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Wayne E. Sabbe Arkansas Soil Fertility Studies 2017

Nathan A. Slaton
University of Arkansas, Fayetteville

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Arkansas Soil Fertility Studies 2017

A runoff water quality monitoring station located on an Arkansas Discovery Farm

Nathan A. Slaton, Editor

DIVISION OF AGRICULTURE
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Cover: The Arkansas Discovery Farm program utilizes state-of-the art, automated water samplers to monitor nitrogen, phosphorus, potassium, and suspended solids in runoff at the edge of agricultural fields on real, working farms in Arkansas. To monitor runoff volume, water is directed through a flume, which is calibrated to measure runoff discharge. Edge-of-field monitoring allows scientists to quantify nutrient and sediment loss, evaluate conservation practices and provide feedback to agricultural producers on environmental stewardship, nutrient use efficiency, and irrigation efficiency. For more information on Discovery Farms and potassium loss, see the report on page 35. Photograph by Andrew Sharpley, Professor, University of Arkansas System Division of Agriculture, Department of Crop, Soil, and Environmental Sciences.

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WAYNE E. SABBE
ARKANSAS
SOIL FERTILITY STUDIES
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SUMMARY

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

INTRODUCTION

The 2017 Arkansas 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 2016. This set of data includes information for counties, soil associations, physiographic areas, and selected cropping systems.

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

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

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

This publication is available as a web-only research series book online at http://arkansas-ag-news.uark.edu/research-series.aspx

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CONTENTS

Arkansas Soil-Test Summary for Samples Collected in 2016

R.E. DeLong[1], N.A. Slaton[1], C.G. Herron[2], and D. Lafex[2]

Background Information and Research Problem

Soil-test data from samples submitted to the University of Arkansas System Division of Agriculture's Soil Testing and Research Laboratory in Marianna between 1 January 2016 and 31 December 2016 were categorized according to geographic area (GA), county, soil association number (SAN), and selected cropping systems. The GA and SAN were derived from the General Soil Map, State of Arkansas (Base 4-R-38034, USDA, and University of Arkansas System Division of Agriculture's Agricultural Experiment Station, Fayetteville, Ark., December, 1982). Descriptive statistics of the soil-test data were calculated for categorical ranges for pH, phosphorus (P), potassium (K), and zinc (Zn). Soil pH and Mehlich-3 extractable (analyzed using inductively coupled argon plasma spectroscopy, ICAP) soil nutrient (i.e., P, K, and Zn) availability index values indicate the relative level of soil fertility. Mehlich-3 extractable manganese (Mn) was also summarized as a supplement since Mn deficiencies sometimes occur in selected crops.

Results and Discussion

Crop Acreage and Soil Sampling Intensity

Between 1 January 2016 and 31 December 2016, 202,680 soil samples were analyzed by the University of Arkansas System Division of Agriculture's Soil Testing and Research Laboratory in Marianna. After removing 17,034 standard solution and check soil samples measured for quality assurance, the total number of client (e.g., researchers, growers, and homeowners) samples was 185,646, comprising 353 research samples and 185,293 samples from the general public (Table 1). A total of 54,206 of the submitted soil samples were collected using the field-average sampling technique, representing 1,294,411 acres for an average of 24 acres/sample, and had complete data for county, total acres, and soil pH, P, K, and Zn. The cumulative number of samples and acres from information listed in Tables 1 to 4 may vary somewhat because not all samples included SAN, GA, and/or previous crop. The remaining 131,087 samples were grid samples collected primarily from row-crop fields.

Values listed in Table 1 include the number of grid samples analyzed but do not include the acreage of grid soil samples. Each grid soil sample likely represents 2.5 to 5.0 acres and most grid samples are collected and submitted by a consultant or soil sampling service. Single clients from Craighead (15,166 samples, 66% of county grid samples); Crittenden (14,189, 52%); Little River (10,486, 74%); Lawrence (7,513, 87%); and Cleveland (7,485, 100%) counties submitted the most grid soil samples for analyses and accounted for 42% of the total grid sample numbers. Thus, the soil sample numbers for these counties and selected others probably represent soil samples from numerous counties that are submitted through a single Extension office that is conveniently located. The large number of grid samples submitted through these counties explains why the acres per sample values in Table 1 are always very low.

Soil samples from the Bottom Lands and Terraces, and Loessial Plains, primarily row-crop areas, represented 55% of the total field-average samples and 77% of the total acreage (Table 2). The average number of acres represented by each field-average soil sample from the 10 geographic areas (GA) ranged from 8 to 40 acres/sample. Soil association numbers (SAN) show that most samples were taken from soils common to row-crop and pasture production areas (Table 3). The soil associations having the most samples submitted were 44 (Calloway-Henry-Grenada-Calhoun), 24 (Sharkey-Alligator-Tunica), 4 (Captina-Nixa-Tonti), and 45 (Crowley-Stuttgart). However, the soil associations representing the largest acreage were 24, 45, 44, and 22 (Foley-Jackport-Crowley) which represented 21%, 20%, 16%, and 7% of the total sampled acreage, respectively.

Crop codes listed on the field-average samples indicate that land used for i) row-crop production accounted for 77% of the sampled acreage and 47% of submitted samples, ii) hay and pasture production accounted for 16% of the sampled acreage and 20% of submitted samples, and iii) home lawns and gardens accounted for 1% of sampled acreage and 18% of submitted samples (Table 4). In row-crop producing areas, 41% of the soil samples were collected following soybean in the crop rotation. The cumulative acreage soil sampled following soybean represents about 14% of the annual soybean acreage, which totaled 3.1 and 3.5 million harvested acres in 2016 and 2017, respectively (USDA-NASS, 2017).

Soil-Test Data

Information in Tables 5, 6, and 7 pertains to the fertility status of Arkansas soils as categorized by GA, county, and the crop grown prior to collecting field-average soil samples (i.e., grid samples not included, except by county), respectively. The soil-test levels and median nutrient availability index values relate to the potential fertility of a soil, but not necessarily to the productivity of the soil. The median is the value that has

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an equal number of higher and lower observations and may be a better overall indicator of a soil's fertility status than a mean value. Therefore, it is not practical to compare soil-test values among SAN without knowledge of factors such as location, topography, and cropping system. Likewise, soil-test values among counties cannot be realistically compared without knowledge of the SAN and a profile of the local agricultural production systems. Soil-test results for cropping systems can be carefully compared by recognizing that specific agricultural production systems often indicate past fertilization practices or may be unique to certain soils that would influence the current soil-test values. The median pH of most soils in Arkansas ranges from 5.7 to 6.6 (Table 5). However, the predominant soil pH range varies among Arkansas counties (Table 6) and cropping systems (Table 7).

Table 7 summarizes the percentage of acreage from field-average soil samples that falls within selected soil-test levels (as defined by concentration ranges) and the median concentrations for each of the cropping system categories. Soil-test nutrient availability index values can be categorized into soil-test levels of Very Low, Low, Medium, Optimum, and Above Optimum. Among row crops, the lowest median P concentration occurs in samples following rice in the rotation and the lowest median K concentrations occur in soils following winter wheat, rice, soybean, and corn. Soils collected following cotton production have the highest median P and K concentrations. The median soil K is lowest in soils used for hay production. The median soil-test P and K for the hay crop codes has decreased for several years and suggests that P and K inputs as fertilizer or manure have declined and K, but not P, is likely limiting forage yields. The 2016 soil-test results for individual crops are consistent with the trends reported by DeLong et al. (2017) and suggest that the relative soil test values are traits of the pervading crop management practices. The highest median concentrations of P and Zn occur in soils used for fruit production and non-agricultural purposes (e.g., lawn, turf, garden, and landscape/ornamental).

Tables 8 to 11 summarize Mehlich-3 extractable Mn in Arkansas soils using the percentage of sampled acres as distributed among five soil-test levels by county, GA, SAN (median only), and previous crop, respectively. The median values for Mn by county were lowest for Clark, Columbia and Union counties, which have soils that are mostly low cation exchange capacity Coastal Plains soils (DeLong et al., 2014). Soil-test Mn was highest in Newton, Yell and Woodruff counties. The SANs having the lowest median soil-test Mn values were 28 (Commerce-Sharkey-Crevasse-Robinsonville) and 35 (Adaton) representing the Bottom Lands and Terraces and 40 (Pheba-Amy-Savannah) for Coastal Plain soils. The highest soil-test Mn was found in SAN 11 (Falkner-Wrightsville) and 14 (Spadra-Guthrie-Pickwick) in the Arkansas Valley and Ridges and 1 (Clarksville-Nixa-Noark) for the geographic area of the Ozark Highlands - Cherty Limestone and Dolomite (Table 10). Soils in the Sharkey series, high cation exchange capacity clayey soils, also tended to be consistently low in Mn. The lowest median Mn values for previous crop were turf, cotton, and home lawn and were highest in wheat, hay, and pasture categories (Table 11).

Practical Applications

The results of annual soil-test summaries, or more specific summaries assembled for selected cropping systems, soils, or geographic areas, can be used in county- or commodity-specific nutrient management education programs. Comparisons of annual soil-test information can document trends in fertilization practices or areas where nutrient management issues may need to be addressed. For soil samples submitted in 2016, 74% of the samples and 98% of the represented acreage had commercial agricultural/farm crop codes.

Acknowledgments

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Table 1. Sample number (includes grid samples) and total acreage by county for soil samples submitted to the University of Arkansas System Division of Agriculture's Soil Testing and Research Laboratory in Marianna from 1 January 2016 through 31 December 2016.

County	Acres sampled	% of total acres	No. of samples	% of total samples	Acres/ sample	County	Acres sampled	% of total acres	No. of samples	% of total sample	Acres/ sample
Arkansas	155,131	12	3398	2	46	Lee	277,911	22	3916	2	71
Ashley	4796	0	367	0	13	Lincoln	1153	0	274	0	4
Baxter	2763	0	418	0	7	Little River	2676	0	14,428	8	0
Benton	11,626	1	1081	1	11	Logan	5276	0	387	0	14
Boone	9113	1	674	0	14	Lonoke	127,534	10	7196	4	18
Bradley	778	0	84	0	9	Madison	7157	1	466	0	15
Calhoun	426	0	37	0	12	Marion	1270	0	133	0	10
Carroll	21,371	2	1124	1	19	Miller	2479	0	308	0	8
Chicot	8167	1	179	0	46	Mississippi	30,980	3	14,642	8	2
Clark	2911	0	237	0	12	Monroe	12,987	1	3418	2	5
Clay	17,930	1	16,694	9	1	Montgomery	1175	0	159	0	7
Cleburne	3750	0	323	0	12	Nevada	970	0	69	0	14
Cleveland	2025	0	7658	4	0	Newton	1762	0	161	0	11
Columbia	966	0	215	0	5	Ouachita	540	0	103	0	5
Conway	11,324	1	443	0	26	Perry	2313	0	126	0	18
Craighead	20,551	2	24,226	13	1	Phillips	4320	0	2442	1	2
Crawford	24,009	2	828	1	29	Pike	696	0	83	0	8
Crittenden	2769	0	27,432	15	0	Poinsett	31,778	3	2940	2	11
Cross	46,012	4	999	1	46	Polk	7992	1	506	0	16
Dallas	396	0	68	0	6	Pope	6954	1	629	0	11
Desha	14,443	1	2338	1	6	Prairie	97,424	8	1906	1	51
Drew	3921	0	596	0	7	Pulaski	6399	1	1412	1	5
Faulkner	8568	1	775	0	11	Randolph	12,323	1	2434	1	5
Franklin	5552	0	305	0	18	Saline	3303	0	834	1	4
Fulton	4329	0	478	0	9	Scott	2651	0	125	0	21
Garland	1840	0	1159	1	2	Searcy	1581	0	129	0	12
Grant	689	0	112	0	6	Sebastian	8240	1	703	0	12
Greene	33,137	3	5284	3	6	Sevier	3330	0	167	0	20
Hempstead	6620	1	449	0	15	Sharp	4987	0	350	0	14
Hot Spring	2036	0	235	0	9	St. Francis	9003	1	2572	1	4
Howard	5060	0	251	0	20	Stone	2776	0	301	0	9
Independence	5099	0	352	0	15	Union	1716	0	344	0	5
Izard	2755	0	253	0	11	Van Buren	2770	0	278	0	10
Jackson	19,096	2	2778	2	7	Washington	23,026	2	2617	1	9
Jefferson	43,967	4	4572	3	10	White	9437	1	1078	1	9
Johnson	2031	0	301	0	7	Woodruff	5440	0	273	0	20
Lafayette	1548	0	107	0	15	Yell	8164	1	469	0	17
Lawrence	56,414	5	10,085	5	6	Sum/Average	1,294,411		185,293		7

Table 2. Sample number and total acreage by geographic area for soil samples submitted to the University of Arkansas System Division of Agriculture's Soil Testing and Research Laboratory in Marianna from 1 January 2016 through 31 December 2016.

