' 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 100 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 100 lb P_2O_5 and 0 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 2007 showed that soil-test P remained very low but had declined numerically in both P and K tests. Soil-test K also declined numerically in each study and was considered 'Medium'. Most other soil-test parameters were comparable between sample times. At both sample times soil-test P in the P study was relatively uniform among soil samples (standard deviation of <2 ppm). In contrast, soil-test K in the K study area varied among samples with standard deviation of 21 ppm for each sample time, which indicated considerable variation within the test area. Therefore, results of the K fertilization studies should be interpreted with caution as the variability was great enough to influence plant growth and yield potential.

Phosphorus Trial - Wheat

Wheat dry matter production at Feekes stage 10.1 was not affected (P>0.10) by application strategy or the P rate × strategy interaction, but was affected (P = 0.0760) by P rate, averaged across strategies. Wheat receiving no P fertilizer (3182 lb/acre) produced significantly less dry matter than wheat in the 100 and 150 lb P_2O_5/acre treatments (3872 and 4045 lb/acre) and similar dry matter, albeit numerically lower, as 200 lb P_2O_5/acre (3579 lb/acre).

Whole plant P concentrations at Feekes stage 10.1 were affected (P=0.0212) by the P rate × strategy interaction (Table 2). Phosphorus concentrations were similar between application strategies within each P rate except for the 200 lb P_2O_5/acre treatment, which showed significantly greater P concentrations when all the P was fall-applied. Although P concentrations between application strategies were not significantly different, wheat receiving a single application of P in the fall tended to have numerically higher P concentrations. Within each application strategy, tissue concentration increased as P application rate increased.

Wheat grain yields were not affected (P>0.10) by P fertilization rate, application strategy, or their interaction. The overall yield averaged 50 bu/acre with individual treatment means ranging from 48 to 54 bu/acre (Table 2). The aforementioned freezing temperatures in April caused visible damage to wheat spikes and reduced yields by an estimated 20 to 50%. Because the soil-test P was very low, significant yield increases to P fertilization were expected in this study.

Potassium Trial - Wheat

Wheat dry matter accumulation at Feekes stage 10.1 was not significantly affected by the main effects or their interaction (data not shown) and averaged 3039 lb/acre across all treatments. Whole plant K concentrations were affected significantly by K rate (P=0.0680, Table 3), but not by application strategy (P=0.4733) or the interaction (P=0.4502). 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 (2.63% K) contained numerically greater K concentrations than when one-half of the K rate was fall-applied (2.57% K). Wheat grain yields were not affected by K fertilization and despite the freeze damage no yield increase was expected as soil-test K concentrations (Table 1) were considered Optimum. Among individual treatments wheat yields ranged from 45 to 51 bu/acre with an overall average of 48 bu/acre (Table 3).

Phosphorus Trial - Soybean

Soybean trifoliate leaf P concentrations were not affected significantly (*P*>0.10) by either main effect or their interaction, but showed a numerical trend to increase gradually as total P rate increased (Table 4). Leaf P concentration of soybean receiving no P averaged 0.27% and increased numerically as P rate increased to a maximum of 0.30% for 200 lb P_2O_5/acre. The established critical concentration for P in trifoliate leaves at flowering is 0.30% suggesting that P may have limited growth and yield of soybean. Seed yield was significantly affected by only P fertilizer rate (*P*=0.0993), but not by strategy or interaction (Table 4).

Potassium Trial - Soybean

Potassium application, averaged across strategies, was the only factor that significantly (*P*=0.0065) affected soybean leaf K concentration (Table 5). Soybean receiving no K had deficient (<1.5% K) trifoliate-leaf K concentrations that increased as K rate increased. This was not surprising since K-deficiency symptoms were observed in several, but not all, plots receiving no K fertilizer, which was not unexpected since soil-test K was not uniform within the area. Trifoliate K concentrations between fertilization strategies, averaged across K rates, were not different, but showed a trend for slightly greater K concentrations when K was fall-applied (data not shown). Soybean yields were not significantly affected by the K rate (*P*=0.1232), application strategy (*P*= 0.4459), or their interaction (*P*=0.8652) at the 0.10 significance level. However, single-degree-of-freedom contrasts showed that soybean receiving no K produced significantly lower yields than soybean receiving K (*P*=0.0014). Furthermore, soybean receiving K showed a non-significant, numerical trend for slightly greater yields when K was split-applied (50 bu/acre) compared with K applied only in the fall (48 bu/acre).

PRACTICAL APPLICATION

The measured wheat yield responses to P and K fertilization may not accurately characterize wheat response to fertilization on a soil that had low soil-test P and Medium to Optimum soil-test K because of freeze injury that reduced yields by an estimated 20 to 50%. Although wheat yields were not different among fertilizer treatments, yields tended to decline as fertilizer rate increased, suggesting that well fertilized wheat may be more sensitive to freezing temperatures. The whole plant P and K concentrations of wheat at Feekes stage 10.1 suggest that application of all the P and K in the fall before wheat is planted enhances wheat uptake of these nutrients, which was expected.

The primary issue, however, is whether soybean growth and yield benefit from split applications of P and K fertilizer when double-cropped following wheat. These results suggest that split-applying P or K had little or no significant influence on soybean P and K nutritional status and yield and suggests that nutrient rate was the most important aspect. However, the variability in soil-test K within the test area may have influenced results of the K study. Additional studies are needed to gain a better understanding of how time of fertilizer application may influence crop yield and fertilizer-use efficiency by plants in Arkansas.

ACKNOWLEDGMENTS

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Table 1. Selected soil chemical property means (*n* = 5, from each unfertilized control) in fall 2006 and June 2007 for P and K fertilization trials conducted during the 2006 to 2007 growing season.

Crop	SOM	Soil pH	P[z]	K[y]	Ca	Mg	S	Na	Fe	Mn	Cu	Zn	B
			Mehlich-3-extractable nutrients										
	(%)		(ppm)										
Phosphorus													
Fall 2006	2.4	7.1	10	117	1507	263	15	47	140	267	1.6	3.5	0.5
June 2007	2.4	7.5	6	94	1414	274	12	34	119	282	1.7	3.1	0.1
Potassium													
Fall 2006	2.3	7.6	12	136	1929	291	11	45	135	228	1.6	2.5	0.5
June 2007	2.2	8.0	7	91	1723	306	10	33	108	242	1.7	2.3	0.2

[z] Standard deviation (*n*=5) of soil-test P in P trials was 1.9 ppm in October 2006 (before wheat) and 1.7 ppm in June 2007 (after wheat).

[y] Standard deviation (*n*= 5) of soil-test K in K trials was 21 ppm at PTBS in October 2006 (before wheat) and 21 ppm in June 2007 (after wheat).

Table 2. Wheat whole-plant P concentrations at Feekes stage 10.1 as affected by the interaction between P rate and application strategy and wheat yields as affected by P rate, averaged across strategies, for the P-fertilization trial conducted during the 2006 to 2007 growing season on a Calloway silt loam.

Total P fertilizer rate	Fertilizer application strategy: Single application (Fall application)	Fertilizer application strategy: Split application (½ Fall and ½ Spring)	Wheat yield
(lb P_2O_5/acre)	(Whole-plant P concentration, %)		(bu/acre)
0	0.202	0.204	54
100	0.276	0.238	51
150	0.283	0.252	49
200	0.388	0.276	48
LSD(0.10)	0.042 (compare strategy means within P rates)		NS[z]
LSD(0.10)	0.047 (compare any two means)		

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

Table 3. Wheat whole-plant K concentrations and grain yields as affected by K rate, averaged across application strategies, in the K-fertilization trial conducted during the 2006 to 2007 growing season on a Calloway silt loam.

Total K fertilizer rate	Plant K concentration	Grain yield
(lb K_2O/acre)	(% K)	(bu/acre)
0	2.46	48
60	2.53	46
120	2.62	48
180	2.80	51
LSD(0.10)	0.22	NS[z]

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

Table 4. Soybean 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 2007 on a Calloway silt loam.

Total P fertilizer rate	Trifoliate-leaf P concentrations	Seed yield
(lb P_2O_5/acre)	(% P)	(bu/acre)
0	0.27	51
100	0.29	53
150	0.29	58
200	0.30	55
LSD(0.10)	NS[z]	5

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

Table 5. Soybean 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 2007 on a Calloway silt loam.

Total K fertilizer rate	Trifoliate leaf K concentration	Seed yield
(lb K_2O/acre)	(% K)	(bu/acre)
0	1.25	40
60	1.59	48
120	1.79	50
180	1.68	49
LSD(0.10)	0.27	9

Bermudagrass Forage Response to Phosphorus Fertilization

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Bermudagrass [*Cynodon dactylon* (L.) Pers.] is grown for hay and pasture which helps sustain cattle production in western Arkansas. Poultry litter has been the primary soil amendment and nutrient source applied to forages in western Arkansas for 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 phosphorus (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) how soil-test P performs across time.

PROCEDURES

Fertilization trials were initiated (year 1) in April 2006 in a field of established common bermudagrass on a Captina silt loam at the Main Agricultural Experiment Station (MAES) located in Fayetteville, Ark., and in April 2007 in a commercial field of established 'Midland' bermudagrass on a Johnsburg silt loam near Fayetteville, Ark. The first year results from the Captina soil were reported by Slaton et al. (2007) and the second year of this trial is described in this report. Each site will be referred to by the soil series name. For the Captina, the same P rates were applied to the same plots each year. The Captina soil had been used for hay production and grazing with a history of manure application. The Johnsburg silt loam had received biosolid applications for several years, but none since 2003 and is used exclusively for hay production. The Captina site was managed with no irrigation, but the Johnsburg site was irrigated once in early September 2007. Forage at the Johnsburg site was a mixture of crabgrass, ryegrass, foxtail, and bermudagrass with the dominate grass species in 2007 being crabgrass.

Weed control at the Captina site consisted of glyphosate (Roundup WeatherMax at 1 pt/acre) applied on 28 February before greenup to suppress/control winter weeds. Cimarron Max (2 qt/acre of 2,4-D + dicamba plus 0.5 oz metsulfuron/acre) was applied on 19 June following the first harvest primarily to control buckhorn plantain (*Plantago coronpus* L.). Weed control was performed by the cooperating producer at the Johnsburg site.

Plots were 20-ft long at both sites and 5-ft wide for the Johnsburg site and 6-ft wide for the Captina site. For the Captina soil, composite soil samples were collected from each plot on 12 January 2007 to a depth of 4 inches to monitor changes in soil-test P following the first year of treatments. For the Johnsburg site, composite soil samples (0- to 4-inches) were collected in April from each plot to determine the initial soil chemical properties and uniformity within the plot area. Each composite 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. Selected soil chemical property means for each site are listed in Table 1. Soil organic matter in the Johnsburg silt loam averaged 4.2% as determined by weight loss on ignition. In late September 2006, 1000 lb pelleted 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 $P_2O_5 \times 2$ at green-up and following harvest 1), 135 (45 lb $P_2O_5 \times 3$ at green-up and following harvest 1 and 2), 180 (60 lb $P_2O_5 \times 3$ at green-up and following harvest 1 and 2), and 225 lb P_2O_5/acre (75 lb $P_2O_5 \times 3$ at green-up and following harvest 1 and 2). For the Johnsburg site, only the 0, 45, 90, and 135 lb P_2O_5/acre rates were evaluated with application at greenup and following the second and third harvests. Phosphorus fertilizer treatments were applied on 17 April (before green-up), 14 June following the first harvest, and 20 July following the second harvest on the Captina soil and 17 April (before greenup), 3 July following the second harvest, and 2 August following the third harvest on the Johnsburg soil. Potassium fertilizer (100 lb K_2O/acre) was applied on 17 April before green-up at both sites and repeated when N fertilizer was applied to each test. The greenup application of N fertilizer consisted of (30 April for Johnsburg and 9 May for Captina) 100 lb $(NH_4)_2SO_4$/acre plus 300 lb NH_4NO_3/acre at each site (~120 lb N/acre). Following the first and second harvests on the Captina, 120 lb N/acre (358 lb NH_4NO_3/acre) were applied to stimulate forage production resulting in a season total of 360 lb N/acre. For the Johnsburg soil, 90 lb N/acre as NH_4NO_3 were applied following the second and third harvests for a season total of 300 lb N/acre.

Forage was harvested by cutting an 18-ft long by 3.8-ft wide swath with a self-propelled sickle-bar mower at a height of 2.0 to 2.5 inches. At the Captina site, forage was harvested on 12 June, 15 July, 17 September, and 1 November. At the Johnsburg site, forage harvest was performed on 31 May, 2 July, 31 July, and 20 September. Hay harvests were scheduled every 28 to 35 days, but the final two harvests were delayed due to poor growth caused by a late summer drought. 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. Forage subsamples were ground to pass a 1-mm sieve and digested in concentrated HNO_3 and 30% H_2O_2 to determine forage P concentrations and calculation of P uptake.

The P-rate trial on the Captina had 5 replicates, but only four replicates were used at the Johnsburg site. For all studies, analysis of variance procedures were conducted by site with the PROC GLM procedure in SAS v9.1 (SAS Institute, Inc., Cary, N.C.). Forage yields were analyzed by harvest time and for season-total production. When appropriate, mean separations were performed using Fisher's Protected Least Significant Difference method at a significance level of 0.10. Linear yield trends for each harvest and season-total were also estimated across P rates.

RESULTS AND DISCUSSION

Precipitation during the spring and early summer of 2007 was near normal allowing for the production of high forage yields. Precipitation measured at Drake Field (Fayetteville, Ark.) totaled 16.6 inches from April through September 2007 compared to the normal amount of 21.3 inches. Rainfall in August and September was approximately 2.5 inches per month and was accompanied by above-normal temperatures which limited late-season forage growth.

Soil-Test P

Mehlich-3-extractable P concentrations in the Johnsburg soil were statistically similar among plots assigned to the six P-fertilizer rates with an average of 1020 ppm (Table 1) and means varying from 989 to 1046 ppm (Table 2). All soil-test P means would be classified as 'Above Optimum' by University of Arkansas guidelines, suggesting that bermudagrass yield would not benefit from the application of P fertilizer and that soil contains sufficient P to sustain high forage yields with no P fertilization.

For the Captina silt loam, soil-test P following the first year of fertilization (2006) declined numerically when 0 and 45 lb P_2O_5/acre were applied whereas soil-test P for the greater P rates remained numerically constant (90 to 135 lb P_2O_5/acre) or increased (≥180 lb P_2O_5/acre, Table 2). The unfertilized control soil-test P level in 2007 was still considered 'Above Optimum' (>50 ppm) and would receive an agronomic recommendation of 0 lb P_2O_5/acre. After a single year of fertilization and cropping, 2007 soil-test P on the Captina soil changed by ~1 ppm P/4 lb P_2O_5 applied (ppm Mehlich-3 P = 91 + 0.26x; $r^2 = 0.92$).

Phosphorus Trial - Captina Soil

Similar to the results of 2006 (Slaton et al., 2007), P-fertilizer rate had no significant influence on bermudagrass yields for harvests 1, 2, 4, and the season-total yield, but was significantly affected by P fertilization for the third harvest (Table 3). Bermudagrass yields also showed no significant trend across P rates for the first and fourth harvests, but forage yields increased significantly and linearly as P rate increased for harvest 2 (slope = 2.8 lb forage/lb P_2O_5/acre; Pr>F = 0.0234), harvest 3 (slope = 4.1 lb forage/lb P_2O_5/acre; Pr>F = 0.0009) and the season total yield (slope = 6.6 lb forage/lb P_2O_5/acre; Pr>F = 0.0235). These data suggest that to achieve maximal forage yield potential, P fertilization may be required on low-cation-exchange capacity soils that have Mehlich-3-extractable P >50 ppm. Late-season forage yields have increased with P fertilization for two consecutive years on the Captina soil, however, the overall yield increase has been relatively small. Application of nominal rates (30-60 lb P_2O_5/acre) of P fertilizer after the first and/or second hay harvests may be warranted to maintain high forage yield potential on soils with a low buffering capacity.

Forage P concentrations were >0.20% (Table 4) for each harvest and P rate and considered sufficient (Plank and Campbell, 2000). Phosphorus fertilization rate influenced forage-P concentrations for each harvest, unlike in 2006 when only harvests 2 and 3 showed increased forage P concentrations due to P rate (Slaton et al., 2007). Application of P rates ≥90 lb P_2O_5/acre increased forage P concentrations at each harvest. Although not statistically compared, forage P concentration within each P-fertilizer rate declined numerically for the first three harvests.

Total P_2O_5 equivalent uptake by harvested forage was affected significantly by annual P rate for each individual harvest and the season-total harvest with the greatest numerical difference among treatments occurring for the third harvest (Table 4). Season total P_2O_5 removal was greater than or nearly equal to P inputs from fertilization when ≤90 lb P_2O_5/acre/yr were applied. The 2007 data showed that 11 to 13 lb P_2O_5/ton forage/acre are removed in harvested bermudagrass. Plant recovery of fertilizer P, calculated by difference, ranged from 11 to 17% of the P fertilizer applied during the second year (2007).

Phosphorus Trial - Johnsburg Soil

For the Johnsburg soil, P fertilization had no significant influence on forage yield for any single harvest, but showed a consistent, non-significant trend for nominal yield increases for harvests 1, 3, and 4 when P fertilizer was applied, which was significant when evaluated only for season-total yield (Table 3, slope = 9.9 lb forage/lb P_2O_5/acre; Pr>F = 0.0413). Forage receiving 90 and 135 lb P_2O_5/acre produced greater total yields than the unfertilized control, which is surprising given this soil had a very high soil-test P (Table 1). These data suggest that soils that test high in P may still require nominal amounts of P fertilizer to satisfy crop P requirements when growth and nutrient uptake are rapid and may exceed the soil's ability to replenish soil solution P.

Forage P concentration was significantly affected by P-fertilizer rate only for the second harvest (Table 5). Similar to the common bermudagrass grown on the Captina soil, the forage-P concentrations tended to decline numerically with each harvest. However, the mixture of forage grasses contained much higher numerical tissue-P concentrations (Table 5) than common bermudagrass on the Captina soil (Table 4). Despite lower season total yields (Table 3) on the Johnsburg soil, the mixed-species forage with high tissue-P concentrations removed greater numerical amounts of P (Table 5) compared with the Captina soil (Table 4) for each applied P rate. Season-total P uptake and removal increased significantly due to P fertilization (Table 5). Forage recovery of fertilizer P, calculated by difference, accounted for 23 to 30% of the applied P fertilizer. Application of the highest P rate (135 lb P_2O_5/acre) was needed to balance P inputs with P uptake and removal. The mixed-grass forage removed 23 to 27 lb P_2O_5/ton/acre, which was two-times the removal rate by common bermudagrass grown in the Captina soil. The greater P removal by harvested forage on the Johnsburg soil may be due to i) high P availability (Table 1), ii) the dominant grass species present may have greater genetic potential for P accumulation compared with bermudagrass, or iii) other factors or combinations of factors which are less obvious.

PRACTICAL APPLICATION

The second year of research on the Captina soil indicated that reduction in soil-test P can occur within a short time on soils with 'Above Optimum' soil-test P levels that are managed for medium to high forage yields. Soil-test P declined numerically from 2006 to 2007 when 0 or 45 lb P_2O_5/acre were applied in 2006. Phosphorus fertilization of warm-season grasses grown on soils with an 'Above Optimum' soil-test P level showed some positive responses to P fertilization suggesting that agronomic recommendations for hay production may need adjusting. Late-season forage yields may require a nominal rate of P fertilizer to maximize yield potential. Nutrient management plans should recognize the short- and long-term importance of estimating crop nutrient removals and developing agronomically and environmentally sound soil sampling and fertilization programs to ensure that soil fertility and productivity are maintained. These studies will be continued for at least one more year to evaluate the effects of annual fertilization rate on forage yields and soil-test P levels.

ACKNOWLEDGMENTS

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

Test	Year	Soil pH	Mehlich-3-extractable nutrients P	K	Ca	Mg	S	Na	Fe	Mn	Zn	Cu
			(ppm)									
Captina[z]	2006	5.1	116	113	613	60	26	9	179	193	7.8	1.5
Captina[z]	2007	5.2	--	213	587	63	21	5	167	147	6.5	1.7
Johnsburg[z]	2007	6.6	1020	229	2611	86	13	12	236	89	29.2	5.2

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

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

Annual P rate	Johnsburg silt loam Mehlich-3 P 2007	Captina silt loam Mehlich-3 P 2006	Captina silt loam Mehlich-3 P 2007
(lb P_2O_5/acre)	(ppm)		
0	1046	112	97
45	999	123	98
90	1033	114	113
135	989	115	116
180	--	118	144
225	--	112	151
LSD(0.10)	NS[z]	NS	17
P-value	0.5069	0.7687	<0.0001

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

Table 3. Forage yields as affected by P fertilization rate for trials conducted on Captina and Johnsburg silt loams in Fayetteville, Ark., during 2007.

Season total P_2O_5 rate	Rate and application frequency	Forage yield Johnsburg silt loam (year 1) Total	Harv1	Harv 2	Harv 3	Harv 4	Captina silt loam (year 2) Total	Harv 1	Harv 2	Harv 3	Harv 4
(lb P_2O_5/acre)		(lb/acre)									
0	--	9873	2944	2082	3982	865	14658	5079	3844	4223	1512
45	45 × 1[z]	10106	3144	2070	4064	828	15023	5049	3804	4611	1559
90	45 × 2	11178	3388	2209	4503	1078	15571	5134	4019	4858	1560
135	45 × 3	10947	3208	2050	4624	1065	15778	5188	4162	4910	1518
180	60 × 3	--	--	--	--	--	16388	5089	4355	5295	1649
225	75 × 3	--	--	--	--	--	15870	4808	4364	5086	1612
LSD(0.10)		1059	NS[y]	NS	NS	NS	NS	NS	NS	503	NS
P-value		0.0862	0.4505	0.8891	0.3774	0.8429	0.2402	0.8844	0.2874	**0.0243**	0.7363
C.V., %		7.0	11.8	15.2	13.7	30.9	7.3	10.0	11.5	9.6	10.2

[z] Phosphorus fertilizer applied in three split applications including at greenup and following selected harvests.
[y] NS = not significant (*P*>0.10).

Table 4. Bermudagrass forage P concentrations and total P uptake as affected by P fertilization rate for a trial conducted on a Captina silt loam in Fayetteville, Ark., during 2007.

	Forage P concentration (by harvest)				Forage P total uptake (by harvest)				
Total P_2O_5 rate	Harv 1	Harv 2	Harv 3	Harv 4	Season	Harv 1	Harv 2	Harv 3	Harv 4
(lb P_2O_5/acre)	(% P)				(lb P_2O_5/acre)				
0	0.24	0.24	0.21	0.24	77	28	21	20	8
45	0.26	0.24	0.21	0.25	82	30	21	23	9
90	0.27	0.25	0.24	0.27	92	32	23	27	10
135	0.29	0.27	0.24	0.28	98	35	26	28	10
180	0.29	0.27	0.25	0.29	101	34	27	29	11
225	0.31	0.28	0.26	0.30	103	34	28	30	11
LSD(0.10)	0.015	0.013	0.016	0.009	6	3	3	3	0.9
P-value	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	0.0102	0.0042	<0.0001	0.0002
C.V., %	4.8	4.5	6.1	3.2	6.1	9.6	12.1	9.4	8.8

Table 5. Bermudagrass and crabgrass mixed forage P concentrations and total P uptake as affected by P fertilization rate for a trial conducted on a Johnsburg silt loam near Fayetteville, Ark., during 2007.

	Forage P concentration (by harvest)				Forage P total uptake (by harvest)				
Total P_2O_5 rate	Harv 1	Harv 2	Harv 3	Harv 4	Season	Harv 1	Harv 2	Harv 3	Harv 4
(lb P_2O_5/acre)	(% P)				(lb P_2O_5/acre)				
0	0.24	0.24	0.21	0.24	77	28	21	20	8
0	0.59	0.53	0.48	0.44	115	39	25	43	9
45	0.60	0.55	0.53	0.40	126	43	26	49	8
90	0.58	0.56	0.56	0.42	142	45	28	57	11
135	0.62	0.58	0.53	0.43	146	46	27	56	10
LSD(0.10)	NS	0.03	NS	NS	18	NS	NS	9	NS
P-value	0.6710	0.0829	0.1927	0.5508	0.0557	0.4568	0.6707	0.0728	0.8559
C.V., %	7.9	4.5	8.9	8.6	9.3	14.6	14.7	14.1	37.4

Bermudagrass Forage Response to Potassium Fertilization

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

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Potassium (K) is an important macronutrient for forage production in Arkansas that has received much less attention than phosphorus (P). 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 of P/ton forage (12 to 15 lb P_2O_5/ton). For this reason, 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 very limited rates, application of inorganic-K fertilizers will be needed to maintain adequate soil K and high forage yield potential.