Geographic area	Acres sampled	% of total acres	No. of samples	% of total samples	Acres/ sample
Ozark Highlands - Cherty Limestone and Dolomite	81,736	9	6981	20	12
Ozark Highlands - Sandstone and Limestone	8218	1	663	2	12
Boston Mountains	16,727	2	1848	5	9
Arkansas Valley and Ridges	57,118	6	424	11	14
Ouachita Mountains	19,916	2	2573	7	8
Bottom Lands and Terraces	396,346	41	11,028	31	36
Coastal Plain	26,578	3	2686	8	10
Loessial Plains	341,756	36	8504	24	40
Loessial Hills	9064	1	927	3	10
Blackland Prairie	571	0	34	0	17
Sum or Average	958,030		35,668		27

Table 3. Sample number, total acreage by soil association number (SAN), average acreage per sample, and median soil pH and Mehlich-3 extractable P, K, and Zn values by soil association for soil samples submitted to the University of Arkansas System Division of Agriculture's Soil Testing and Research Laboratory in Marianna from 1 January 2016 through 31 December 2016.

							Median			
SAN	Soil association	Acres sampled	% of total acres	No. of samples	% of total samples	Acres/ sample	pH	P	K	Zn
1.	Clarksville-Nixa-Noark	11,784	2	752	1	16	6.1	63	114	5.6
2.	Gepp-Doniphan-Gassville-Agnos	8225	2	864	1	10	6.4	47	127	5.0
3.	Arkana-Moko	26,296	4	1615	3	16	6.1	126	163	11.9
4.	Captina-Nixa-Tonti	34,730	9	3695	4	9	6.2	89	146	8.2
5.	Captina-Doniphan-Gepp	292	0	16	0	18	5.6	23	66	2.7
6.	Eden-Newnata-Moko	409	0	39	0	11	6.2	67	126	5.5
7.	Estate-Portia-Moko	295	0	17	0	17	5.6	134	137	19.1
8.	Brockwell-Boden-Portia	7923	2	646	1	12	6.0	27	102	2.9
9.	Linker-Mountainburg-Sidon	4290	1	349	1	12	6.0	60	102	5.4
10.	Enders-Nella-Mountainburg-Steprock	12,437	4	1499	1	8	6.0	71	109	5.7
11.	Falkner-Wrightsville	94	0	15	0	6	6.5	63	168	4.5
12.	Leadvale-Taft	29,487	5	2088	3	14	5.9	53	109	5.8
13.	Enders-Mountainburg-Nella-Steprock	5946	1	337	1	18	6.0	39	93	3.3
14.	Spadra-Guthrie-Pickwick	3272	1	177	0	19	5.6	68	108	6.8
15.	Linker-Mountainburg	18,319	4	1407	2	13	5.8	52	108	4.9
16.	Carnasaw-Pirum-Clebit	3792	1	330	0	12	5.8	88	106	6.4
17.	Kenn-Ceda-Avilla	9419	2	690	1	12	5.6	105	113	8.4
18.	Carnasaw-Sherwood-Bismarck	4467	3	1138	1	4	5.8	66	99	5.1
19.	Carnasaw-Bismarck	215	0	21	0	10	5.8	85	67	6.9
20.	Leadvale-Taft	1629	1	306	0	5	5.9	84	106	6.6
21.	Spadra-Pickwick	1394	0	88	0	16	5.6	44	114	4.9
22.	Foley-Jackport-Crowley	69,267	5	1970	7	35	6.4	24	112	3.4
23.	Kobel	15,885	1	537	2	30	6.2	24	100	3.1
24.	Sharkey-Alligator-Tunica	197,374	11	4403	21	45	6.6	33	224	3.6
25.	Dundee-Bosket-Dubbs	21,929	3	1061	2	21	6.3	33	113	3.3
26.	Amagon-Dundee	7872	1	338	1	23	6.4	46	128	3.6
27.	Sharkey-Steele	1751	1	296	0	6	6.4	29	148	3.3
28.	Commerce-Sharkey-Crevasse-Robinsonville	1474	0	105	0	14	5.7	46	139	2.4
29.	Perry-Portland	12,864	1	388	1	33	6.4	34	168	3.5
30.	Crevasse-Bruno-Oklared	2228	0	39	0	57	6.7	55	193	4.8
31.	Roxana-Dardanelle-Bruno-Roellen	5903	1	210	1	28	6.2	54	131	5.3
32.	Rilla-Hebert	45,056	3	1288	5	35	6.3	37	136	2.7
33.	Billyhaw-Perry	422	0	17	0	25	5.8	32	104	5.8
34.	Severn-Oklared	3543	0	101	0	35	6.2	64	127	6.6
35.	Adaton	28	0	2	0	14	5.3	14	55	2.7
36.	Wrightsville-Louin-Acadia	10,616	1	268	1	40	6.2	31	120	3.4
37.	Muskogee-Wrightsville-McKamie	134	0	5	0	27	6.4	55	185	13.0
38.	Amy-Smithton-Pheba	780	0	111	0	7	5.6	68	71	3.7
39.	Darco-Briley-Smithdale	104	0	25	0	4	7.3	8	270	2.1
40.	Pheba-Amy-Savannah	2036	0	165	0	12	5.6	39	99	3.9
41.	Smithdale-Sacul-Savannah-Saffell	7467	2	763	1	10	5.6	76	95	6.4
42.	Sacul-Smithdale-Sawyer	12,197	4	1423	1	9	5.9	51	92	4.6
43.	Guyton-Ouachita-Sardis	3994	1	199	0	20	5.7	112	106	8.8
44.	Calloway-Henry-Grenada-Calhoun	153,623	13	5001	16	31	6.6	28	99	3.2
45.	Crowley-Stuttgart	188,133	9	3503	20	54	6.5	28	117	3.3
46.	Loring	587	0	65	0	9	6.3	43	96	7.2
47.	Loring-Memphis	8210	2	848	1	10	6.2	33	116	3.9
48.	Brandon	267	0	14	0	19	6.0	16	63	2.0
49.	Oktibbeha-Sumter	571	0	34	0	17	5.9	63	155	6.6
	Sum or Average	959,030		39,268		24	6.1	54	121	5.3

Table 4. Sample number and total acreage by previous crop for soil samples submitted to the University of Arkansas System Division of Agriculture's Soil Testing and Research Laboratory in Marianna from 1 January 2016 through 31 December 2016.

Previous crop	Acres sampled	% of total acres	No. of samples	% of total samples	Acres/ sample
Corn	121,328	12	2565	6	47
Cotton	78,832	8	1094	2	72
Grain sorghum, non-irrigated	3818	0	82	0	47
Grain sorghum, irrigated	23,423	2	714	2	33
Rice	147,024	14	3596	8	41
Soybean	434,611	41	13,297	29	33
Wheat	2977	0	164	0	18
Cool-season grass hay	5627	1	350	1	16
Native warm-season grass hay	3191	0	212	1	15
Warm-season grass hay	35,224	3	1860	4	19
Pasture, all categories	128,236	12	6739	15	19
Home garden	4912	1	4319	10	1
Turf	3385	0	975	2	4
Home lawn	4757	1	3883	9	1
Small fruit	694	0	195	0	1
Ornamental	1836	0	1183	3	2
Miscellaneous[a]	50,365	5	4130	9	12
Sum or Average	1,050,240		45,358		23

[a] Miscellaneous includes all crop codes not specifically listed in the table and may include row crops, commercial vegetable codes, and turf-related codes (playgrounds) among others.

Table 5. The percentage of sampled acres as distributed within five soil-test levels and median soil chemical property values by geographic area for soil samples submitted to the University of Arkansas System Division of Agriculture's Soil Testing and Research Laboratory in Marianna from 1 January 2016 through 31 December 2016.

Geographic area	Soil pH[a]						Mehlich-3 soil P[b] (ppm)						Mehlich-3 soil K[b] (ppm)						Mehlich-3 soil Zn[b] (ppm)					
	<5.4	5.4-5.7	5.8-6.2	6.3-6.9	>6.9	Md[c]	<16	16-25	26-35	36-50	>50	Md	<61	61-90	91-130	131-175	>175	Md	<1.6	1.6-3.0	3.1-4.0	4.1-8.0	>8.0	Md
	---(% of sampled acreage)--						--(% of sampled acreage)--					(ppm)	--(% of sampled acreage) --					(ppm)	--(% of sampled acreage) --					(ppm)
Ozark Highlands - Cherty Limestone and Dolomite	11	26	19	27	17	6.2	5	7	8	11	69	82	10	15	20	18	37	142	5	13	9	24	49	8.0
Ozark Highlands - Sandstone and Limestone	16	23	28	23	10	6.0	21	26	15	8	30	27	16	25	30	13	16	102	13	40	12	18	17	3.0
Boston Mountains	16	29	23	23	9	6.0	8	10	9	12	61	69	20	20	20	16	24	109	7	20	13	24	36	5.6
Arkansas Valley and Ridges	22	24	26	22	6	5.9	16	13	10	10	51	52	18	21	25	16	20	107	10	21	12	25	32	5.3
Ouachita Mountains	27	24	29	18	2	5.7	8	9	9	11	63	78	18	23	25	16	18	104	6	19	13	24	38	5.9
Bottom Lands and Terraces	8	21	13	34	24	6.4	13	23	22	20	22	32	5	13	22	18	42	153	7	36	27	26	4	3.4
Coastal Plain	29	20	25	21	5	5.8	15	11	10	10	54	61	29	19	19	13	20	93	14	21	9	22	34	5.3
Loessial Plains	9	18	12	29	32	6.6	15	28	24	18	15	28	7	24	40	19	10	107	11	38	18	28	5	3.3
Loessial Hills	19	19	18	27	17	6.2	21	17	17	14	31	33	13	22	26	20	19	114	11	29	13	28	19	4.0
Blackland Prairie	12	29	29	0	30	5.9	24	12	6	0	58	63	12	12	9	29	38	155	3	24	9	18	46	6.6
Average	17	23	22	22	16	6.0	15	16	13	11	45	53	15	19	24	18	24	119	9	26	14	24	27	5.0

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

Table 6. The percentage of sampled acres as distributed within five soil test levels and median soil chemical property values by county for soil samples submitted to the University of Arkansas System Division of Agriculture's Soil Testing and Research Laboratory in Marianna from 1 January 2016 through 31 December 2016.

	Soil pH[a]						Mehlich-3 soil P[b] (ppm)						Mehlich-3 soil K[b] (ppm)						Mehlich-3 soil Zn[b] (ppm)					
County	<5.4	5.4-5.7	5.8-6.2	6.3-6.9	>6.9	Md[c]	<16	16-25	26-35	36-50	>50	Md	<61	61-90	91-130	131-175	>175	Md	<1.6	1.6-3.0	3.1-4.0	4.1-8.0	>8.0	Md
	(% of sampled acreage)-----						--(% of sampled acreage)--					(ppm)	--(% of sampled acreage)--					(ppm)	--(% of sampled acreage)--					(ppm)
Arkansas	4	7	12	24	53	7.0	9	27	27	21	16	30	2	14	45	27	12	121	5	25	21	42	7	4.2
Ashley	10	14	18	27	31	6.5	31	12	10	7	40	33	14	25	19	16	26	108	19	34	11	14	22	2.9
Baxter	7	7	15	26	45	6.9	6	8	12	11	63	81	7	11	23	19	40	145	2	12	9	19	58	10.7
Benton	11	19	24	28	18	6.2	2	6	6	8	78	122	9	13	19	20	39	148	2	9	8	24	57	9.9
Boone	7	21	32	28	12	6.1	5	10	9	11	65	72	17	14	16	15	38	139	5	17	10	25	43	7.2
Bradley	20	14	24	33	9	6.1	7	12	2	11	68	104	18	16	33	1	32	106	7	14	8	33	38	6.8
Calhoun	30	19	24	22	5	5.9	11	5	3	24	57	75	32	30	16	16	6	72	22	19	5	30	24	4.3
Carroll	9	21	32	26	12	6.1	1	2	3	5	89	171	7	11	14	13	55	194	0	5	6	17	72	15.3
Chicot	9	13	16	26	36	6.6	22	12	12	11	43	40	6	15	12	13	54	184	8	27	20	22	23	4.0
Clark	37	26	17	11	9	5.6	16	15	15	11	43	40	31	22	20	11	16	87	19	30	12	25	14	3.3
Clay	5	11	26	46	12	6.4	9	22	23	24	22	33	6	24	39	22	9	10	13	33	18	29	7	3.4
Cleburne	29	23	22	23	3	5.8	16	18	12	16	38	38	32	22	20	14	12	86	16	33	12	20	19	3.2
Cleveland	9	18	27	36	10	6.2	12	14	15	20	39	42	6	14	24	17	39	143	5	28	24	40	3	3.9
Columbia	37	28	22	13	0	5.6	11	11	10	9	59	71	37	28	20	9	6	70	14	24	7	31	24	5.0
Conway	20	20	16	28	16	6.1	13	12	8	12	55	61	13	19	27	17	24	116	9	19	11	31	30	5.3
Craighead	4	8	19	40	29	6.6	6	15	17	23	39	42	3	10	20	23	44	164	4	33	28	34	1	3.6
Crawford	11	18	26	26	19	6.2	13	17	14	14	42	41	16	21	25	15	23	112	5	27	17	30	21	4.4
Crittenden	6	9	17	37	31	6.6	10	26	25	23	16	31	2	6	13	15	64	222	6	28	30	36	0	3.7
Cross	4	3	6	29	58	7.1	8	27	26	24	15	31	6	29	38	10	17	103	7	39	24	26	4	3.3
Dallas	40	25	19	12	4	5.6	12	21	7	6	54	54	41	22	12	6	19	71	19	29	12	18	22	3.2
Desha	7	8	17	41	27	6.6	6	19	22	27	26	37	6	14	28	17	35	134	7	35	27	29	2	3.4
Drew	22	35	26	17	0	5.7	11	16	21	22	30	37	13	25	30	18	14	106	15	26	12	37	10	4.0
Faulkner	29	24	21	22	4	5.8	18	17	11	10	44	43	19	21	28	15	17	101	17	25	11	19	28	4.0
Franklin	17	42	25	12	4	5.7	6	8	9	12	65	88	10	18	24	19	29	126	3	10	8	28	51	8.7
Fulton	23	36	21	20	0	5.8	16	26	19	16	23	30	10	21	36	18	15	110	20	40	15	13	12	2.7
Garland	24	24	26	22	4	5.9	7	9	11	15	58	65	16	26	30	15	13	100	4	21	16	27	32	5.3
Grant	33	35	18	13	1	5.6	15	12	14	11	48	48	30	30	18	11	11	76	14	27	10	21	28	4.1
Greene	9	16	28	35	12	6.2	15	16	16	19	34	38	11	25	33	22	9	107	12	35	19	30	4	3.3
Hempstead	26	27	16	23	8	5.8	22	11	10	9	48	49	33	18	13	11	25	88	17	23	8	21	31	4.4
Hot Spring	39	33	15	13	0	5.5	22	9	12	9	48	47	39	19	16	9	17	75	23	23	10	24	20	3.7
Howard	30	4	22	14	0	5.6	5	10	5	5	75	127	22	15	19	18	26	115	5	12	7	18	58	11.7
Independence	13	26	24	26	11	6.1	9	17	13	13	48	46	26	24	21	15	14	92	9	30	9	26	26	4.7
Izard	17	22	27	24	10	6.0	13	19	14	14	40	38	17	36	25	11	11	86	16	37	11	17	19	2.9
Jackson	8	14	26	38	14	6.3	23	26	19	17	15	26	3	16	33	27	21	128	12	43	19	24	2	3.0
Jefferson	11	14	23	37	15	6.3	10	16	20	24	30	37	9	19	27	18	27	124	17	53	17	12	1	2.5
Johnson	23	31	22	17	7	5.8	18	13	8	9	52	53	21	22	22	14	21	103	6	25	11	31	27	5.3
Lafayette	24	28	19	16	13	5.8	14	7	3	6	70	92	14	19	26	19	22	117	8	21	8	17	46	6.7
Lawrence	6	14	26	35	19	6.3	24	28	22	16	10	25	10	26	33	19	12	106	12	40	18	23	7	3.1
Lee	8	15	27	32	18	6.3	4	13	25	32	26	38	2	12	24	20	42	157	19	45	18	18	0	2.5
Lincoln	37	35	19	9	0	5.4	11	35	13	13	28	27	4	11	21	28	36	152	6	49	28	16	1	3.0
Little River	6	10	24	33	27	6.5	13	18	17	22	30	36	3	9	25	23	32	154	18	42	18	21	1	2.7
Logan	17	30	31	17	5	5.8	8	8	7	10	67	92	17	19	17	15	32	121	2	17	8	20	53	8.8
Lonoke	10	19	32	32	7	6.1	17	27	22	16	18	28	11	20	33	20	16	112	22	54	13	10	1	2.2
Madison	8	25	31	27	9	6.1	3	6	6	9	76	121	8	14	18	19	41	157	2	8	10	23	57	10.2

continued

Table 6. Continued.

County	Soil pH[a]						Mehlich-3 soil P[b] (ppm)						Mehlich-3 soil K[b] (ppm)						Mehlich-3 soil Zn[b] (ppm)					
	<5.4	5.4-5.7	5.8-6.2	6.3-6.9	>6.9	Md[c]	<16	16-25	26-35	36-50	>50	Md	<61	61-90	91-130	131-175	>175	Md	<1.6	1.6-3.0	3.1-4.0	4.1-8.0	>8.0	Md
	--(% of sampled acreage)--						--(% of sampled acreage)--					(ppm)	--(% of sampled acreage)--					(ppm)	--(% of sampled acreage)--					(ppm)
Marion	2	6	18	25	49	6.9	8	6	16	20	50	57	5	19	20	19	37	144	6	18	8	20	48	7.9
Miller	20	23	24	25	8	5.9	13	13	12	10	52	53	28	21	20	13	18	92	11	19	12	23	35	5.1
Mississippi	4	9	25	37	25	6.5	5	15	18	24	38	43	1	7	25	27	40	157	2	29	33	32	4	3.8
Monroe	5	6	9	25	55	7.1	20	32	22	16	10	25	19	39	26	11	5	83	13	45	18	23	1	2.8
Montgomery	24	18	22	28	8	6.1	11	8	8	9	64	91	18	24	26	9	23	102	9	19	13	19	40	6.1
Nevada	33	23	17	25	2	5.7	15	6	7	13	59	76	30	9	17	9	35	116	4	13	7	22	54	8.9
Newton	9	20	36	28	7	6.1	5	13	12	20	50	50	18	24	18	16	24	112	6	26	16	30	22	4.6
Ouachita	26	36	15	19	4	5.7	10	10	8	9	63	74	32	24	25	11	8	82	11	12	15	27	35	6.1
Perry	39	26	15	18	2	5.6	15	17	11	13	44	44	19	21	25	13	22	103	10	28	17	18	27	3.8
Phillips	4	5	15	54	22	6.6	3	11	17	27	42	45	2	14	39	30	15	126	22	44	13	20	1	2.5
Pike	40	24	17	15	4	5.5	6	7	5	4	78	131	27	19	23	13	18	96	8	18	6	16	52	8.5
Poinsett	2	5	13	30	50	7.0	23	33	23	12	9	24	10	24	25	10	31	112	9	23	22	34	12	4.0
Polk	31	37	17	15	0	5.6	2	6	8	8	76	141	13	23	22	18	24	116	3	14	10	20	53	9.5
Pope	21	25	27	20	7	5.9	17	10	8	9	56	64	12	23	24	16	25	111	12	20	12	21	35	5.2
Prairie	17	25	24	22	12	6.0	36	22	13	14	15	21	6	17	36	31	10	121	21	46	13	17	3	2.4
Pulaski	20	17	22	28	13	6.2	6	10	10	11	63	72	11	21	31	19	18	112	5	12	10	24	49	8.3
Randolph	3	9	24	50	14	6.4	16	31	25	17	11	26	6	20	38	24	12	115	3	20	16	45	16	5.0
Saline	29	21	23	22	5	5.8	8	14	10	13	55	55	13	22	25	23	17	111	7	23	15	32	23	4.7
Scott	19	25	28	23	5	6.0	6	8	11	8	67	79	17	18	21	18	26	123	2	9	4	31	54	8.8
Searcy	18	21	31	14	16	6.0	9	5	16	12	58	59	10	19	22	19	30	130	13	23	14	28	22	4.5
Sebastian	18	26	27	21	8	5.9	15	13	11	11	50	51	13	22	25	20	20	114	1	13	12	31	43	7.2
Sevier	27	31	21	16	5	5.7	5	7	9	7	72	125	24	18	17	13	28	106	5	13	7	20	55	9.5
Sharp	13	23	23	25	16	6.1	22	20	12	10	36	32	18	26	24	15	31	100	17	31	12	21	19	3.3
St. Francis	6	12	22	26	34	6.5	10	14	18	24	34	40	1	9	12	17	61	204	10	30	21	38	1	3.7
Stone	28	25	20	21	6	5.9	12	10	11	15	52	54	26	23	19	16	16	94	12	24	13	22	29	4.4
Union	25	21	28	22	4	5.9	16	15	11	8	50	50	29	20	18	22	11	92	18	24	7	15	36	4.6
Van Buren	20	28	34	16	2	5.8	13	15	12	13	47	46	22	22	27	13	16	98	15	31	17	17	20	3.4
Washington	11	17	25	28	19	6.2	5	7	8	12	68	82	8	14	20	20	38	145	4	12	10	29	45	7.6
White	15	21	27	29	8	6.1	11	13	13	13	50	53	20	23	23	16	18	102	11	24	14	28	23	4.4
Woodruff	6	23	41	26	4	6.0	13	26	23	18	20	30	10	24	39	18	9	106	7	36	24	28	5	3.3
Yell	26	39	24	11	0	5.6	15	11	7	7	60	73	21	17	18	15	29	117	6	19	12	28	35	5.7
Average	18	21	23	25	13	6.0	12	15	13	14	46	58	15	20	24	17	24	116	10	26	14	25	25	5.0