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 north Arkansas (Keisling et al., 1979)

Research investigating forage yield and quality 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, forage quality, and soil-test K.

PROCEDURES

Fertilization trials were initiated (year 1) in April 2006 on an established common bermudagrass field on a Captina silt loam at the Main Agricultural Experiment Station (MAES) located in Fayetteville, Ark., and in April 2007 on an established field of 'Midland' bermudagrass in a production field near Fayetteville, Ark. The first year results at MAES were reported by Slaton et al. (2007) and the second year of this trial is described in this report. For the Captina, the same K rates were applied to the same plots each year. The Captina soil had been used for hay production and grazing with a history of manure application. The Johnsburg silt loam had received biosolid applications for several years, but none since 2003 and is used only for hay production. The Captina site was managed with no irrigation, but the Johnsburg site was irrigated once in early September. Forage at the Johnsburg site was a mixture of crabgrass, ryegrass, foxtail, and bermudagrass with the dominate grass species in 2007 being crabgrass.

Weed control on the Captina soil was performed by applying glyphosate (Roundup WeatherMax at 1 pt/acre) on 28 February before greenup to suppress/control winter weeds. Cimarron Max (2 qt/acre of 2,4-D + dicamba plus 0.5 oz metsulfuron/acre) was applied on 19 June following the first harvest primarily to control buckhorn plantain (*Plantago coronopus* L.).

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 the Captina soil, composite soil samples were collected from each plot on 12 January 2007 to a depth of 4 inches from each plot to monitor changes in soil-test K following the first year (2006) of treatments. For the Johnsburg soil, composite soil samples were collected to a depth of 4 inches to determine the initial soil chemical properties and uniformity among plots. 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 organic matter in the Johnsburg silt loam averaged 4.6% as determined by weight loss on ignition. In late September 2006, 1000 lb pelleted lime/acre were applied to the Captina soil to maintain soil pH.

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 on 17 April (before green-up), 14 June following the first harvest, and 20 July following the second harvest on the Captina and on 17 April, 3 July following the second harvest, and 2 August following the third harvest on the Johnsburg soil. Phosphorus fertilizer (100 lb triple superphosphate/acre) was broadcast after the second harvest on the Captina. At green-up (30 April for Johnsburg and 9 May for Captina) 100 lb $(NH_4)_2SO_4$/acre plus 300 lb NH_4NO_3/acre were applied (~120 lb N/acre) to each site. Following the first and second harvests on the Captina, applications of 120 lb N/acre as NH_4NO_3 were made to stimulate forage production resulting in a season total of 360 lb N/acre. For the Johnsburg soil, 90 lb N/acre as NH_4NO_3 were applied following the second and third harvest for a season total of 300 lb N/acre.

Forage was harvested by cutting an 18-ft long by 3.8-ft wide swath with a self-propelled sickle-bar mower at a height of 2.0 to 2.5 inches. Forage was harvested on 12 June, 15 July, 17 September, and 1 November on the Captina and 31 May, 2 July, 31 July, and 20 September on the Johnsburg soil. Hay harvests were scheduled every 28 to 35 days, but some harvest times were delayed due to poor growth caused by a late summer drought. 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 sub-sample 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 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. Forage was also analyzed for NO_3-N, crude protein (CP), acid digestible fiber (ADF), and total-digestible nutrients (TDN).

The K-rate experiments were randomized complete block designs with each fertilizer rate replicated five times. Analysis of variance procedures were conducted by site with the PROC GLM procedure in SAS v9.1 (SAS Institute, Inc., Cary, N.C.). Forage yields were analyzed by harvest time and for the season total production. 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 2007 was near normal allowing for the production of high forage yields. Precipitation measured at Drake Field (Fayetteville, Ark.) totaled 16.6 inches from April through September 2007 compared to the normal amount of 21.3 inches. Rainfall in August and September was approximately 2.5 inches per month and was accompanied by above-normal temperatures which may have limited late-season forage growth.

Soil-Test Potassium

Mean Mehlich-3-extractable K concentrations were statistically similar among plots assigned to the six K-fertilizer rates at the Johnsburg site for an average of 207 ppm (Table 1) with treatment means ranging from 192 to 225 ppm (Table 2). All the treatment soil-test K means were classified as 'Above Optimum' suggesting that bermudagrass yields would not be increased by K fertilization.

For the Captina soil, soil-test K in 2007, after one year of K fertilization, declined numerically when no K was applied in 2006 and soil-test K for the other K rates remained numerically constant (100 to 200 lb K_2O/acre) or increased (≥300 lb K_2O/acre, Table 2) compared to 2006 values. Soil K extracted with the HNO_3 method followed similar trends across K rates as described for Mehlich-3 K. The unfertilized control soil-test K level in 2007 would be considered 'Low' (61 to 90 ppm) and receive a recommendation for 230 to 380 lb K_2O/acre for annual yield goals of 4 to 8 tons/acre. Soil-test K in treatments receiving ≥300 lb K_2O/acre in 2006 was increased above 175 ppm which is the threshold considered 'Above Optimum' and would have received a recommendation for no K fertilizer in 2007. After a single year of fertilization and cropping, soil-test K on the Captina soil changed by 0.31 ppm/1 lb K_2O applied (ppm Mehlich-3 K = 83 + 0.31x; $r^2 = 0.98$; mean soil-test K data in Table 2).

Potassium Trial - Captina Soil

Forage yields on the Captina soil were affected significantly by K fertilization for each harvest and the sum total of all four harvests in 2007 (Table 3). Bermudagrass plots receiving 0 and 100 lb K_2O/acre could be visually identified throughout the year by a darker green color, brown spot on leaves, and overall reduced growth. Forage yields receiving no K produced only 59% of the yield produced by the highest yielding treatment (500 lb K_2O/acre). Sum total forage yields, by K application rate, followed the order of 0 < 100 < 300 = 200 = 400 < 500 lb K_2O/acre. The relative yield potential of bermudagrass receiving 0 and 100 lb K_2O/acre across the first three harvests ranged from 45 to 62% and 62 to 87%, respectively, with lower relative yields produced by the second or third harvest compared to the highest yielding treatment. Yields for the fourth and final harvest were also affected significantly, but the magnitude of yield difference among K rates was less than previous harvests presumably due to the slow rate of forage growth. The trend for relative yields to decline after the first harvest suggests frequency, timing, and rate of K-fertilization can influence forage yields on K-deficient soils. For the season, forage yields showed a trend to increase linearly at a rate of 11.1 lb forage/1 lb K_2O applied.

Forage K concentrations were below 1.5%, the established critical concentration, for forage receiving 0 lb K_2O/acre at the first three harvests, 100 lb K_2O/acre for harvests 2 and 3, and 200 lb K_2O/acre for harvest 4 (Table 4). In general, K concentrations increased as K rate increased and decreased with each subsequent harvest for K rates <300 lb K_2O/acre. Total K uptake followed similar trends as described for K concentration. Season total K uptake increased as K rate increased with >400 lb K_2O/acre removed by forage receiving 400 and 500 lb K_2O/acre/yr. The rate of K removal ranged from 21 to 55 lb K_2O/ton/acre among K application rates with removal by K rates producing moderate to high forage yields ranging from

50 to 55 lb K_2O/ton/acre. Recovery of K fertilizer applied in 2007, calculated by difference, was high and ranged from 67 to 110%. The high K-fertilizer recovery values may be attributed to plant uptake of some K applied in 2006 and the moderate to high yields in 2007.

Potassium Trial - Johnsburg Soil

The mixed-grass forage species on the Johnsburg soil showed no significant yield differences to K fertilization for the first, second, fourth, and season total harvest yields (Table 3). For the third harvest, season-total K application rates of 200 to 500 lb K_2O/acre increased yields by 12 to 29% above forage receiving no K. The lack of significant yield increases from K fertilization is likely due to the lower overall forage yields and an above-optimum soil-test K level compared with the Captina soil.

Within each K rate, forage K concentrations declined numerically with each subsequent harvest (Table 5). Significant differences in forage K concentrations were observed for all harvests and generally showed that K concentration increased as K rate increased. Total K uptake and removal by harvested forage increased as K rate increased. Depending on K rate, 300 to 500 lb K_2O/acre/yr was required to balance K inputs and removals. On average, the amount of K_2O/ton/acre removed increased as K rate increased and ranged from 53 to 79 lb K_2O/ton/acre among K rates, suggesting luxury consumption and removal of K. The K removal rate by the mixed grass species grown on the Johnsburg soil was numerically greater than for common bermudagrass grown on the Captina soil. Plant recovery of the applied K fertilizer declined as K rate increased and ranged from 36 to 53% of the applied K rate. Reasons for the greater K removal per ton of harvested forage on the Johnsburg soil are not clearly understood but may be due in part to the mixture of grass species having greater genetic potential to accumulate K than bermudagrass.

Forage Quality Evaluations

Forage from selected treatments and the first three harvests on the Captina soil was also evaluated for forage quality. Numerical forage quality values varied among harvest times and data were analyzed by harvest using single-degree-of-freedom contrasts to identify potential differences between i) forage receiving 0 lb K_2O/acre/year compared to forage receiving 100 to 500 lb K_2O/acre/year, and ii) forage receiving 0 to 100 lb K_2O/acre/year compared to forage receiving 300 to 500 lb K_2O/acre/year. These treatments were selected for analysis and comparison because they produced different yields (Table 3). Forage crude protein (CP) and NO_3-N concentrations followed similar patterns among harvest times (Table 6) with tendencies for both to be greater in forage receiving little or no K fertilizer. These data suggest that K-deficient forage may contain high NO_3-N and protein contents which may be explained by the functions of K in plant metabolism of N. When K nutrition limits plant growth, N may accumulate in plant tissues rather than be diluted by additional plant growth. Although K-deficient plants had greater total N and CP contents the total amount of forage CP (calculated from plant total N) produced during the season was much greater when K was applied in sufficient amounts due to greater yield production. Potassium also aids in reduction of NO_3-N into amino acids, the building blocks of protein. A proportion of the N taken up by plants receiving no K apparently remained in the NO_3-N form rather than be assimilated into amino acids and proteins due to K deficiency. Acid digestible fiber and TDN showed no consistent trends across forage harvest times among annual K rates (Table 7).

PRACTICAL APPLICATION

The second year of research on the Captina soil indicated that depletion of soil K can occur within a short time on soils with 'Medium' soil-test K levels that are managed for medium to high forage yields. Inadequate K fertilization for two-years caused K deficiency with second-year yield losses ranging from 21 to 43% when 100 and 0 lb K_2O/acre/yr, respectively, were applied to a soil with an initial (2006) Medium soil-test K level. Furthermore, relative to the highest yielding K treatments, yield losses were larger on mid- to late-season harvests compared to the first harvest suggesting that K application rate, frequency, and/or time of application are important considerations for forage production on low cation-exchange-capacity soils. When only a limited amount of K fertilizer will be applied, K fertilization after the first harvest may help reduce yield losses from K deficiency. Growers should routinely monitor soil-test K and evaluate the balance between estimates of K removal and actual K inputs to maintain soil productivity for forages. These studies will be continued for at least one more year to evaluate the effects of annual fertilization rate on forage yields and soil-test K levels.

ACKNOWLEDGMENTS

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

		Soil	Mehlich-3-extractable nutrients									
Soil series	Year	pH	P	K	Ca	Mg	S	Na	Fe	Mn	Zn	Cu
			(ppm)									
Captina[z]	2006	5.0	121	116	710	71	29	11	179	193	6.9	1.6
Captina[z]	2007	5.3	109	--	629	76	21	6	163	123	6.2	1.9
Johnsburg[z]	2007	6.5	1284	207	2919	94	13	33	225	69	45.6	7.5

[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 before K fertilization and 2007 as affected by K fertilizer rate applied in 2006 on a Captina silt loam and in 2007 before K fertilizer rates were applied to a Johnsburg silt loam.

		Captina silt loam			
	Johnsburg silt loam	Mehlich-3 K		HNO_3 K	
Annual K rate	Mehlich-3 K 2007	2006	2007	2006	2007
(lb K_2O/acre)	(ppm)				
0	207	113	85	427	382
100	198	118	124	440	438
200	210	125	128	462	463
300	225	108	176	473	539
400	192	106	211	430	590
500	209	121	240	440	647
LSD(0.10)	NS[z]	NS	25	NS	47
P-value	0.7555	0.3633	<0.0001	0.6413	<0.0001

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

Table 3. Forage yields as affected by K fertilization rate for trials conducted on Captina and Johnsburg silt loams in Fayetteville, Ark., during 2007.

	Rate and	Forage yield									
Season total	application	Johnsburg silt loam (year 1)					Captina silt loam (year 2)				
K_2O rate	frequency	Total	Harv1	Harv 2	Harv 3	Harv 4	Total	Harv 1	Harv 2	Harv 3	Harv 4
(lb K_2O/acre)		(lb/acre)									
0	--	10523	3569	2337	3241	1376	9610	3315	2670	2385	1240
100	100 × 1[z]	9991	3335	2161	3286	1209	13025	4717	3378	3574	1356
200	100 × 2	10269	3412	2241	3833	783	15172	5147	4203	4227	1595
300	100 × 3	10769	3405	2313	4188	863	14553	4593	3997	4442	1521
400	133 × 3	11079	3521	2641	3641	1276	15194	4918	4306	4403	1567
500	167 × 3	11579	3770	2253	4100	1456	16197	5449	4117	5230	1401
LSD(0.10)		NS[y]	NS	NS	397	NS	834	325	615	564	173
P-value		0.3576	0.9472	0.2389	0.0055	0.3966	<0.0001	<0.0001	0.0011	<0.0001	0.0140
C.V., %		9.6	21.0	13.2	9.7	34.0	5.5	6.3	14.9	12.8	11.0

[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. Bermudagrass forage K concentration and total K uptake as affected by K-fertilization rate for a trial conducted on a Captina silt loam in Fayetteville, Ark., during 2007.

	Forage K concentration (by harvest)				Forage K uptake (by harvest)				
Total K_2O rate	Harv 1	Harv 2	Harv 3	Harv 4	Total	Harv 1	Harv 2	Harv 3	Harv 4
(lb K_2O/acre)	(% K)				(lb K_2O/acre)				
0	0.98	1.03	0.79	0.57	103	39	34	23	9
100	1.67	1.35	0.97	0.70	203	95	55	42	11
200	1.96	2.07	1.50	1.10	323	121	105	76	21
300	2.25	2.39	1.85	1.70	367	125	115	97	31
400	2.38	2.46	2.05	1.78	419	141	125	108	34
500	2.24	2.67	2.02	1.95	440	147	132	127	33
LSD(0.10)	0.19	0.45	0.23	0.10	34	14	21	13	4
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
C.V., %	9.1	20.5	13.8	7.4	10.2	11.7	20.7	14.9	16.4

Table 5. Bermudagrass and crabgrass mixed forage K concentration and total K uptake as affected by K fertilization rate for a trial conducted on a Johnsburg silt loam in Fayetteville, Ark., during 2007.

	Forage K concentration (by harvest)				Forage K uptake (by harvest)				
Total K_2O rate	Harv 1	Harv 2	Harv 3	Harv 4	Total	Harv 1	Harv 2	Harv 3	Harv 4
(lb K_2O/acre)	(% K)				(lb K_2O/acre)				
0	3.12	2.55	1.46	1.10	276	133	72	57	19
100	3.69	3.22	1.83	1.47	329	148	84	80	22
200	3.94	3.20	2.72	1.55	384	161	87	126	14
300	3.80	3.07	2.62	2.00	393	158	85	133	21
400	3.67	3.22	3.17	2.21	430	155	102	139	34
500	3.61	3.42	3.27	2.32	450	163	93	161	42
LSD(0.10)	0.29	0.22	0.33	0.16	44	NS[z]	11	20	10
P-value	0.0021	<0.0001	<0.0001	<0.0001	<0.0001	0.7919	0.0044	<0.0001	0.0032
C.V., %	7.2	6.6	11.9	7.2	10.7	23.4	11.9	15.6	31.6

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

Table 6. The effect of selected K fertilization rates on crude protein and NO_3-N of forage for the first three harvest times in 2007 at the MAES.

	Forage crude protein			Forage NO_3-N		
Total K_2O rate	Harv 1	Harv 2	Harv 3	Harv 1	Harv 2	Harv 3
(lb K_2O/acre)	(%)			(ppm)		
0	20.4	20.8	20.8	1042	1325	814
100	18.1	21.8	19.1	708	1018	585
300	18.5	20.5	17.9	724	1200	600
500	17.0	20.2	16.5	692	1249	564
C.V., %	6.8	3.6	7.4	34.1	17.1	26.2
Single Degree of Freedom Contrasts - *P*-values						
0 K vs 100-500 K	0.0023	0.7569	0.0013	0.0353	0.1482	0.0204
0 & 100 K vs 300 & 500 K	0.0234	0.0167	0.0009	0.1881	0.6349	0.1429

Table 7. The effect of selected K fertilization rates on Acid Digestible Fiber (% ADF) and Total Digestible Nutrients (% TDN) of forage for the first three harvest times in 2007 at the MAES.

	Forage ADF			Forage TDN		
Total K_2O rate	Harv 1	Harv 2	Harv 3	Harv 1	Harv 2	Harv 3
(lb K_2O/acre)	(%)			(%)		
0	20.4	20.8	20.8	1042	1325	814
0	31.5	30.4	28.0	79.3	78.2	78.2
100	32.1	28.6	28.1	77.4	80.0	75.4
300	31.8	29.5	28.6	77.5	79.1	75.1
500	31.8	28.3	28.7	75.0	79.4	73.2
C.V., %	3.6	5.6	2.0	2.7	1.0	3.0
Single Degree of Freedom Contrasts (*P*-values)						
0 K vs 100-500 K	0.4754	0.0895	0.1464	0.0274	0.0108	0.0103
0 & 100 K vs 300 & 500 K	0.9755	0.4250	0.0389	0.0399	0.7132	0.0237

Wheat Grain Yield Response to Phosphorus and Potassium Fertilizer Rate

N.A. Slaton, R.E. DeLong, M. Mozaffari, S. Clark, C. Allen, and R. Thompson

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Phosphorus (P) is a common yield-limiting nutrient for winter wheat (*Triticum aestivum* L.) grown in Arkansas. Because wheat frequently shows P deficiency and responds favorably to P fertilization, numerous research trials have been performed to improve P fertilization recommendations. In contrast, few studies have been conducted to determine how wheat responds to K fertilization. Sweeney et al. (2000) reported that potassium (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 a USDA survey of Arkansas wheat growers, 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^{-1} (USDA-NASS, 2001).

Soil-test results are used by many farmers to determine whether P and K fertilizers should be applied to wheat. Soil-test-based fertilizer recommendations must be adequately researched to determine the range of soil-test nutrients within which wheat responds to P and K fertilization and to calibrate the optimum fertilizer rates needed to produce maximum yields for P- and K-deficient soils. A large number of fertilization trials must be conducted to provide accurate fertilization recommendations. During the 2006 to 2007 growing season, P and K fertilization trials were established with the ultimate objectives 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 2006 to evaluate the effect of P and K fertilization rate on wheat yield. Tests were located in commercial production fields on a Dundee silt loam in Poinsett County (Trumann) following corn (*Zea mays* L.) and a Hillemann silt loam in Poinsett County (White Hall) following soybean [*Glycine max* (Merr) L.]. The tillage practices, wheat cultivar, previous crop, and dates of agronomic importance for each site are listed in Table 1.

Individual plots consisted of 9 or 10 rows 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, *n* = 6) 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, and salt pH. Mean values of selected soil chemical properties are listed in Table 2.

Planting, pest control, and N fertilization of wheat were performed by each cooperating grower and were identical to the management practices applied to the field surrounding each test. Wheat was drill seeded at the Trumann site and broadcast and incorporated at White Hall. 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 fall or early winter to ensure these nutrients were not yield-limiting factors. Phosphorus fertilizer treatments were applied to the soil surface after wheat was seeded at rates of 0, 30, 60, 90, or 120 lb P_2O_5/acre as triple superphosphate. Potassium fertilizer treatments were applied to the soil surface at rates of 0, 40, 80, 120, or 160 lb K_2O/acre as muriate of potash.

Whole, aboveground plant samples were taken at Feekes stage 10.1 (early heading) at both sites to determine whole-plant P and K concentrations. For the Trumann site, 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. Because the White Hall site was broadcast seeded, a sample of wheat plants was collected from an area near the edge of each plot. 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% moisture.

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 levels of 0.05 and 0.10.

RESULTS AND DISCUSSION

The soil-test level associated with the average Mehlich-3-extractable P was classified as 'Very Low' (<16 ppm) at White Hall and 'Optimum' (36 to 50 ppm) at Trumann (Table 2). Based on the University of Arkansas fertilizer guidelines for winter wheat, the recommended P-fertilizer rates were 100 lb P_2O_5/acre for White Hall and 0 lb P_2O_5/acre for Trumann. The revised recommendations were designed to build and maintain soil-test P concentrations in the 'Medium' (26 to 35 mg P/kg) soil-test category for wheat yields of 70 bu/acre. For K trials, the average Mehlich-3-extractable K was 'Medium' for White Hall (91 to 130 ppm) and 'Optimum' (131 to 175 ppm) for Trumann. The recommended rates of K fertilizer were 60 lb K_2O/acre for White Hall and 0 lb K_2O/acre for Trumann.

Whole-plant P and K concentrations of wheat at early heading were not affected significantly by P or K rate for wheat grown at Trumann (Table 3), which contained optimum soil-test P and K levels (Table 2). However, P and K concentrations of wheat grown at White Hall were significantly affected by P and K fertilizer rate (Table 3). Phosphorus concentrations declined significantly as P rate increased. Although wheat dry matter production was not measured in this study, visual observations of wheat growth among P rates clearly indicated that P fertilization increased wheat growth dramatically in all replications. The decline in tissue P concentrations was likely due to increased dry matter production, which is known as a 'dilution effect'. Late-planted wheat has been shown to respond more readily to P fertilization than wheat planted at optimal dates and has potential to offset some of the negative influence of late seeding (Blue et al., 1990). In contrast to P, wheat K concentrations increased as K rate increased (Table 3). Potassium fertilization had no visually detectable influence on wheat dry matter production like P. Plant tissue samples were taken after freezing temperatures (-2 to -4°C or 24 to 28°F in northeast Arkansas) occurred on 7 and 8 April.

Wheat yield potential at both sites was affected negatively by the freezing temperatures in early April. Reports throughout Arkansas indicated that early planted and well-fertilized wheat may have suffered the greatest damage from the freezing temperatures. Wheat yields in these studies (Table 4) would be considered 'below average' in most years, however, for the 2006 to 2007 production year, these yields were considered average or better than average.

Wheat yields were affected significantly by fertilizer treatments only in the P-rate study at White Hall (Table 4). Grain yield declined significantly when >30 lb P_2O_5/acre were applied to the Hillemann soil with very low soil-test P. This was surprising because visual observations indicated that wheat vegetative growth and tillering increased dramatically as P rate increased. The increased growth may have promoted early maturity and increased wheat yield potential which subsequently increased yield loss due to freeze damage. Wheat at White Hall had not yet headed when the freezing temperatures occurred, but P may have accelerated plant development such that wheat plants receiving P were at a growth stage more sensitive to freezing temperatures than wheat receiving no P or only low rates of P. Although wheat yields at the Truman site or the K-rate trial in the Hillemann soil were not affected significantly by fertilizer treatments, they also showed that numerical wheat yields tended to decline as fertilizer rate increased. These data hint, but do not conclusively prove, that well fertilized wheat, especially with P, may be more susceptible to freeze damage.

PRACTICAL APPLICATION

The potential benefits of providing sufficient P and K for wheat, as well as other plants, often include promoting early plant maturity, resistance to diseases and other pests, stalk strength, tillering, vigorous growth, and improved yield. During the 2006 to 2007 growing season some of these potential benefits (e.g., early maturity) were realized, but were offset by the abnormally cold temperatures that damaged developing wheat grain in early April. Data collected from P and K rate trials during the 2006 to 2007 growing year will not be used in the database being developed to correlate soil-test recommendations and calibrate fertilizer rates for P and K due to significant damage from freezing temperatures that influenced wheat yield potential. Although these data do not aid in developing soil-test-based recommendations they may be useful at some future time for evaluating wheat response to fertilization in abnormal climatic conditions.