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

Table 7. The percentage of sampled acres as distributed within five fertilizer levels and median soil chemical property values by previous crop for soil samples submitted to the University of Arkansas System Division of Agriculture's Soil Testing and Research Laboratory in Marianna from 1 January 2016 through 31 December 2016.

Previous crop	Soil pH[a]						Mehlich-3 soil P[b] (ppm)						Mehlich-3 soil K[b] (ppm)						Mehlich-3 soil Zn[b] (ppm)					
	<5.4	5.4-5.7	5.8-6.2	6.3-6.9	>6.9	Md[c]	<16	16-25	26-35	36-50	>50	Md	<61	61-90	91-130	131-175	>175	Md	<1.6	1.6-3.0	3.1-4.0	4.1-8.0	>8.0	Md
	---(% of sampled acreage)--						--(% of sampled acreage)--					(ppm)	--(% of sampled acreage)--					(ppm)	--(% of sampled acreage)--					(ppm)
Corn	7	18	34	30	11	6.2	8	18	27	26	21	34	5	16	33	20	26	124	9	38	17	32	4	3.3
Cotton	4	10	24	38	24	6.5	2	10	18	37	33	43	1	13	22	25	39	154	20	42	16	20	2	2.5
Grain sorghum, non-irrigated	24	28	21	23	4	5.8	2	13	27	24	34	41	2	16	31	31	20	131	21	34	20	18	7	2.9
Grain sorghum, irrigated	7	11	19	40	23	6.6	6	17	24	23	30	36	2	15	38	22	23	125	7	33	23	37	0	3.6
Rice	11	14	20	34	21	6.4	23	32	24	15	6	24	7	21	27	17	28	123	11	47	21	21	0	2.9
Soybean	5	10	17	33	35	6.7	14	30	26	18	12	28	5	18	31	18	28	124	10	39	26	24	1	3.2
Wheat	27	23	17	28	5	6.0	11	21	17	22	29	36	8	21	32	24	15	119	27	33	18	17	5	2.8
Cool-season grass hay	13	19	34	30	4	6.0	6	13	16	16	49	48	32	23	19	11	15	83	7	31	15	26	21	3.9
Native warm-season grass hay	35	31	20	13	1	5.6	30	13	12	10	35	31	32	27	21	10	10	80	19	31	9	19	22	3.1
Warm-season grass hay	27	29	22	21	1	5.7	14	13	11	12	50	50	34	22	19	12	13	80	12	25	13	24	26	4.2
Pasture, all categories	19	29	29	22	1	5.8	13	12	10	10	55	61	17	19	20	16	28	118	9	20	10	22	39	6.1
Home garden	8	10	16	30	36	6.7	4	4	4	7	81	135	7	13	19	19	42	155	3	8	6	18	65	13.1
Turf	12	20	31	25	12	6.1	5	6	9	11	69	79	25	22	21	12	20	96	3	14	15	35	33	5.9
Home lawn	26	21	23	23	7	5.9	8	11	12	16	53	53	9	21	30	22	18	116	4	18	16	38	24	5.2
Small fruit	27	23	22	20	8	5.8	8	9	11	12	60	72	12	19	29	18	22	115	6	21	9	25	39	6.1
Ornamental	14	13	17	27	29	6.5	10	8	8	10	64	74	13	21	24	19	23	117	5	9	7	19	60	10.7
Average	17	19	23	27	14	6.1	10	14	16	17	43	53	13	19	26	19	23	116	11	28	15	25	21	5.0

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

Table 8. The percentage of sampled acres as distributed within five soil-test levels and median Mehlich-3 extractable manganese (Mn) by county for soil samples submitted to the University of Arkansas System Division of Agriculture's Soil Testing and Research Laboratory in Marianna from 1 January 2016 through 31 December 2016.

	Mehlich-3 extractable Mn[a] (ppm)							Mehlich-3 extractable Mn[a] (ppm)					
County	<31	31-60	61-120	121-240	>240	Md[b]	County	<31	31-60	61-120	121-240	>240	Md[b]
	(% of sampled acres)					(ppm)		(% of sampled acres)					(ppm)
Arkansas	2	6	19	52	21	172	Lee	9	29	30	21	11	78
Ashley	3	11	37	32	17	117	Lincoln	11	48	24	16	1	54
Baxter	1	1	13	48	37	206	Little River	1	26	40	27	3	86
Benton	1	8	33	47	11	134	Logan	2	4	25	57	12	157
Boone	1	3	10	37	49	237	Lonoke	2	14	31	28	25	132
Bradley	1	4	30	56	9	142	Madison	0	4	25	44	27	173
Calhoun	8	27	41	19	5	82	Marion	0	2	16	43	39	211
Carroll	0	2	15	49	34	200	Miller	21	45	25	8	1	45
Chicot	23	29	31	10	7	55	Mississippi	8	39	46	7	0	63
Clark	38	25	19	14	4	43	Monroe	2	11	20	36	31	173
Clay	6	14	33	36	11	115	Montgomery	7	9	45	33	6	103
Cleburne	2	10	35	40	13	127	Nevada	12	25	29	7	27	79
Cleveland	7	28	48	15	2	77	Newton	1	2	6	47	44	220
Columbia	31	48	16	4	1	41	Ouachita	19	32	28	18	3	58
Conway	5	16	36	33	10	105	Perry	2	10	25	41	22	149
Craighead	9	32	41	14	4	69	Phillips	2	7	29	48	14	144
Crawford	5	20	37	31	7	97	Pike	5	23	43	24	5	85
Crittenden	8	35	43	14	0	67	Poinsett	6	29	33	24	8	82
Cross	2	10	25	44	19	157	Polk	2	12	38	39	9	118
Dallas	13	34	35	15	3	65	Pope	4	17	34	30	15	111
Desha	4	35	45	14	2	75	Prairie	3	17	37	33	10	109
Drew	11	29	40	15	5	74	Pulaski	6	25	46	18	5	79
Faulkner	1	11	34	39	15	129	Randolph	4	6	14	38	38	209
Franklin	2	10	26	51	11	145	Saline	8	25	44	21	2	78
Fulton	2	1	41	36	20	138	Scott	0	2	16	54	28	177
Garland	4	18	54	22	2	86	Searcy	2	9	19	46	24	164
Grant	17	27	33	21	2	68	Sebastian	2	12	33	43	10	128
Greene	3	12	32	36	17	128	Sevier	9	17	38	28	8	95
Hempstead	23	26	26	19	6	63	Sharp	1	3	17	53	26	182
Hot Spring	19	17	31	26	7	89	St. Francis	8	30	30	26	6	78
Howard	9	24	36	24	7	78	Stone	5	16	31	36	12	117
Independence	1	8	32	38	21	140	Union	29	45	23	3	0	43
Izard	2	5	24	47	22	167	Van Buren	4	19	40	26	11	94
Jackson	2	4	15	37	42	215	Washington	1	6	32	46	15	139
Jefferson	6	30	48	16	0	73	White	15	16	22	31	16	110
Johnson	4	25	28	30	13	101	Woodruff	0	2	8	35	55	259
Lafayette	13	39	29	10	9	56	Yell	0	5	14	41	40	220
Lawrence	4	12	21	35	28	164	Average	7	18	30	31	14	119

[a] Analysis by inductively coupled argon plasma spectroscopy ICAP) in 1:10 soil: volume.
[b] Md = median.

Table 9. The percentage of sampled acres as distributed within five soil-test levels and median Mehlich-3 extractable manganese (Mn) by geographic area for soil samples submitted to the University of Arkansas System Division of Agriculture's Soil Testing and Research Laboratory in Marianna from 1 January 2016 through 31 December 2016.

	Mehlich-3 extractable Mn[a] (ppm)					
Geographic area	<31	31-60	61-120	121-240	>240	Md[b]
	(% of sampled acres)					(ppm)
Ozark Highlands, Cherty Limestone and Dolomite	1	5	25	45	24	161
Ozark Highlands, Sandstone and Limestone	2	3	28	45	22	162
Boston Mountains	9	14	27	34	16	123
Arkansas Valley and Ridges	3	13	31	39	14	129
Ouachita Mountains	5	14	41	33	7	104
Bottom Lands and Terraces	6	29	38	17	10	76
Coastal Plain	19	32	28	17	4	59
Loessial Plains	2	13	29	38	18	135
Loessial Hills	2	9	30	37	22	148
Blackland Prairie	18	38	27	15	2	51
Average	7	17	30	32	14	115

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

Table 10. The median Mehlich-3 extractable manganese (Mn) values by soil association number (SAN) for soil samples submitted to the University of Arkansas System Division of Agriculture's Soil Testing and Research Laboratory in Marianna from 1 January 2016 through 31 December 2016.

SAN	Soil Association	Mehlich-3 soil Mn	SAN	Soil Association	Mehlich-3 soil Mn
		(ppm Mn)			(ppm Mn)
1.	Clarksville-Nixa-Noark	208	26.	Amagon-Dundee	79
2.	Gepp-Doniphan-Gassville-Agnos	196	27.	Sharkey-Steele	51
3.	Arkana-Moko	200	28.	Commerce-Sharkey-Crevasse-Robinsonville	49
4.	Captina-Nixa-Tonti	137	29.	Perry-Portland	87
5.	Captina-Doniphan-Gepp	168	30.	Crevasse-Bruno-Oklared	50
6.	Eden-Newnata-Moko	141	31.	Roxana-Dardanelle-Bruno-Roellen	88
7.	Estate-Portia-Moko	188	32.	Rilla-Hebert	72
8.	Brockwell-Boden-Portia	161	33.	Billyhaw-Perry	108
9.	Linker-Mountainburg-Sidon	134	34.	Severn-Oklared	99
10.	Enders-Nella-Mountainburg-Steprock	118	35.	Adaton	47
11.	Falkner-Wrightsville	237	36.	Wrightsville-Louin-Acadia	83
12.	Leadvale-Taft	130	37.	Muskogee-Wrightsville-McKamie	96
13.	Enders-Mountainburg-Nella-Steprock	112	38.	Amy-Smithton-Pheba	74
14.	Spadra-Guthrie-Pickwick	215	39.	Darco-Briley-Smithdale	100
15.	Linker-Mountainburg	120	40.	Pheba-Amy-Savannah	45
16.	Carnasaw-Pirum-Clebit	133	41.	Smithdale-Sacul-Savannah-Saffell	68
17.	Kenn-Ceda-Avilla	121	42.	Sacul-Smithdale-Sawyer	55
18.	Carnasaw-Sherwood-Bismarck	87	43.	Guyton-Ouachita-Sardis	94
19.	Carnasaw-Bismarck	81	44.	Calloway-Henry-Grenada-Calhoun	125
20.	Leadvale-Taft	103	45.	Crowley-Stuttgart	151
21.	Spadra-Pickwick	172	46.	Loring	134
22.	Foley-Jackport-Crowley	145	47.	Loring-Memphis	150
23.	Kobel	153	48.	Brandon	170
24.	Sharkey-Alligator-Tunica	60	49.	Oktibbeha-Sumter	51
25.	Dundee-Bosket-Dubbs	142		Sum or Average	118

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

Table 11. The percentage of sampled acres as distributed within five soil-test levels and median Mehlich-3 extractable manganese (Mn) values by previous crop for soil samples submitted to the University of Arkansas System Division of Agriculture's Soil Testing and Research Laboratory in Marianna from 1 January 2016 through 31 December 2016.

Previous crop	Mehlich-3 extractable Mn[a] (ppm)					
	<31	31-60	61-120	121-240	>240	Md[b]
	--------------(% of sampled acres) --------------					(ppm)
Corn	6	23	32	21	18	95
Cotton	8	28	42	14	8	76
Grain sorghum, non-irrigated	6	10	27	43	14	127
Grain sorghum, irrigated	5	15	39	21	20	109
Rice	3	18	36	31	12	109
Soybean	7	23	31	26	13	92
Wheat	8	8	12	36	36	180
Cool-season grass hay	1	10	17	43	29	173
Native warm-season grass hay	3	11	24	48	14	161
Warm-season grass hay	5	11	24	40	20	144
Pasture, all categories	3	9	25	41	22	156
Home garden	3	13	33	36	15	122
Turf	36	35	18	10	1	40
Home lawn	6	20	43	27	4	91
Small fruit	3	15	29	39	14	135
Ornamental	4	17	44	29	6	100
Average	7	17	30	32	14	119

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

Variability in Soil-Test Phosphorus and Potassium in Several Arkansas Fields

L. Espinoza[1] *and M. Ismanov*[2]

Background Information and Research Problem

The majority of the soil samples analyzed by the University of Arkansas System Division of Agriculture's Soil Testing and Research Lab in Marianna, Ark., are collected with the objective of applying fertilizer in a variable-rate fashion. The overarching goal of this project is to evaluate the agronomic and economic benefits of variable-rate fertilization (VRF). However, successful VRF requires the proper characterization of the spatial dependence of the nutrients of interest. Currently in Arkansas, service providers take soil samples based on 2.5 or 5 acre grids, or they may use apparent electrical conductivity (EC_a) and perhaps yield maps to develop management zones. The choice of soil sampling method appears to be arbitrary and probably driven by convenience. Therefore, it is of critical importance to identify the density and/or method of soil sampling that best describes the spatial dependence of the nutrient(s) of interest. There is a need to understand which soil factors and management practices have a bigger weight on the spatial variability of a nutrient in a particular field. Before an attempt is made to evaluate VRF, one needs to be certain that fertilizer is applied only to areas where a fertilizer recommendation would have been generated. While it is not realistic to expect that VRF will account for 100% of the variability in a field, there should be a reasonable expectation that VRF will better address the variability than the conventional fertilizer application method. The objective of this paper is to report on a preliminary evaluation of the spatial dependence of nutrients, particularly phosphorus (P) and potassium (K) in several fields in eastern Arkansas.

Procedures

Soil samples were collected from 5 fields (nearly 740 acres) located in Lee and Cross counties in Arkansas. Each field was divided into 1 acre grids, with each grid center being geo-referenced. Once the center of each grid was located, 6 to 8 soil cores were collected to a depth of 4 or 6 in. (Table 1) from a 12-ft radius around the grid center point and composited. The soil was extracted for plant-available nutrients.

Five fields were sampled for the purpose of this study. Table 1 shows a description of sample fields, which were chosen because they included several soil series, and historical soil-test results showed significant spatial variability in the concentration of nutrients. Fields 1 and 2 are furrow-irrigated, while fields 3, 4, and 5 are irrigated with a center pivot. The pivot covers nearly 70% of Field 3, 100% of Field 4, and 90% of Field 5. Fields 1 and 2 were precision-leveled several years ago, while Fields 3, 4, and 5 have not received any type of land-forming practice. Fertilizers, particularly K, have been applied with variable-rate technology. Fields 2, 3, and 4 have a mixture of silt loam and clayey soils with undulating topography. All the selected fields contain more than 100 acres to assure sufficient sampling points to facilitate statistical analysis.

Descriptive statistics were estimated with the CAPABILITY Procedure in SAS (SAS Institute, Cary, N.C.), including the Shapiro-Wilk statistic, which was used to test for normality. When the test for normality failed, the data were log-transformed to stabilize the variance. Figure 1 shows an example of a frequency distribution for soil-test P before (Fig. 1a) and after transformation (Fig. 1b) for Field 4. Empirical semivariograms were fit to both raw and log-transformed data using ArcGIS Geostatistical Analyst (ESRI, Redlands, Calif.), with both Gaussian and spherical models tested. The selection of the fitted model was mostly based on the coefficient of determination (R^2) and visual observation. A semivariogram describes the nature of spatial autocorrelation of soil samples at a specific distance and direction from each other (Fig. 2). A semivariogram is composed of three parameters including the range, which is the distance where the predicted response curve flattens out. The range defines the minimum separation between soil samples that will ensure the two samples are independent. Soil samples collected at distances closer than the range are assumed to be spatially auto correlated. The *y*-axis (dependent variable) value corresponding to the range is called the sill. The sill represents the maximum semivariance between two sampling points and should approximate the population variance. It gives an indication of the degree of uncertainty when interpolating the points. Theoretically, the model should intercept at the 0 value; however, in real life measurement, errors prevent this from occurring. The point at which the line intercepts the *y*-axis is called the nugget, a measure of experimental and/or human error.

Results and Discussion

The descriptive statistics for soil-test P and K for each of the five fields are shown in Table 2. The coefficients of variation (CV) for P ranged from 37% to 58% among the five fields, which is considerably higher than the CV range for K (17% to 33%). The distribution of soil-test P failed the normality test

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for each site, based on the Shapiro-Wilk statistic. In the case of K, Field 5 was the only location with a skewed distribution. Regardless of the level of variability exhibited by the P and K concentrations in each field, the median and average concentrations were fairly similar. Results in Table 2 show the median values for both P and K are consistently lower than the corresponding mean concentrations. This situation may be an indication that the variability observed is not necessarily due to outliers among the soil samples, but rather to intrinsic variability in a particular field as proposed by Cambardella and Karlen (1999). Soil-test P concentrations for each field were log transformed to reduce the variance and calculate the semivariogram.

Figure 3 shows examples of the semivariograms for P and K in Fields 3 and 4. All the generated semivariograms were isotropic. A semivariogram is isotropic when, for our purposes, the variability in concentration of soil-test P or K is statistically similar, regardless of the direction of sampling (i.e., South to North compared to East to West). When, in addition to distance, direction is a factor in the variance characteristics, then the semivariogram is referred to as anisotropic. Spherical models were fitted for each one of the fields, based on the model R^2 and visual observation (data not shown). The semivariogram parameters are shown in Table 3. There was considerable variability among the ranges calculated for each field, even for fields that have received similar management for years. The soil-test P and K range values for Field 1 are 2 to 2.65 times larger than the ranges for Field 2. Fields 3, 4, and 5 have been planted to cotton during most years and show range values for K of 197, 436, and 525 feet, which approximate sampling grid sizes of 1, 5, and 6 acres, respectively. For P, the ranges vary from 239 to 1416 ft and would approximate sampling every 1.3 to 20 acres, respectively. Soil survey maps (Soil Survey Staff, 2017) show that the calculated range values cross several soil series, which is an indication that other factors such as micro-topography may have a larger effect on the observed variability. It is possible that sampling based on elevation or the incorporation of EC_a could improve the prediction of nutrient concentrations at non sampled locations. Apparent electrical conductivity will be collected in these fields. The range values calculated for Fields 2, 4, and 5 were numerically similar for P and K. As stated before, Field 3 receives irrigation in only 70% of its area. This situation could be a contributing factor for the low range for K. Also, a clustering effect associated with previous history of VRF could contribute to large range values for P. These hypotheses need to be further evaluated.

A large nugget effect was observed for K in Field 4 (nugget = 2800). As stated before, a nugget effect is associated with experimental error, human error, or both. In Field 4, there are large differences in elevation (3 to 4 ft) at distances considerably smaller than the calculated range. This situation will be further evaluated.

Cambardella and Karlen (1999) used the nugget-to-sill ratio to characterize the degree of spatial dependence for P and K (Table 3). Ratio values smaller than 25% were considered strongly spatial dependent; ratios between 25% and 75% were considered moderately spatially dependent; and ratios larger than 75% were weakly spatially dependent. Based on this interpretation, nugget-to-sill ratio for P and K was found to be strongly spatially dependent for Fields 1, 2, and 5 for P and Fields 1, 3, and 5 for K. Strong spatial dependency is typically associated with soil properties having a large influence on the observed variability. Spatial dependency was moderate for P in Fields 3 and 4, and for K in Fields 2 and 4.

Practical Applications

The objective of this study was to assess the nature of the variability in P and K in some soils in eastern Arkansas, to eventually develop recommendations regarding the proper grid size to collect soil samples for VRF. Soil-test P and K showed moderate to strong spatial dependence for 3 of the 5 fields under study. The analysis showed that, depending on the field, sampling densities between 1 and 6 acres would be required to characterize the spatial dependence of K. For P, grid sizes between 1.3 and 20 acres would be required. It is well known that the concentration of different nutrients is affected differently by specific soil properties, and our results show that. The observed variability in concentration of both P and K may have been affected by “outside” factors such as human and experimental error and previous fertilization history. Even with the variability observed, there were also some similarities in the calculated range for some fields, particularly Fields 4 and 5. As more data is collected and analyzed, perhaps we can identify specific soil properties and management practices that have a heavier weight on variability of the nutrients of interest and use such information to provide guidance on how to sample fields with a specific set of conditions. Apparent electrical conductivity, elevation and yield maps will be incorporated in the analysis at a later date.

Acknowledgments

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Table 1. Description of the fields sampled during 2017.