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Table 1. Selected agronomic information for P-rate trials with winter wheat conducted during the 2006 to 2007 growing season.

			Tillage/	Date of event		
Site	Soil series	Cultivar	previous crop	Plant	P applied	Harvest
				---------------------- (month/day) ------------------------		
White Hall	Hillemann	DK 9577	Conv/Soybean	Nov 27	Dec 18	June 8
Trumann	Dundee	Armor 3035	Conv/Corn	Oct 16	Dec 18	June 8

Table 2. Selected soil chemical property means (*n* = 6) of phosphorus and potassium fertilization trials conducted during the 2006 to 2007 growing season .

		Soil	Mehlich-3-extractable nutrients										
Nutrient site	SOM	pH	P[z]	K[x]	Ca	Mg	S	Na	Fe	Mn	Cu	Zn	B
	(%)		--- (ppm) ---										
Phosphorus													
White Hall	2.8	7.7	10	106	2029	285	22	32	257	153	1.7	1.9	1.0
Trumann	2.3	6.9	36	134	2101	356	13	22	262	38	2.2	4.9	0.9
Potassium													
White Hall	2.8	7.5	10	98	1775	281	23	31	253	151	1.5	1.7	0.8
Trumann	2.5	6.7	47	154	1954	344	12	16	268	46	2.0	5.0	0.9

[z] Standard deviation (*n*=6) of soil-test P in P trials was 1.7 ppm for the Hillemann soil at White Hall and 4.1 ppm for the Dundee soil at Trumann.

[y] Standard deviation (*n*=6) of soil-test K in K trials was 9.4 ppm for the Hillemann soil and 29.7 ppm for the Dundee soil.

Table 3. Winter wheat whole-plant P and K concentrations at Feekes stage 10.1 as affected by P and K fertilizer application rates at two sites during the 2006 to 2007 growing season.

Phosphorus trials			Potassium trials		
P rate	Trumann	White Hall	K rate	Trumann	White Hall
(lb P_2O_5/acre)	-------------- (% P) ---------------		(lb K_2O/acre)	-------------- (% K) ----------------	
0	0.25	0.30	0	2.07	1.32
30	0.27	0.27	0	2.27	1.46
60	0.28	0.28	80	2.36	1.58
90	0.28	0.26	120	2.20	1.83
120	0.28	0.24	160	2.28	1.90
P-value	0.1273	0.0050	*P*-value	0.2121	0.0024
LSD(0.10)	NS[z]	0.023	LSD(0.10)	NS	0.240

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

Table 4. Winter wheat grain yields as affected by P and K fertilizer application rate at two sites during the 2006 to 2007 growing season.

Phosphorus trials			Potassium trials		
P rate	Trumann	White Hall	K rate	Trumann	White Hall
(lb P_2O_5/acre)	------------ (bu/acre) -------------		(lb K_2O/acre)	------------ (bu/acre) --------------	
0	0.25	0.30	0	2.07	1.32
0	50	39	0	50	39
30	48	42	40	52	38
60	47	36	80	51	31
90	47	35	120	49	37
120	46	33	160	48	37
P-value	0.1326	0.0178	*P*-value	0.6527	0.2702
LSD(0.05)	NS[z]	5	LSD(0.05)	NS	NS
LSD(0.10)	NS	4	LSD(0.10)	NS	NS

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

Soybean Response to Phosphorus and Potassium Fertilization Rate

N.A. Slaton, R.E. DeLong, M. Mozaffari, J. Shafer, and J. Branson

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). The application rates of P and K fertilizers, as well as the state average soybean yields, have increased gradually across time while the planted soybean 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 USA the average prices of muriate of potash and triple superphosphate in 2006 were approximately \$271/ton (~\$0.23/lb K_2O) and \$395/ton (~\$0.43/lb P_2O_5), respectively. Based on these prices, the cost of 0-40-60, a relatively low rate of fertilizer, is \$31.00/acre which requires a soybean yield increase of about 4 to 6 bu/acre to break even when soybean prices range from \$5.00 to 8.00/ bu.

Many growers and consultants have questioned whether existing P and K fertilizer recommendations for soybean, developed from research in the 1970s and 1980s, are adequate to maximize and sustain high soybean and rotation crop yields. The primary objectives of this project 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 four Agricultural Experiment Stations (Cotton Branch Experiment Station, CBES; Pine Tree Branch Station, PTBS; Rice Research Extension Center, RREC; and Southeast Research Extension Center at Rohwer, SEREC) and one commercial production field during 2007. Specific soil and agronomic information for each site is listed in Table 1. Each location will be referred to by the site name listed in Table 1. In the commercial field, 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 field, 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 measuring 20-ft long by 13-ft wide were flagged in two adjacent areas for each nutrient trial. Before fertilizer was applied to the research tests, a composite soil sample was collected from the 0- to 4-inch depth from each replicate (*n* = 6-7) 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, CBES, and SEREC trials. Each trial was a randomized complete block design with at least 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 (60-120 lb K_2O/acre) was broadcast to the soil surface to ensure that K was not yield-limiting at sites with silt-loam soil texture. Granular B fertilizer (1.0 lb B/acre) was applied to all sites except the CBES, RREC, and SEREC trials. Each trial was a randomized complete block design with six replications.

For all tests, 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 18-ft-long section of the middle 4- to 5-ft 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 PTBS and PTBS-37 trials were 'Very Low' (<61 ppm); PTBS-38 was 'Low' (61 to 90 ppm); CBES and Hilleman trials were 'Medium' (91 to 130 ppm); RREC was 'Optimum' (131 to 175 ppm), and SEREC-cl and SEREC-sl were 'Above Optimum' (>175 ppm). The soil-test levels suggest that trials at RREC, SEREC-cl, and SEREC-sl would need no K fertilizer to produce maximal soybean yields. The trials at CBES and Hilleman were expected to show only small or no positive yield response to K fertilization, but nominal rates of K fertilizer would be recommended to maintain soil-K fertility. At RREC, no yield response was expected, but 50 lb K_2O/acre are recommended to replace the K removed by a 50 bu/acre soybean crop and account for field variability in soil-test K.

Long-term K trials located at Pine Tree Branch Station showed that soil-test K has been affected by annual K application rate following 8 years of K fertilization (Table 4). Mehlich-3 soil-test K has changed by 1 ppm/28 lb K_2O/acre and HNO_3 K has changed by 1 ppm/11 lb K_2O/acre. These estimates are for the gross amount of K applied and do not account for removal of K by harvested rice and soybean seed. Although Mehlich-3 soil-test K increases very slowly across time, a portion of the applied K is retained in the non-exchangeable pool, as measured by the HNO_3 extraction, which helps sustain soil productivity in regard to K fertility.

Potassium concentrations in recently matured trifoliate leaves at the R1 to R2 growth stage were affected by K fertilization at 6 of 8 sites (Tables 4 and 5). For the two sites that had the greatest soil-test K (Table 2), both located at SEREC, trifoliate leaf K concentrations were not affected by K fertilizer rate (Table 5). When significantly affected by K rate, tissue-K concentrations generally increased as K-fertilizer rate increased with maximal leaf K concentrations occurring for K rates of 80 to 160 lb K_2O/acre. Trifoliate K concentrations of the unfertilized control were considered deficient (<1.5% K) in all three trials at the PTBS and low in trials at CBES, Hillemann, and RREC (Slaton et al., 2007), suggesting that moderate to large yield responses might occur at these six sites. In general, leaf K concentrations of the unfertilized control decreased as soil-test K decreased among sites.

Soybean yields were significantly increased by K fertilization at the PTBS, PTBS-37, PTBS-38, CBES, and Hillemann sites (Tables 4 and 6). Application of ≥80 lb K_2O/acre produced near maximal soybean yields that were always significantly greater than the unfertilized control and usually greater than 40 lb K_2O/acre. Application of 80 lb K_2O/acre increased soybean yields by 9 to 53% compared to the unfertilized control. Soybean yields at the other sites showed no statistically significant positive or negative response to K fertilization. However, soybean yields receiving no K fertilizer at RREC were always numerically lower than yields of soybean receiving K.

P-Rate Trials

The University of Arkansas soil-test guidelines for soybean showed that soil-test P (Table 3) was 'Low' (16 to 25 ppm) at RREC and Hilleman sites; 'Medium' (26 to 35 ppm) at PTBS and CBES; and 'Above Optimum' (36 to 50 ppm) at SEREC-cl and SEREC-sl. Positive yield responses were expected to occur at the two sites having a 'Low' soil-test P level. No significant, positive response to P fertilization was expected at the PTBS and CBES, but 60 lb P_2O_5/acre are recommended to replace the P removed by a 50 bu/acre soybean yield, ensure adequate P nutrition for field areas that may have lower soil-test P levels, and maintain soil-P fertility.

Phosphorus concentrations in recently matured trifoliate leaves at the R2 growth stage were significantly affected by P application rate at 3 of 6 sites including CBES, Hillemann, and RREC (Table 7), which had the lowest soil-test P values (Table 3). At the three responsive sites, trifoliate leaf P concentrations increased as P rate increased, but were all above the established 0.30% P critical concentration. Previous P-rate trial results suggest that when tissue P concentrations increase from P fertilization, soybean yields oftentimes respond positively to P fertilization.

Soybean yields were significantly increased by P fertilization only at the RREC (Table 8). Application of ≥80 lb P_2O_5/acre produced similar yields that were significantly greater than for soybean receiving 0 or 40 lb P_2O_5/acre. The soil at RREC had the lowest soil-test P of all sites (Table 3) and is consistent with previous data collected which suggest that positive yield responses to P fertilization generally occur only on soils with Mehlich-3 P values <20 ppm in the top 4 inches.

PRACTICAL APPLICATION

Soybean is recognized as a crop that is responsive to K fertilization, but is considered less responsive to P fertilization. Results of trials conducted in 2007 support this generalization. The revised soil-test-based K-fertilizer recommendations for soybean appear to be reasonably accurate in identifying soils that respond to moderate to high rates of K fertilization. Soybean yields are usually increased when soil-test K is <110 ppm with yield increases from K becoming larger as soil-test K declines. Adequate data have been collected to correlate Mehlich-3 soil-test K with relative soybean yield and calibrate K-fertilizer rates needed to produce near maximal yields. Research on K fertilization should continue with emphasis on collecting data to determine whether fertilization strategies that rely on foliar-feeding are feasible, evaluate fall vs spring fertilization timings, and consider other soil textures (i.e., clayey soils) and soybean production systems (i.e., double-crop).

Recommendations for P require some adjustments to improve their accuracy for predicting soybean yield response to P fertilization. However, additional data are needed as the current database with P is not yet large enough to identify clear trends. Other soil (e.g., pH) and/or crop management (e.g., expected yield goal, irrigation, or previous crop) factors that influence crop response to fertilization may need to be considered to improve the accuracy of P recommendations for soybean on Arkansas soils. Such factors will be considered in future fertilizer recommendation revisions once sufficient data have been collected.

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Table 1. Selected soil and agronomic management information for eight P and K fertilization trials conducted in 2007.

Site	County	Soil series	Cultivar	Tillage - previous crop[z]	Row spacing	Plant date
					(in.)	(month/day)
CBES	Lee	Convent	Armor 52U2	Conv/Milo	30	May 11
Hillemann	Woodruff	Dubbs	DK 5066	No-till/Soybean	19	April 21
PTBS	St. Francis	Crowley	Ozark	Conv./Soybean	30	May 30
PTBS37	St. Francis	Calhoun	Armor 52U2	Conv/Rice	19	May 1
PTBS38	St. Francis	Calhoun	Armor 52U2	Conv/Rice	15	May 1
RREC	Arkansas	Dewitt	Armor 52U2	Conv/ Rice	7.5	May 7
SEREC-cl	Desha	Desha clay	Armor GP454	Conv./Soybean	19	May 15
SEREC-sl	Desha	Desha silt loam	Armor 47G7	Conv/Milo	19	May 19

[z] Conv. = conventional tillage.

Table 2. Selected soil chemical property means (*n* = 6 or 7) of K-fertilization trials conducted at eight sites during 2007.

	Soil	Organic	Mehlich-3-extractable nutrients											
Site	pH	matter	P	K	Ksd[z]	Ca	Mg	S	Na	Fe	Mn	Cu	Zn	B
K rate trials		(%)	---------- (ppm) ----------											
CBES	7.2	1.5	28	102	13	1116	243	7	21	148	155	1.0	0.8	0.3
Hillemann	7.1	2.1	27	113	6	1105	137	8	10	123	297	0.9	1.9	0.4
PTBS	7.1	2.4	26	55	3	1487	236	11	64	253	30	0.9	3.2	0.1
PTBS37	8.1	3.1	27	60	10	2587	373	11	46	258	205	1.2	5.3	1.0
PTBS38	8.0	3.0	24	71	5	1736	359	10	53	219	192	1.1	5.0	0.9
RREC	5.3	2.0	25	139	14	933	141	12	87	399	180	0.7	1.4	0.1
SEREC-cl	7.4	3.7	75	354	7	3590	93	11	134	211	69	2.2	2.9	0.6
SEREC-sl	7.8	2.6	135	272	*21*	3112	21	12	16	158	144	4.6	12.2	1.6

[z] Ksd is the standard deviation of the mean soil-test K value for each site.

Table 3. Selected soil chemical property means (*n* = 6) of P-fertilization trials conducted at six sites during 2007.

	Soil	Organic	Mehlich-3-extractable nutrients											
Site	pH	matter	P	Psd[z]	K	Ca	Mg	S	Na	Fe	Mn	Cu	Zn	B
P rate trials		(%)	(ppm)											
CBES	6.5	1.3	30	3	120	993	209	7	19	137	109	0.8	0.5	0.2
Hillemann	7.2	1.9	23	4	109	983	119	8	11	118	289	0.9	1.5	0.4
PTBS	7.2	2.6	33	4	53	1525	235	13	63	251	29	0.9	2.9	0.1
RREC	5.7	2.0	17	3	125	960	151	11	93	301	183	0.9	0.9	0.1
SEREC-cl	7.6	3.3	68	5	349	3695	98	11	158	205	72	2.3	2.9	0.5
SEREC-sl	7.1	2.5	107	20	235	1819	21	9	16	192	127	3.2	11.2	1.0

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

Table 4. Soil-test K, trifoliate-leaf K (at R2 stage), and seed yield data means from tests 37 and 38 at PTBS in 2007 as affected by annual soil-test K rate (same K rates applied since 2000).

Annual K rate	Soil-test K	HNO_3 K	R2 trifoliate	Seed yield
(lb K_2O/acre/yr)	(ppm)		(% K)	(bu/acre)
PTBS 37				
0	60	261	1.07	44
40	72	278	1.38	58
80	78	308	1.49	61
120	81	315	1.65	67
160	96	349	1.70	62
LSD(0.10)	11	21	0.11	7
P-value	0.0010	<0.0001	<0.0001	0.0006
C.V., %	10.9	5.6	6.2	9.3
PTBS 38				
0	71	279	1.25	47
40	67	282	1.67	66
80	72	301	1.94	68
120	78	315	1.99	67
160	97	361	2.09	72
LSD(0.10)	9	23	0.17	6
P-value	0.0008	0.0002	<0.0001	0.0011
C.V., %	9.5	5.9	7.6	7.4

Table 5. Trifoliate-leaf K concentrations of soybean at the R2 stage response to K-fertilizer rate at six sites during 2007.

K rate	CBES	Hillemann	PTBS	RREC	Desha-sl	Desha-cl
(lb K_2O/acre)	(% K)					
0	1.52	1.71	1.05	1.65	1.82	1.76
40	1.58	1.76	1.28	1.74	1.86	1.80
80	1.61	2.01	1.36	1.81	1.89	1.80
120	1.75	2.00	1.56	1.79	1.86	1.82
160	1.70	2.16	1.63	1.80	1.90	1.80
LSD(0.10)	0.15	0.09	0.10	0.10	NS[z]	NS
P-value	0.0829	<0.0001	<0.0001	0.0374	0.4255	0.7017
C.V., %	8.9	5.3	7.5	5.4	4.4	6.1

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

Table 6. Soybean seed yield response to K-fertilizer rate at six sites during 2007.

K rate	CBES	Hillemann	PTBS	RREC	Desha-sl	Desha-cl
(lb K_2O/acre)	(bu/acre)					
0	46	57	19	47	57	39
40	48	65	21	48	64	33
80	50	64	24	54	58	39
120	48	69	27	51	58	37
160	47	64	28	49	59	34
LSD(0.10)	2	6	4	NS^z	NS	NS
P-value	0.0572	0.0486	0.0127	0.7055	0.6411	0.4682
C.V., %	4.4	10.5	17.5	14.5	12.9	20.4

^{z} NS = not significant (P > 0.10)

Table 7. Trifoliate-leaf P concentrations of soybean at the R2 stage response to P-fertilizer rate at six sites during 2007.

P rate	CBES	Hillemann	PTBS	RREC	Desha-sl	Desha-cl
(lb P_2O_5/acre)	(% P)					
0	0.39	0.42	0.38	0.31	0.49	0.38
40	0.41	0.45	0.39	0.33	0.49	0.37
80	0.41	0.48	0.39	0.33	0.49	0.38
120	0.40	0.47	0.40	0.35	0.51	0.38
160	0.44	0.48	0.41	0.35	0.51	0.39
LSD(0.10)	0.020	0.028	NS^z	0.02	NS	NS
P-value	0.0090	0.0056	0.3769	0.0191	0.8028	0.5478
C.V., %	4.9	6.2	5.5	6.2	6.2	6.9

^{z} NS = not significant (P > 0.10)

Table 8. Soybean yield response to P-fertilizer rate at six sites during 2007.

P rate	CBES	Hillemann	PTBS	RREC	Desha-sl	Desha-cl
(lb P_2O_5/acre)	(bu/acre)					
0	41	65	25	48	52	50
40	40	66	25	51	53	40
80	39	64	26	62	55	46
120	40	63	27	58	55	41
160	41	67	28	59	57	42
LSD(0.10)	NS^z	NS	NS	3	NS	NS
P-value	0.8049	0.6546	0.4325	<0.0001	0.7521	0.3472
C.V., %	10.4	7.4	11.3	5.3	12.6	17.9

^{z} NS = not significant (P > 0.10).

Green Bean Yield as Affected by Nitrogen Fertilization Strategy

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

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Green or snap bean (*Phaseolus vulgaris L.*) is grown for processing on nearly 3,000 acres in Arkansas annually (USDA-NASS, 2007). Green beans comprise about 22% of the Arkansas vegetable acres grown for sale and about 43% of the vegetable acres grown for processing annually. The majority of Arkansas' green bean production is located in northwest Arkansas, which was at one time known as the state's 'Cannery Center' (Moke, 1952).

Green beans are a legume, but, on most soils, require some nitrogen (N) fertilizer to maximize yields. Few studies have been conducted to investigate how green bean responds to N fertilization rate and time of application. In the Midwest, no N fertilizer is recommended when green beans follow a legume crop like soybean or forages with legumes when soil organic matter is >3.0%, whereas 30 lb N/acre are recommended when soil organic matter is <3.0% (Midwest Vegetable Production Guide for Commercial Growers, 2007). When following a grain or vegetable crop in the rotation, 40 to 60 lb N/acre are recommended. In northwest Arkansas, growers manage green bean production without the benefit of annual research that aims to identify the most efficient rates and methods of N fertilization. The primary objective of this preliminary study was to evaluate how green bean yield responds to different N-fertilization programs.

PROCEDURES

A fertilization trial with green beans was initiated in May 2007 on a Captina silt loam at the Main Agricultural Experiment Station (MAES) at Fayetteville, Ark. Two composite soil samples were collected from the 0- to 4-inch depth within the plot area. Soil samples were oven-dried at 120°F, crushed to pass through a 2-mm sieve, and analyzed for water pH, organic matter by weight loss on ignition, inorganic N by extraction with KCl, and plant available nutrients by extraction with Mehlich-3 solution. The soil chemical property averages were 7.1 soil pH, 46 ppm soil-test P, 138 ppm soil-test K, 2058 ppm soil-test Ca, 47 ppm soil-test Mg, 12 ppm soil-test S, 117 ppm soil-test Mn, 4.3 ppm soil-test Zn, 18 ppm NO_3-N, 27 ppm NH_4-N, and 3.2% organic matter. Based on University of Arkansas fertilization guidelines, application of 40-40-40 (N-P_2O_5-K_2O) would have been recommended per acre for this soil.

Green bean seeds ('KSI 196' cv) were planted on 14 May in 30-inch-wide rows at a rate of 7 seed per row ft with a four-row planter into a conventionally tilled seedbed. Each plot was 15-ft long and contained 4 rows of beans. The specific fertilizers, application rates, and application times (stages of growth) that comprised each treatment are listed in Table 1. Fertilizer treatment applications identified as preplant, V2 to V3 stage, first bloom, and first bloom plus 1 week were applied on 14 May, 7 June, 15 June, and 22 June, respectively. The foliar treatments were applied with a CO_2-propelled backpack sprayer calibrated to deliver 15 gal/acre at 3 mph. The foliar-applied product was DuraPlant Mag-Net (Estes, Inc., Irving, Texas) with an analysis of 7-25-3 plus 0.05% B, 0.20% Fe, 0.10% Mn, and 0.50% Zn. The early-N treatment (Table 1) included a polymer-coated urea fertilizer (ESN, Environmentally Smart Nitrogen, 44-0-0) that was applied to the soil surface before planting.

The maturity of green beans for harvest was determined on 3 July by selecting the 10 largest beans from unfertilized border rows and removing one of the middle bean seeds from each pod. The length of 10 bean seeds averaged 104 mm (mean of 3 measurements) and harvest was scheduled for 6 July. The middle two rows of green beans were trimmed to approximately 10-ft, measured, and harvested on 6 July. The weight of fresh green beans from each plot was measured and 20 green beans were selected from each bag for size determination. The 20 green beans were sized by placing the middle of each bean on a ruler with bean sieve sizes of 1, 2, 3, 4, and 5. The sieve size of each bean was recorded and expressed as the percentage of beans in each sieve size category. Green bean fresh weights were adjusted to an acre basis for statistical analysis.

The experiment was a randomized complete block design with four replicates of each treatment. Yield and sieve size data were analyzed using the PROC GLM procedure in SAS v9.1 (SAS Institute, Inc., Cary, N.C.). When appropriate, mean separations were performed using Fisher's Protected Least Significant Difference method at a significance level of 0.10. Single degree of contrasts were also used to compare selected treatments or groups of treatments.

RESULTS AND DISCUSSION

Fresh green bean yields ranged from 9,189 to 11,702 lb/acre among treatments with an overall average of 10,407 lb/acre. Statistical analysis with the Fisher's Protected LSD multiple mean comparison indicated no significant yield or green bean size differences among treatments at the 0.10 probability level (Table 1). However, single-degree-of-freedom contrasts used to compare selected treatments showed that green beans receiving no N (the unfertilized control) yielded less (P=0.0261) than green beans receiving 73 lb N/acre (NH_4NO_3 and Urea Base Programs) and the NH_4NO_3 base program plus foliar fertilization (P=0.0378), but produced similar yields as green beans receiving the Base N rate plus additional N (P=0.1458). Yields among treatments receiving Base or Base Plus N rates were not different. Likewise, green beans receiving no N (the unfertilized control) had a lower percentage of sieve size 5 beans (P=0.0606) than green beans receiving 73 lb N/acre (NH_4NO_3 and Urea Base Programs), Base Program plus additional N (128 lb N/acre; P=0.0099), and the NH_4NO_3 base program plus foliar fertilization (P=0.0908). All harvested and measured green beans had sieve sizes of 3 or larger with only 5 to 12% of green beans having sieve size #3. Thus, the greatest difference in green bean size was between sieve sizes 4 and 5.

PRACTICAL APPLICATION

Data suggest that N applied at the times and rates designated for the base program was sufficient to maximize green bean yield for this experiment regardless of the N source (urea or NH_4NO_3). Addition of extra N did not benefit green bean yield or size. Additional research (i.e., site-years) is needed to better identify the rates and times of N application for green bean production in northwest Arkansas. The soil at the MAES had an appreciable amount of inorganic N present at planting and research with other crops (i.e., wheat) at this site has shown less response to N soils in eastern Arkansas. Furthermore, soil moisture was not a growth-limiting factor during the time this study was conducted.