				Soil series						
Field ID	Field size	Crop	Sample depth	Arkabutla silt loam	Calloway silt loam	Henry silt loam	Dubbs loam	Earle silty clay	Sharkey clay	Dundee silt loam
	(acres)		(inches)	----------(% of field acreage)----------						
1	101	Corn	6	42	57	--	--	--	--	--
2	130	Soybean	4	--	55	45	--	--	--	--
3	190	Cotton	6	--	--	--	17	44	39	--
4	174	Cotton	6	--	--	--	51	14	9	27
5	145	Cotton	6	--	--	--	13	48	39	--

Table 2. Descriptive statistics for P and K concentrations in the five fields under study. Composite soil samples were collected in 1-acre grids.

Statistic	Field	P	K	Ln (P)	Ln (K)
		---------- (ppm) ----------			
Mean	1	21	73	3	4
	2	24	103	3	5
	3	43	190	4	5
	4	37	211	4	5
	5	42	187	4	5
		---------- (ppm) ----------			
Median	1	16	70	3	4
	2	22	97	3	5
	3	39	175	4	5
	4	35	208	3	5
	5	37	176	4	5
		---------- (ppm) ----------			
Maximum	1	51	139	4	5
	2	61	149	4	5
	3	51	51	4	6
	4	74	395	4	6
	5	123	434	5	6
		---------- (ppm) ----------			
Minimum	1	6	39	2	4
	2	8	57	2	4
	3	6	99	2	5
	4	13	78	2	4
	5	17	91	3	4
		---------- (%) ----------			
CV	1	58	28	19	7
	2	44	17	14	4
	3	43	29	12	5
	4	37	33	11	6
	5	43	32	10	6
		---------- [***P*-value (Pr < W)**] ----------			
Shapiro-Wilk Statistic	1	<0.0001	0.0368		
	2	<0.0001	0.5500		
	3	<0.0001	0.1134		
	4	<0.0001	0.0451		
	5	<0.0001	0.0001		

Table 3. Semivariogram parameters for the fields under study.

Parameter	Field	P	K
Transformation	1	Log normal	None
	2	Log normal	None
	3	Log normal	None
	4	Log normal	None
	5	Log normal	Log normal
		----------------(feet) -------------	
Range	1	741	1627
	2	370	613
	3	1416	197
	4	290	525
	5	239	436
Sill	1	0.397	0.168
	2	0.125	364
	3	0.206	3000
	4	0.111	5100
	5	0.137	0.9
Nugget	1	0.064	0.025
	2	0.063	208
	3	0.153	200
	4	0.025	2800
	5	0.095	0.08
		----------------- (%) --------------	
Nugget/Sill	1	24	15
	2	20	57
	3	74	6
	4	50	55
	5	16	8

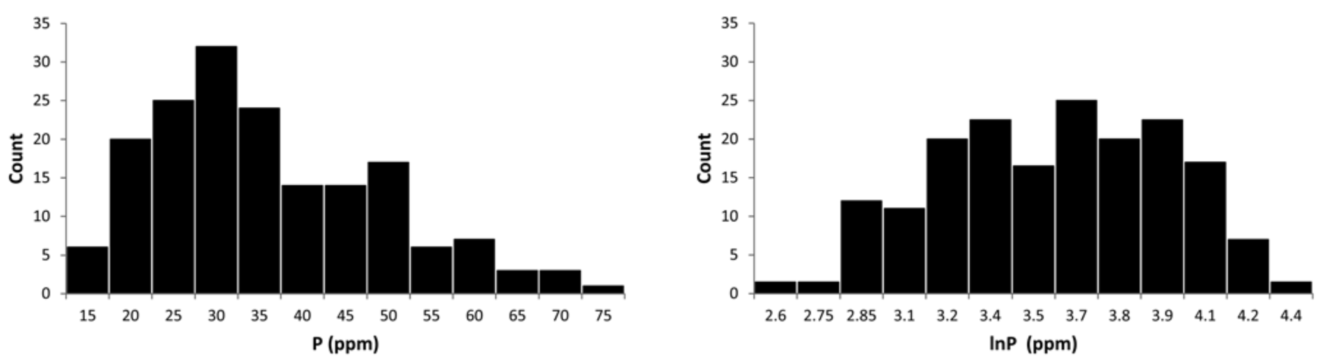

Fig. 1. Frequency distributions of soil-test P (left) and transformed soil-test P (lnP, right) for Field 4.

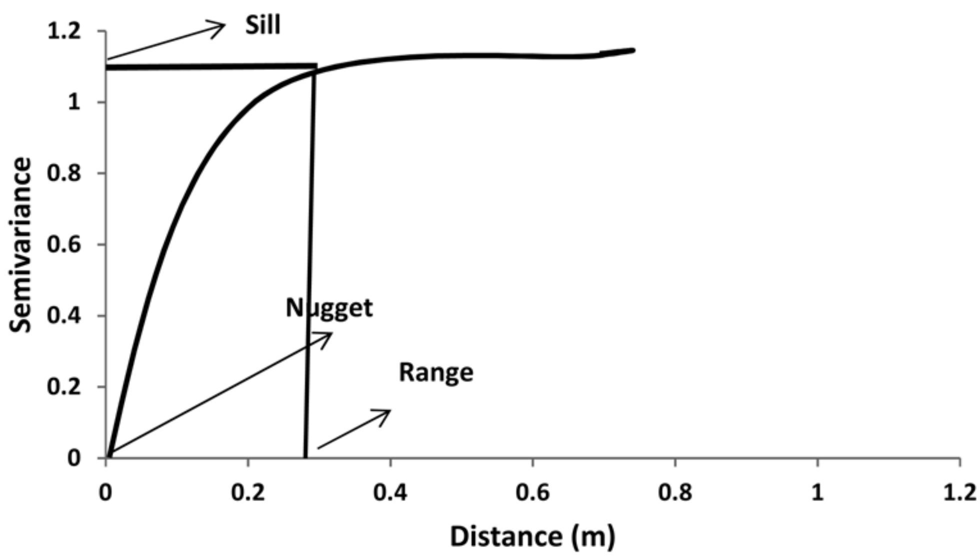

Fig. 2. Parameters of a semivariogram.

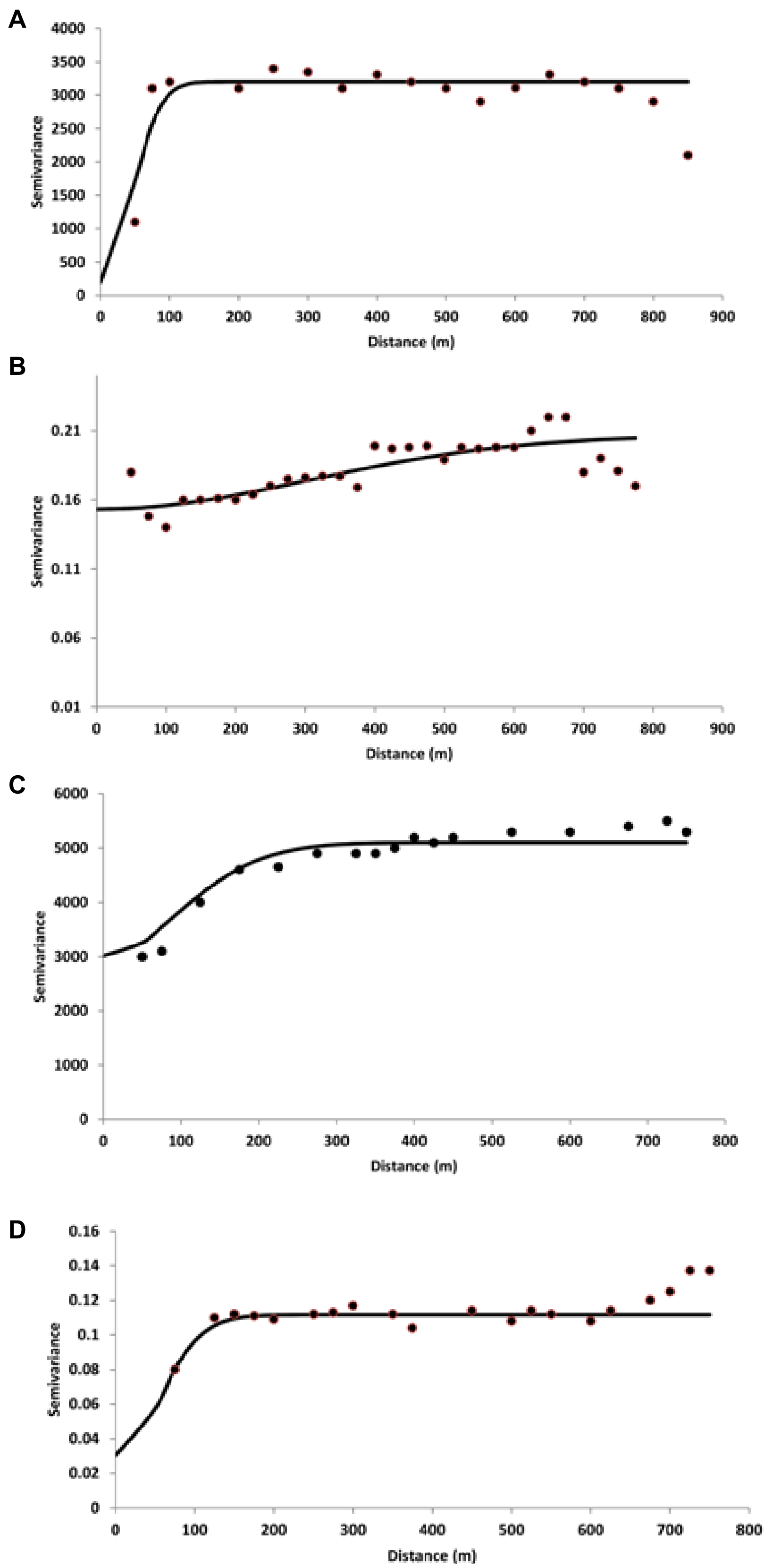

Fig. 3. Semivariogram models for Field 3 soil-test K (A) and transformed soil-test P (B), and Field 4 soil-test K (C) and transformed soil-test P (D). A spherical model was used to fit the data.

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

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Background Information and Research Problem

Corn (*Zea mays* L.) is a major row crop in Arkansas. In 2015, approximately 445,000 acres of corn were harvested in Arkansas. The equivalent of about 60 pounds of P_2O_5 and 45 lb K_2O/acre are removed from the soil by a corn grain yield of 175 bu/acre (International Plant Nutrition Institute, 2012). Between 1992 and 2015, the average corn grain yield in Arkansas increased from 130 to 181 bu/acre, which represents a substantial increase in phosphorus (P) and potassium (K) removal from the soil nutrient reserves. Phosphorus and K play important roles in many plant physiological processes. The deficiency of either nutrient will limit corn yield. Failure to replace the macronutrients removed by the harvested grain with adequate fertilizer rates contributes to soil nutrient depletion and eventually yield-limiting nutrient deficiencies.

Phosphorus transport from agricultural soils has been implicated as one of the factors contributing to the hypoxic zone in the Gulf of Mexico. Applying the right rates of P and K will enable growers to maximize the net returns from corn production and minimize P loss into the surrounding landscape. Reliable soil-test-based fertilizer recommendations are the most effective tool for applying the right P- and or K-fertilizer rates. In 2010, we initiated replicated field experiments to evaluate corn response to P and K fertilization in Arkansas. Multiple site-years of research are needed to increase the reliability and applicability of soil-test correlation and calibration curves. The specific objective of this research was to evaluate corn grain yield response to soil-applied fertilizer-P or -K rates at multiple locations on soils typically used for corn production in Arkansas.