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Table 1. List of fertilizers, application rates, and application times comprising seven different fertilization strategies for green bean production.

		Fertilizer rates and sources			
Treatment	Fertilizer	Preplant	V2-V3	First bloom	Bloom + 1 wk
Control	--	100 lb 0-46-0/acAre	100 lb 0-0-60/acAre	--	--
NH_4NO_3 Base Program	DAP, 18-46-0	100 lb/acre	--	--	--
	NH_4NO_3, 34-0-0	--	100 lb/acre	--	--
	Amm Sulfate, 21-0-0-24S	--	100 lb/acre	--	--
	Potash 0-0-60	--	100 lb/acre	--	--
NH_4NO_3 Base Plus	18-46-0	100 lb/acre	--	--	--
	34-0-0	--	100 lb/acre	100 lb/acre	--
	21-0-0-24	--	100 lb/acre	100 lb/acre	--
	0-0-60	--	50 lb/acre	50 lb/acre	--
Urea Base Program	18-46-0	100 lb/acre	--	--	--
	Urea, 46-0-0	--	74 lb/acre	--	--
	21-0-0-24	--	100 lb/acre	--	--
	0-0-60	--	100 lb/acre	--	--
Urea Base Plus	18-46-0	100 lb/acre	--	--	--
	46-0-0	--	74 lb/acre	74 lb/acre	--
	21-0-0-24	--	100 lb/acre	100 lb/acre	--
	0-0-60	--	50 lb/acre	50 lb/acre	--
NH_4NO_3 Base + Foliar Feed	18-46-0	100 lb/acre	--	--	--
	34-0-0	--	100 lb/acre	--	--
	21-0-0-24	--	100 lb/acre	--	--
	0-0-60	--	100 lb/acre	--	--
	Foliar applied	--	--	1 gal/acre	1 gal/acre
Early N	18-46-0	100 lb/acre	--	--	--
	44-0-0	77 lb/acre	--	--	--
	46-0-0	--	--	74 lb/acre	--
	21-0-0-24	--	--	100 lb/acre	--
	0-0-60	100 lb/acre	--	--	--

Table 2. Fresh green bean yield and percentage of green beans of sieve size 5 as affected by N fertilization strategy.

Nitrogen fertilization strategy	Total N applied	Green bean yield	Sieve size 5
	(lb N/acre)	(lb/acre)	(%)
Unfertilized control	0	9,189	37
NH_4NO_3 Base	73	11,252	54
NH_4NO_3 Base Plus	128	10,194	60
Urea Base	73	11,557	46
Urea Base Plus	128	10,985	51
NH_4NO_3 Base + Foliar Feed	73	11,702	51
Early N	107	9,193	45
LSD(0.10)		NS[z]	NS
P-value		0.1809	0.1614
C.V., %		17.8	27.9

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

Effect of EDTA on the Foliar Absorption of Trace Element Fertilizers

S.P. Stacey and D.M. Oosterhuis

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Foliar fertilization is an important method of supplementing soil nutrient additions, particularly on soils that readily adsorb and fix trace-element ions. A large number of fertilizer companies and extension groups have recommended that chelating agents be used to complex Fe, Mn, Mg, Zn, and Cu in foliar sprays, at considerable expense to the farmer. The scientific literature contains limited information on the use of chelates in foliar fertilizers. One recent study showed that chelates slowed Fe (III) absorption into leaves (Schonherr et al., 2005). However, published data are still limited, so it is difficult to advise farmers about the pros and cons of using chelates in a broad range of trace element sprays.

The leaf cuticle is a hydrophobic layer, comprised of high molecular weight biopolymers such as cutins and suberins, and hydrophobic C_{14}-C_{72} epicuticular waxes (Holloway, 1993). Recent physiological studies have identified polar aqueous pores, which may facilitate the absorption of charged ions into leaf epidermal cells (Schonherr, 2000). Nutrient sorption via aqueous pores is a relatively slow process, however, as the cuticle still represents the primary barrier for foliar nutrient absorption.

We hypothesized that the negative charge of metal-EDTA complexes and their high molecular weight would reduce the rate of trace-element absorption through leaf cuticles. The narrow size (0.3 nm) and negative charge of aqueous pores (Popp et al., 2005; Schonherr and Schreiber, 2004) may hinder the diffusion of anionic, high molecular weight species such as EDTA. The aim of this investigation was to determine whether EDTA would affect trace element sorption by leaf cuticles and slow nutrient absorption into leaves.

PROCEDURES

Using a cork borer, 14 mm leaf disks were removed from Valencia orange (*Citrus sinensis*) leaves, avoiding major veins. Cuticles were excised from the leaf disks by immersing them in a 6% pectinase solution (Sigma-Aldrich P2736, 3405 units/mL), which contained mainly pectintranseliminase, polygalacturonase, and pectinesterase from *Aspergillus niger*. The solution contained 1 *mM* sodium azide to reduce microbial activity and 20 *mM* citric acid, adjusted to pH 3.8 with NaOH (Schonherr and Riederer, 1986). Leaf disks remained in the enzymatic solution under dark conditions until the cuticles completely separated from the leaf tissue (approximately 21 days). Isolation was undertaken without agitation. The isolated cuticles were carefully removed and rinsed thoroughly in double deionised water until they were free of cellular debris.

Pre-weighed isolated cuticles were immersed in 1 *mM* zinc sulfate ($ZnSO_4.7H_2O$) and iron sulfate ($FeSO4.7H_2O$) solutions, either as the sulfate salt or chelated by EDTA (1 *mM*). EDTA complexes divalent metal ions in a 1:1 molar ratio. Therefore, almost 100% of the Zn and Fe were complexed in the plus-EDTA treatments. After 48 hours the cuticles were removed, rinsed in double deionised water, digested in concentrated HNO_3, and analysed for total metal concentration by ICP-OES. All treatments were replicated four times.

Cotton plants (DPL444BR), one plant per pot, were grown in Sungro™ sunshine mix #1 in the glasshouse under a mixture of natural and artificial light (12 hours per day). Plants were watered every second day with Zn-free half-strength Hoaglands solution.

Five weeks after emergence, 1 *mM* Zn fertilizer treatments were sprayed on the foliage using a CO_2-pressurized backpack sprayer calibrated to deliver 10 gal H_2O per acre. Zinc fertilizer solutions were applied as either the sulfate salt ($ZnSO_4.7H_2O$) or were complexed by EDTA (1 *mM*). A rainfall simulator (Humphry et al., 2002) applied 12.5 mL of water to the plants over 30 minutes, at 0 (no rainfall control), 1, 3, 6, and 12 hours after fertilizer application. Each fertilizer-by-rainfall treatment was replicated four times. Whole plant shoots were harvested, dried, and ground before 1g of the leaf material was digested in concentrated HNO_3 and analysed by ICP-OES for Zn.

RESULTS AND DISCUSSION

EDTA significantly ($P \leq 0.05$) reduced Fe and Zn sorption by isolated Valencia orange (*Citrus sinensis*) cuticles by 96% and 83%, respectively (Table 1). These results suggest that EDTA competed against aqueous pores (fertilizer transport sites) for Zn and Fe. EDTA also significantly ($P \leq 0.05$) reduced the rate of Zn fertilizer absorption by live cotton plants (Fig. 1). The $ZnSO_4$ was absorbed by cotton leaves more rapidly than ZnEDTA.

PRACTICAL APPLICATION

This study showed that EDTA should not be used in trace element foliar sprays, particularly given the high cost of these chelates to farmers. These results do not invalidate the use of chelates in soil-applied fertilizers, as chelates reduce sorption and fixation processes in soil. On leaves, sorption and fixation sites are far fewer (there is no soil). Therefore, the use of chelating agents in foliar sprays may be redundant.

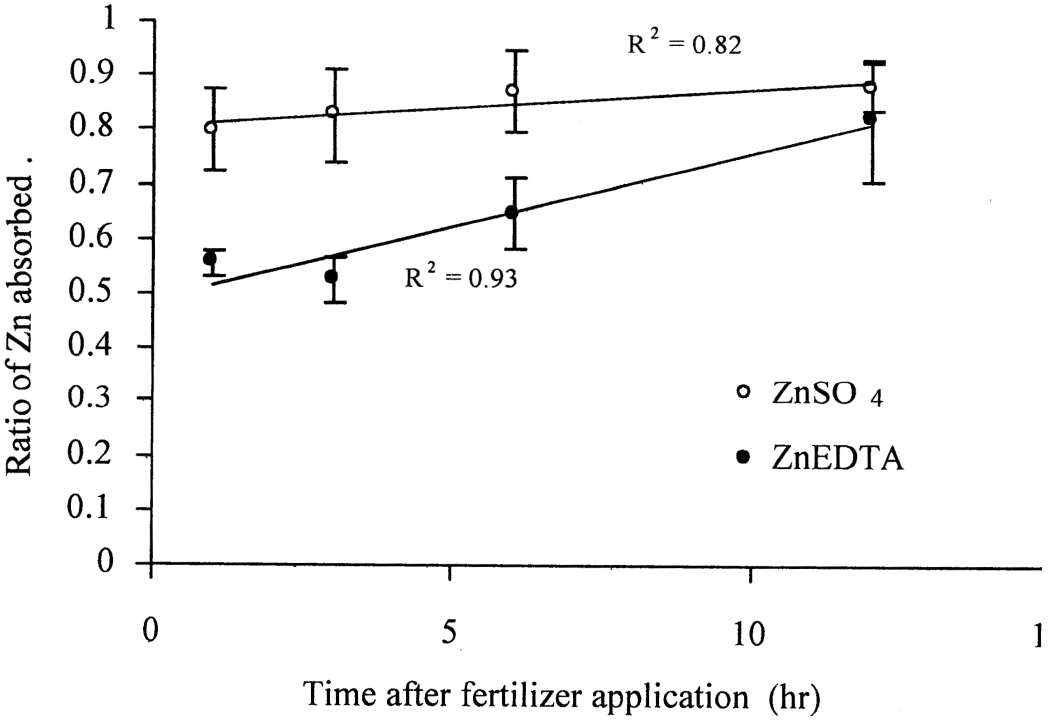

Fig. 1. Sorption of foliar-applied $ZnSO_4$ and ZnEDTA by cotton plants.

Table 1. Sorption of Zn and Fe fertilizers by enzymatically excised *Citrus sinensis* leaf cuticles.

	Sorption by leaf cuticle (µg metal/mg cuticle)	
Fertilizer	Fe	Zn
Chelate-free	10.72 ± 1.47	2.87 ± 0.11
Plus EDTA	0.45 ± 0.57	0.48 ± 0.05

Predicting Soil Phosphorus Saturation using Mehlich-3-Extractable Nutrients

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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 surfacewater and groundwater 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 degree to which P soil 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. 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 that receive hundreds of soil samples daily. Alternatively, other methods have been proposed to estimate P saturation using ammonium oxalate, Mehlich-3, or Mehlich-1 extractants. Beauchemin and Simard (1999) reviewed the literature on various P saturation methods and concluded that the relationship between P solubility and saturation index depends closely upon the range of soils studied. Our research objective was to determine P saturation indices for several Arkansas soils with a wide range of physical and chemical properties. Soil P saturation will be measured and compared to P saturation indices calculated from ammonium oxalate and Mehlich-3-extractable P, Fe, and Al. The data will be used to determine if routine soil test data can accurately predict soil P saturation.

PROCEDURES

Soil series were selected based on one or more factors including wide-spread distribution, land use, and/or to provide a wide range of physical, chemical, and mineralogical properties. Soil samples were collected from the top 4 or 6 inches and were oven-dried and ground to pass a 2 mm sieve. Soil pH was measured in a 1:2 soil weight/water volume mixture. Plant-available nutrients were determined by extraction with the Mehlich-3 method (2 g soil + 20 mL Mehlich-3 solution shook for 5 min at 200 rpms) and analyzed using an inductively coupled plasma spectrophotometer (ICP, Spectro Ciros). Total recoverable metals were determined using EPA Method 3050B with analysis by ICP. Acid ammonium oxalate extractable P, Al, and Fe were measured by shaking 1.5 g soil with 30 mL oxalate solution (pH 3.0) on a lateral shaker for 2 hours as described by Schoumans (2000). Amber Nalgene 50 mL bottles were used to block light, which can influence the reducing action of oxalic acid. Samples were filtered and the extract stored in amber bottles in the refrigerator until analysis. Before analysis by ICP, acid ammonium oxalate extracts were diluted with 0.01 *M* HCl to decrease the salt effect on the ICP torch. Total soil nitrogen (N) and carbon (C) were analyzed by combustion (Elementar Variomax CN). Soil particle size analysis will be performed by the hydrometer method (not yet complete).