Procedures

Phosphorus Experiments

A total of 9 replicated P-fertilization trials were conducted in 2017 in Arkansas. One trial was located at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) in Mississippi County (MSZ71), two at the Pine Tree Research Station (PTRS) in St. Francis County (SFZ71, SFZ73), and one at the Lon Mann Cotton Research Station (LMCRS) in Lee County (LEZ71). Additional on-farm trials were conducted in Arkansas County (ARZ71, ARZ73), Clay County (CLZ71, CLZ75), and Prairie County (PRZ71). Selected agronomic information for each trial is listed in Table 1.

Prior to P application, a composite soil sample was taken from the 0- to 6-inch depth of each replication. Each composite soil sample consisted of a total of 5 or 6 cores with an equal number of cores collected from the top of the bed and bed shoulder. Soil samples were oven-dried, crushed, extracted with Mehlich-3 solution, and the concentrations of elements in the extracts were measured by inductively coupled plasma atomic emission spectroscopy. Soil pH was measured in a 1:2 (volume: volume) soil-water mixture. Mean soil chemical properties are listed in Table 2.

Phosphorus application rates ranged from 0 to 160 lb P_2O_5/acre in 40 lb P_2O_5/acre increments applied as triple superphosphate. The experimental design was a randomized complete block where each treatment was replicated five times at all sites except CLZ75 where the test included four replicates. Phosphorus treatments were applied onto the soil surface in a single application between 5 days before planting and 6 days after emergence. At sites where the P was applied before planting, the treatments were mechanically incorporated into the top 3 to 4 inches of the soil. The beds were then re-pulled with a hipper and corn was planted on the top of the bed. Blanket applications of muriate of potash and $ZnSO_4$ supplied 90 to 120 lb K_2O, ~5 lb S, and ~10 lb Zn/acre. All experiments were fertilized with a total of 260 to 290 lb N/acre as urea in a single or split application (e.g., preplant, 3- to 6-leaf stage and/or pre-tassel) depending on the location. Corn was grown on beds and furrow-irrigated as needed either by research station staff or by the cooperating producer. Each plot was 25-ft long and 10- to 12.6-ft wide allowing for 4 rows of corn spaced 30 or 38 inches apart depending on the location. Corn management closely followed University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) recommendations. The middle two rows of each plot were harvested either with a plot combine (MSZ71, LEZ71) or by hand (ARZ71, ARZ73, CLZ71, CLZ75, PRZ71, SFZ71, SFZ73) with ears placed through a combine following hand harvest. The calculated grain yields were adjusted to a uniform moisture content of 15.5% before statistical analysis.

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[5] County Extension Agent - Agriculture, Arkansas County - Dewitt.

Potassium Experiments

Eight replicated field experiments were conducted in 2017 including trials at the NEREC, PTRS, LMCRS, and commercial production fields in Arkansas County (ARZ72, ARZ74), Clay County (CLZ72, CLZ76), and Prairie County (PRZ72). Agronomic information for K trials is listed in Table 1. Soil sampling, K fertilization and other practices were similar to the P studies. At PRZ72, the K-fertilizer treatments were applied approximately 3 weeks after emergence due to weather and scheduling problems. All K fertility tests were located adjacent to the P fertility trials described earlier. Soil property means are listed in Table 3. Potassium application rates ranged from 0 to 200 lb K_2O/acre in 50 lb K_2O/acre increments using muriate of potash. Triple superphosphate and $ZnSO_4$ were broadcast to supply 80 to 90 lb P_2O_5, ~10 lb Zn, and ~5 lb S/acre. Nitrogen fertilizer management and harvest were performed the same as described for the P trials.

Analysis of variance was performed for each individual P or K trial using the GLM procedure of SAS (SAS Institute, Cary, N.C.). When appropriate, significant differences among means were separated by the Least Square Means procedure with significance interpreted at the 0.10 level.

Results and Discussion

Phosphorus Experiments

The soil pH ranged from 5.5 to 6.9 and Mehlich-3 extractable P ranged from 13 to 54 ppm (Table 2). According to the current University of Arkansas interpretation, the soil-test P level was Very Low (<16 ppm) at LEZ71 and SFZ73; Low (16 to 25 ppm) at ARZ71 and CLZ75; Medium (26 to 35 ppm) at ARZ73, PRZ71, and SFZ71; Optimum (26 to 35 ppm) at CLZ71; and Above Optimum (>50 ppm) at MSZ71. According to the current CES soil-test-based P fertilization guidelines, for corn with a yield goal of >200 bu/acre, the Very Low, Low, Medium, Optimum, and Above Optimum soil-test levels receive recommendations of 130, 110, 80, 0, and 0 lb P_2O_5/acre, respectively.

Phosphorus fertilization significantly influenced ($P <$ 0.10) corn grain yield (Table 4) at only two sites, which had either Low (ARZ71) or Medium (PRZ71) Mehlich-3 extractable soil-P levels (Table 2). At ARZ71, the grain yield of corn that did not receive any P was 221 bu/acre and the yield of corn fertilized with P ranged from 203 to 239 lb/acre with the yield of corn receiving no P being similar to all other P rates. At PRZ71, the yield of the corn that received no P averaged 167 bu/acre and the yields of corn receiving P ranged from 152 to 187 bu/acre with the response to P fertilization being inconsistent among the P rates. Unfortunately, the yields at the two sites rated Very Low (LEZ71, SFZ73) were negatively impacted by late-season foliar diseases or wildlife, respectively. Phosphorus application rate did not significantly influence the corn grain yield at the remaining five sites.

Potassium Experiments

Soil pH and Mehlich-3 extractable P ranged from 5.8 to 7.0 and 15 to 51 ppm, respectively (Table 3). The average Mehlich-3 extractable K ranged from 60 to 305 ppm among the 8 sites. According to the CES soil-test interpretation, soil-test K was Very Low (<61 ppm) at ARZ72; Low (61 to 90 ppm) at the ARZ74, CLZ76, LEZ72, and PRZ72; Medium (91 to 130 ppm) at CLZ72 and SFZ72; and Above Optimum (>175 ppm) at MSZ72. Current fertilization guidelines for corn with a yield goal of >200 bu/acre would have recommended 160 and 115, 50, and 0 lb K_2O/acre for the Very Low, Low, Medium and Above Optimum soil-test K levels, respectively.

Potassium fertilization significantly ($P \leq 0.10$) affected corn grain yield at ARZ72 where the yield of the corn that did not receive any K was 143 bu/acre and 75 to 91 bu/acre lower than corn that received K fertilizer (Table 5). At ARZ74 and SFZ72, the grain yield of the corn not fertilized with K was numerically lower than the corn that was fertilized with K. Late application of K fertilizer at PRZ72 may have contributed to the lack of response to K fertilization at this site. The late-season rust diseases present at LEZ72 limited corn yield. As expected, K fertilization did not influence grain yield at MSZ72, which was rated Above Optimum in soil K. The positive response to K fertilization at ARZ72 and lack of response at MSZ72 are consistent with current CES recommendations for soil-test-based fertilizer-K recommendations.

Practical Applications

The 2017 results show that P fertilization did not increase corn grain yield when Mehlich-3 extractable P in the 0- to 6-inch depth was within the Medium level or above it. At the P-responsive sites, corn receiving 80 lb P_2O_5/acre produced the numerically greatest corn grain yield. Potassium fertilization significantly increased corn grain yield at only one site, which had Very Low soil-test K. Potassium fertilization failed to influence corn yield at two sites with Medium and Above Optimum K levels. The results from these studies will be added to a database on corn response to P or K fertilization to evaluate the utility of existing soil-test thresholds and recommended fertilizer-P and K rates needed to produce maximal corn yield. Additional single-year and long-term trials on soils with Medium and lower soil-test P and K values are needed to increase the reliability of soil-test-based P- and K-fertilizer recommendations for irrigated corn production in the region.

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Table 1. Site identification code, test nutrient(s), corn hybrid; planting and harvest dates for corn P- or K-fertilizer rate trials conducted in Arkansas (ARZ71, ARZ72, ARZ73, ARZ74), Clay (CLZ71, CLZ72, CLZ75, CLZ76), Lee (LEZ71, LEZ72), Mississippi (MSZ71, MSZ72) Prairie (PRZ71, PRZ72), and St. Francis (SFZ71, SFZ72, SFZ73) counties during 2017.

Site ID	Test nutrient	Hybrid	Soil Series	Previous crop	Planting date	P application date	Harvest date
ARZ71, ARZ72	P, K	Armor 1550	Dewitt silt loam	Soybean	12-April	14-April	23-Aug
ARZ73, ARZ74	P, K	Armor 1550	Tichnor silt loam	Soybean	12-April	20-April	24-Aug
CLZ71, CLZ72	P, K	Cropland 6640	Crowley silt loam	Corn	8-April	19-April	7-Sep
CLZ75, CLZ76	P, K	Dekalb 66-87	Falaya silt loam	Soybean	13-April	19-April	6-Sep
LEZ71, LEZ72	P, K	Cropland 6274	Calloway silt loam	Grain sorghum	3-May	5-May	21-Aug
MSZ71, MSZ72	P, K	Armor 1500	Sharkey silty clay	Soybean	17-April	-	11-Sep
PRZ71, PRZ72	P, K	Cropland 6274	Calloway silt loam	Corn	9-April	17-April	21-Aug
SFZ71, SFZ72, SFZ73	P, K	Cropland 6274	Calhoun silt loam	Corn	10-May	4-May	25-Aug

Table 2. Selected chemical property means of soil samples collected from the 0-to 6-inch depth before P-fertilizer application for 9 P-fertilization trials established in Arkansas (ARZ71, ARZ73), Clay (CLZ71, CLZ75), Lee (LEZ71), Mississippi (MSZ71), Prairie (PRZ71), and St. Francis (SFZ71, SFZ73) counties during 2017.

Site ID	Soil pH†	SOM	Mehlich-3-extractable nutrients						
			P	SD P‡	K	Ca	Mg	Cu	Zn
		(%)	----	----	----	(ppm)	----	----	----
ARZ71	6.7	3.3	22	±2	75	1566	212	2.6	4.5
ARZ73	6.5	2.7	32	±4	65	1955	284	2.3	4.1
CLZ71	6.6	2.6	44	±9	89	1188	133	2.8	13.9
CLZ75	5.5	1.6	20	±6	77	838	220	2.0	2.3
LEZ71	5.9	1.4	13	±1	68	812	228	2.1	4.9
MSZ71	6.4	2.7	54	±4	251	2645	560	4.2	4.3
PRZ71	6.9	1.9	27	±7	76	1135	145	1.7	4.4
SFZ71	6.3	2.3	30	±7	118	1285	206	2.1	10.8
SFZ73	6.6	2.2	13	±1	18	1302	268	1.8	5.2

† Soil pH was measured in a 1:2 (weight: volume) soil-water mixture.
‡ SD, Standard deviation of Mehlich-3 extractable soil-test P means.

Table 3. Selected chemical property means of soil samples taken from the 0- to 6-inch depth before K-fertilizer application for 8 trials conducted in Arkansas (ARZ72, ARZ74), Clay (CLZ72, CLZ76), Lee (LEZ72), Prairie (PRZ72), Mississippi (MSZ72), and St. Francis (SFZ72) counties during 2017.