Ammonium oxalate and Mehlich-3 soil P saturation index (% PSI) values were calculated as described by Zhang et al. (2005) as $PSI = [(P \div (Al + Fe)) \times 100]$ with P, Fe, and Al concentrations expressed as mmol/kg. Phosphorus adsorption batch isotherms are not yet complete, but will be compared and correlated to PSI values from Mehlich-3 and Oxalate extractions.

The correlation between Mehlich-3 and acid ammonium oxalate P, Fe, Al, and %PSI were examined using the PROC CORR procedure in SAS version 9.1. When appropriate, linear regression was performed to describe the relationship for selected data that were significantly ($P<0.05$) correlated.

RESULTS AND DISCUSSION

The selected soils represented three soil orders including Alfisols, Ultisols, and Vertisols and had a wide range of physical properties with anticipated textures ranging from clay to sandy loam and slopes from 0 to 70% (Table 1). Land use included agronomic crops, pasture, and hardwood forest. The relationship between runoff P and soil P is reportedly soil specific (Pote et al., 1996; Sharpley, 1995), making it important to compare P saturation indices among Arkansas soils having a wide range of chemical and physical properties.

Selected chemical properties of the 16 soils are listed in Table 2. Soil pH ranged from 4.6 to 8.1, soil total C ranged from 0.8 to 3.4%, and Mehlich-3 P ranged from 3 to 124 mg kg^{-1}. Because the soils varied in land use and mineralogical properties, total-soil P (Table 2) was determined to evaluate whether total-soil P was related with Mehlich-3 P. The percentage of total-soil P extracted with Mehlich-3 ranged from 1 to 20% and soil P extracted between methods was significantly, albeit weakly, correlated (r=0.61, *P*=0.0126).

Ammonium oxalate extractable P, Fe, and Al have been established as the basis for calculating soil DPS (Breeuwsma and Reijerink, 1992, Schoumans, 2000), but similar indices using Mehlich-3 P (Sims et al., 2002) have been proposed. Table 3 lists ammonium oxalate and Mehlich-3 P, Fe, and Al concentrations (expressed as mmol kg^{-1}) for the soils in this study. For the 16 Arkansas soils, Mehlich-3 concentrations of P (r = 0.86) and Al (r = 0.64) were significantly correlated ($P<0.01$) to ammonium oxalate P and Al with Mehlich-3 extracting 0.14 and 0.44 times less P and Al, respectively, than ammonium oxalate. Ammonium oxalate also extracted more Fe than Mehlich-3 but the concentrations were not significantly correlated (r = 0.24). On average, Mehlich-3 extracted approximately 16 % of the soil P, 9% of the Fe, and 60% of the Al extracted by the acid ammonium oxalate. These results are similar to results reported by Sims et al. (2002) for soils in the Mid-Atlantic region and Zhang et al. (2005) for soils in Oklahoma.

Beauchemin and Simard (1999) indicated DPS was expressed as $[(P_{ox} /(0.5(Fe_{ox} + Al_{ox}))) \times 100]$ in many studies although the 0.5 factor is empirical and based upon soil-specific properties (Sims et al., 2002). Schoumanns (2000) presented a modification of DPS as the P saturation index with $PSI = P_{ox} / (Fe_{ox} + Al_{ox})$ in an attempt to standardize further research on P saturation indices. Zhang et al. (2005) used PSI from ammonium oxalate and from Mehlich-3 extractions to determine P saturation indices in Oklahoma soils. They reported the Mehlich-3 PSI was highly correlated to ammonium oxalate PSI for all 28 Oklahoma soils studied and may be useful in predicting a soil's potential for P loss. The ammonium oxalate and Mehlich-3 PSI values calculated for Oklahoma soils were linearly correlated $[r^2 = 0.87; PSI_{M3} = (0.84 \times PSI_{OX}) - 2.88)]$ and possessed a similar relationship as we found for the 16 Arkansas soils (Fig. 1). Soil PSI values >25 to 30% are considered critically high, suggesting greater soil P solubility and risk for P movement. The PSI values for the 16 Arkansas soils evaluated were generally low with three soils having PSI values >10% and only the Clarksville soil, which had a Mehlich-3 soil-test P of 124 ppm, having a PSI >20% (Breeuwsma and Reijerink, 1999).

PRACTICAL APPLICATION

Continuing work for this study includes analysis of P saturation isotherms to determine Smax, the maximum P sorption capacity of soil, and textural analysis to determine the % clay for each soil. Both of these parameters are important in predicting P saturation and will be used to correlate PSI indices to P saturation measurements. 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 of Arkansas.

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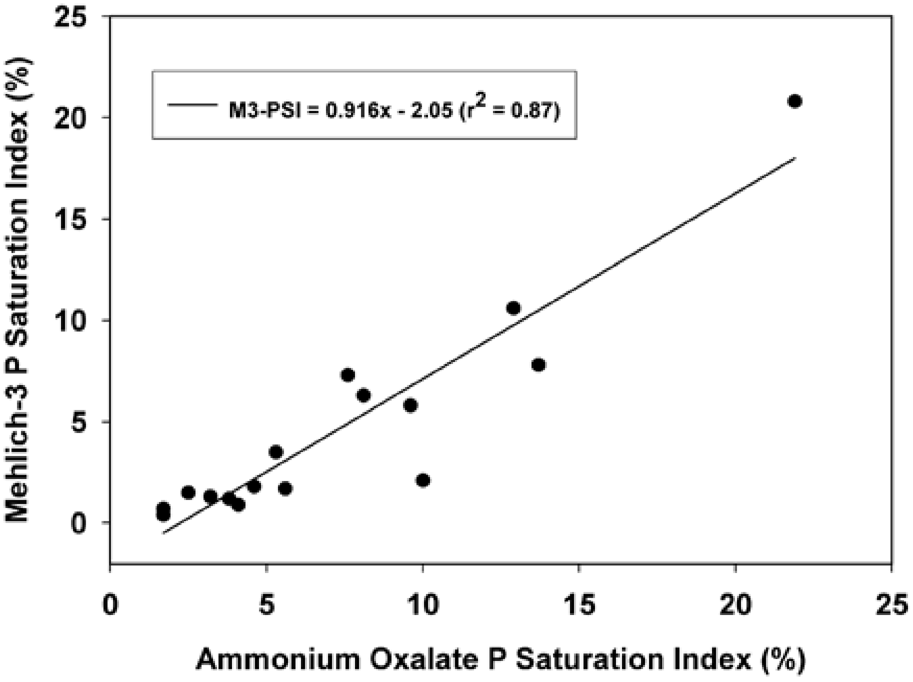

Fig. 1. Relationship between phosphorus saturation index (PSI) values calculated with ammonium oxalate or Mehlich-3 procedures for 16 Arkansas soils.

Table 1. Taxonomic classification, texture, slope, permeability, distribution (% of Arkansas acreage), and current land use of 16 soil series (Soil Survey Staff, NRCS).

Series name	Taxonomy	Texture	Slope	Permeability	Distribution	Land use
Bottom Lands and Terraces		(%)		(acres)		
Alligator	Chromic Dystraquerts	clay	0 - 1	Very poorly drained	219,506	Row crops
Dundee	Typic Endoaqualfs	loam	0 - 8	Very poorly drained	294,011	Row crops
Perry	Chromic Epiaquerts	clay	0 - 3	Very poorly drained	516,581	Row crops
Sharkey	Chromic Epiaquerts	clay	0 - 1	Very poorly drained	853,188	Row crops
Loessial Plains and Hills						
Calloway	Aquic Fraglossudalfs	silt loam	0 - 3	Poorly drained	505,583	Row crops
Dewitt	Typic Albaqualfs	silt loam	0 - 1	Poorly drained	107,441	Row crops
Henry	Typic Fragiaqualfs	silt loam	0 - 1	Very poorly drained	386,625	Row crops
Hillemann	Glossic Natraqualfs	silt loam	0 - 3	Poorly drained	119,109	Row crops
Boston Mountains and Ozark Highlands						
Enders	Typic Hapludults	fine sandy loam	1 - 65	Well drained	1,331,915	Forest
Fayetteville	Rhodic Paleudalfs	fine sandy loam	3- 40	Well drained	13,468	Pasture & Hay
Linker	Typic Hapludults	fine sandy loam	1 - 15	Well drained	956,742	Pasture & Hay
Clarksville	Typic Paleudults	gravelly silt loam	1- 70	Excessively drained	609,758	Pasture & Forest
Oachita Mountains						
Carnasaw	Typic Hapludults	loam	1- 60	Well drained	830,960	Woodland
Leadvale	Typic Fragiudults	silt loam	0 - 7	Well drained	725,224	Pasture & Hay
Mountainburg	Lithic Hapludults	fine sandy loam	1 - 6	Well drained	1,085,081	Woodland
Coastal Plains						
Amy	Typic Endoaquults	silt loam	0 - 3	Poorly Drained	411,488	Woodland

Table 2. Selected chemical characteristics of 16 soils.

	Soil	Total	Mehlich-3-extractable					Total recoverable		
Soil series	pH	C	P	K	Ca	Fe	Al	P	Fe	Al
		(%)	(mg kg^{-1})					(g kg^{-1})		
Alligator	8.1	1.1	9	202	3680	155	449	0.21	22	18
Dundee	6.6	1.4	43	135	1757	238	242	0.39	12	7
Perry	5.7	2.1	54	559	3617	201	713	0.89	36	32
Sharkey	5.9	1.3	17	258	3156	208	719	0.48	37	22
Calloway	6.9	0.8	9	91	3256	241	265	0.35	12	9
Dewitt	6.0	1.1	11	124	963	227	602	0.27	17	14
Henry	7.4	1.2	25	74	1166	346	183	0.21	8	6
Hillemann	7.4	1.1	31	91	1619	336	220	0.30	11	8
Enders	6.1	3.4	24	126	1798	86	547	0.38	35	8
Fayetteville	5.5	1.6	13	152	881	100	635	0.32	17	10
Linker	5.9	1.7	3	197	1620	67	761	0.30	39	22
Clarksville	6.0	2.2	124	154	1130	144	451	0.61	15	8
Carnasaw	5.3	2.1	11	82	406	99	765	0.32	45	10
Leadvale	6.7	2.3	6	89	1766	130	477	0.48	38	12
Mountainburg	5.6	2.1	51	180	915	175	481	0.66	40	10
Amy	4.6	0.8	7	27	98	236	669	0.09	8	8

Table 3. Ammonium oxalate and Mehlich-3-extractable P, Fe, and Al concentrations expressed as mmol/kg soil and phosphorus saturation index values (PSI).

	Ammonium oxalate				Mehlich-3			
Soil	P	Fe	Al	PSI	P	Fe	Al	PSI
	(mmol kg^{-1})			(%)	(mmol kg^{-1})			(%)
Alligator	2.0	46	33	2.5	0.3	2.8	17	1.5
Dundee	5.9	34	12	12.9	1.4	4.3	9	10.6
Perry	18.3	129	62	9.6	1.7	3.6	26	5.8
Sharkey	9.0	137	57	4.6	0.6	3.7	27	1.8
Calloway	5.5	35	20	10.0	0.3	4.3	10	2.1
Dewitt	3.8	79	41	3.2	0.3	4.1	22	1.3
Henry	3.5	34	10	8.1	0.8	6.2	7	6.3
Hillemann	4.9	47	17	7.6	1.0	6.0	8	7.3
Enders	3.3	28	34	5.3	0.8	1.5	20	3.5
Fayetteville	3.1	23	32	5.6	0.4	1.8	24	1.7
Linker	0.9	18	37	1.7	0.1	1.2	28	0.4
Clarksville	10.6	23	25	21.9	4.0	2.6	17	20.8
Carnasaw	2.6	23	45	3.8	0.4	1.8	28	1.2
Leadvale	4.0	60	38	4.1	0.2	2.3	18	0.9
Mountainburg	7.6	30	26	13.7	1.6	3.1	18	7.8
Amy	1.2	41	34	1.7	0.2	4.2	25	0.7

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