Site ID	Soil pH†	SOM	Mehlich-3-extractable nutrients						
			P	K	SD K‡	Ca	Mg	Cu	Zn
		(%)	----	----	----	(ppm)	----	----	----
ARZ72	6.3	3.3	25	60	±12	1985	288	2.3	4.0
ARZ74	6.9	2.6	20	70	±9	1516	212	2.3	3.5
CLZ72	6.4	2.4	40	101	±11	1133	136	1.9	14.0
CLZ76	5.8	1.5	17	72	±10	765	219	2.0	1.9
LEZ72	5.8	1.7	18	74	±7	861	231	2.3	5.1
MSZ72	6.4	2.9	51	305	±17	3186	697	4.3	4.1
PRZ72	7.0	1.9	15	66	±8	1232	151	1.7	3.2
SFZ72	7.0	2.1	25	107	±5	1276	222	1.9	1.9

† Soil pH was measured in a 1:2 (weight: volume) soil-water mixture.
‡ SD, Standard deviation of Mehlich-3 extractable soil-test K means.

Table 4. Effect of P-fertilization rate on corn grain yield for 8 trials conducted in Arkansas (ARZ71, ARZ73), Clay (CLZ71, CLZ75), Lee (LEZ71), Mississippi (MSZ71), Prairie (PRZ71), and St. Francis (SFZ71) counties during 2017.

Fertilizer-P Rate	ARZ71	ARZ73	CLZ71	CLZ75	LEZ71	MSZ71	PRZ71	SFZ71
(lb P_2O_5/acre)	[corn grain yield (bu/acre)]†							
0	221 AB	201	249	210	136	254	167 BC	178
40	211 B	215	265	230	138	256	157 C	188
80	239 A	227	214	213	140	262	187 A	178
120	203 B	213	223	226	139	233	152 C	180
160	213 B	212	240	230	134	251	180 A	182
C.V., %‡	7.5	8.7	6.5	7.2	9.2	6.7	7.8	7.8
P-value	0.0303	0.4643	0.1649	0.3112	0.9510	0.1247	0.0178	0.8994

† Means listed within a column (site) followed by different uppercase letters are significantly different at $P \leq 0.10$.
‡ C.V., Coefficient of variation.

Table 5. Effect of K-fertilization rate on corn grain yield for 8 trials conducted in Arkansas (ARZ72, ARZ74), Clay (CLZ72, CLZ76), Lee (LEZ72), Mississippi (MSZ71), Prairie (PRZ72), and St. Francis (SFZ72) counties during 2017.

Fertilizer-K Rate	ARZ72	ARZ74	CLZ72	CLZ76	LEZ72	MSZ72	PRZ72	SFZ72
(lb K_2O/acre)	[corn grain yield (bu/acre)]†							
0	143 B	187	234	226	144	258	173	148
50	218 A	190	237	229	149	249	189	174
100	234 A	207	248	211	144	248	189	173
150	225 A	206	230	221	143	244	175	176
200	226 A	197	234	231	147	250	173	192
C.V., %‡	11.5	9.9	6.9	7.4	6.1	4.9	9.9	12.1
P-value	0.0089	0.5360	0.9632	0.5019	0.7794	0.4705	0.4759	0.1779

† Means listed within a column (site) followed by different uppercase letters are significantly different at $P \leq 0.10$.
‡ C.V., Coefficient of variation.

Toward Developing an Improved Agricultural Limestone Recommendation for Arkansas Soils

M. Mozaffari[1]

Background Information and Research Problem

Soil pH is one of the most important properties that control soil nutrient availability and potential metal contaminant retention by the soil solid phase. Most agricultural crops require a pH range between 5.5 and 6.5 for optimal crop growth and development. Crop production practices such as root respiration and intensive nitrogen fertilization lower the soil pH. University of Arkansas System Division of Agriculture Cooperative Extension Service (CES) guidelines for soil-test-based fertility currently consider soil pH of <5.8 as below optimum and recommend application of 2000 to 7000 lb/acre of agricultural lime depending on soil pH and clay content. Growers, consultants, and other interested parties have questioned the foundation and scientific data that support our existing lime recommendations. We have not been able to find any published records that support the recommendation logic. The research reported here is part of a larger effort to develop research-based lime recommendations for the diverse array of soil and cropping systems in Arkansas. As a part of the project, we have collected bulk soil samples from 72 sites across the state of Arkansas. The specific objectives of this report are, to summarize the results of an incubation study that evaluated the soil pH response to $CaCO_3$ application rate, evaluate the relationship between Mehlich-3 extractable basic cations and soil clay content, and identify soil properties that play an important role in developing improved soil-test-based lime recommendation.

Procedures

Five gallons of bulk soil was collected from the 0- to 6-inch depth at 72 locations across Arkansas for laboratory use. At all sites, the GPS coordinates were recorded and the soil series identified using the Natural Resources Conservation Service (NRCS) Web Soil Survey site (USDA-NRCS, 2015; Table 1). Soil samples were dried thoroughly, mixed in a clean cement mixer, and ground to pass a 2-mm sieve. Soil samples were tested for pH (w/w, 1:2 water and 0.01 M $CaCl_2$), soil organic matter (SOM), Mehlich-3 extractable nutrients, and particle size analysis by the hydrometer method. Mehlich-3 extractable potassium (K), calcium (Ca), magnesium (Mg), and sodium (Na) concentrations were used to calculate the cmolc/kg soil (meq/100 g soil) of each basic cation and the estimated soil cation exchange capacity (ECEC) was derived by summing the charge of Mehlich-3 extractable basic cations.

The initial soil characterization data were used to select a cross section of soils with a wide range of soil physical and chemical properties (Table 2) for a 120-day laboratory incubation study. The incubation study evaluated soil pH response to five rates of pure $CaCO_3$ equivalent to 0, 2000, 4000, 6000, and 8,000 lb/acre assuming 2,000,000 lb soil/acre in an acre furrow slice. Data for 20 soils are presented here.

Each experimental unit consisted of one 300-mL round bottom plastic container. A 220-g sample of each soil plus the appropriate amount of $CaCO_3$ was mixed thoroughly and added to the plastic container. We used soil particle size analysis to estimate gravimetric soil moisture content at field capacity using the SPAW program developed by USDA (SPAW, v. 6.02.75, USDA-ARS; Saxton and Rawls, 2006). Deionized water was added to each container to obtain a gravimetric moisture content equivalent to gravimetric field capacity, which ranged from 16% (MIL1) to 45% (MIL6). On day 1, a subsample was taken from each container for the determination of soil pH and Mehlich-3 extractable nutrients (Table 2). The weight of the remaining moist soil and the container was recorded after subsample removal. The top of each container was covered with plastic film and 8 to 10 pinholes were made in the plastic film to allow for air exchange. Each treatment was replicated 4 times. Containers were arranged on shelves in a randomized complete block configuration and incubated at room temperature (68° to 77° F). The containers were periodically (every 2 to 3 weeks) checked, and if the soil appeared completely dry, then the container weight was recorded and deionized water was added to bring the weight of the container plus soil to the weight at day 1. The soil was allowed to go through at least 6 wet-drying cycles to simulate the field conditions. Gravimetric moisture content at the end of drying cycle was 0% to 4%.

At the end of the 120-day incubation, the soil samples were removed from the containers, dried, ground, and subsamples were taken for measurement of soil pH and Mehlich-3 extractable nutrients.

Descriptive statistics were used to determine the range of soil chemical and physical properties. For each soil, the slope of the line relating the lime ($CaCO_3$) rate to the final soil pH was calculated and lime requirement (LR, defined as the lb/acre of lime required to raise the soil pH by one unit) was calculated by taking the inverse of the slope. Data were examined and the $CaCO_3$ rate(s) that increased the water pH above 6.5 were excluded from the slope calculation. Regression analysis was used to establish a relationship between $CaCO_3$ application rate and the soil pH on day 120, quantify the relationship between soil properties, and the relationship between lime requirement and routinely measured soil properties.

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Results and Discussion

The 20 soils reported here represent a wide range of geographical locations, land use, and soil properties (Table 1). Eleven samples came from row-crop fields, seven samples were collected from pasture and hay fields, and the remaining samples were collected from fallow land. Soil organic matter content ranged from 1.40% to 6.45% and clay content ranged from 10% to 66% with soil textural classifications varying from sandy loam to clay (Table 2). Soil water pH ($pH_{w,\ 1:2}$) ranged from 4.1 to 5.9 and only two soils had a pH higher than 5.8. Sodium (0.03 to 0.37 cmolc/kg soil) and Ca (1.15 to 17.42 cmolc/kg soil) were the least and most abundant Mehlich-3 extractable basic cations. The relationship between ECEC and soil clay content was best described by a linear equation [% clay content = 12.9 + (2.21 × ECEC), $R^2 = 0.85$, $P < 0.0001$]. Soil clay content was also significantly ($P < 0.0001$) correlated with exchangeable K, Ca, Mg, and Na (as estimated by Mehlich-3 extraction) where a 1% increase in clay content was brought about by an increase of 56.7, 3.35, 6.2, and 137.9 cmolc/kg of soil K, Ca, Mg, and Na, respectively ($R^2 = 0.35$ to 0.81). Mehlich-3 extractable Na was very weakly correlated with soil clay content ($R^2 = 0.35$). The sum of Ca and Mg was a slightly better predictor of soil clay content than Ca only ($R^2 = 0.89$ vs 0.85). The above significant linear relationships suggest that soil clay content can be reasonably estimated from routinely measured soil properties. This highlights the possibility of refining lime recommendations by using the information from a routine soil test. The relation between water and salt pH was best described by $pH_{W\ 1:2} = 0.541 + (0.9785 \times pH_{CaCl_2})$ [$R^2 = 0.81$, $P < 0.0001$].

The LR (pure $CaCO_3$) ranged from 1860 to 7921 lb/acre and 1633 to 6061 lb/acre when the final soil pH was measured by pH_W, and pH_{CaCl_2}, respectively. The LR measured by the two methods were significantly and strongly correlated ($LR_{H_2O} = 70 + (1.1 \times LR_{CaCl_2})$, $R^2=0.86$, $P < 0.0001$). As expected, there was no significant correlation between the initial soil pH and the LR. The LR_{H_2O} was significantly ($P \leq 0.0015$) and moderately correlated with ECEC ($R^2 = 0.44$) and SOM ($R^2 = 0.57$). This suggests that routinely measured soil properties such as ECEC or exchangeable Ca plus soil pH can be used for determining LR, as has been done by the CES for many years.

Practical Applications

The 20 soils in this study are representative of the range of physical and chemical properties of pasture and row-crop fields in Arkansas. This study developed a pH response curve to lime rate for 20 soils using reagent grade $CaCO_3$. Soil clay content was highly correlated with ECEC, as estimated from the summation of Mehlich-3 extractable K, Ca, Mg, and Na ($R^2 = 0.85$). Lime requirement was moderately and significantly correlated with SOM or ECEC ($R^2 = 0.44$ to 0.57). Therefore, routinely measured basic cations are a good predictor of soil clay content and likely can be used with soil pH to estimate reserve acidity for predicting lime requirement. Another incubation study with other soils is underway. Correlation studies with several methods of predicting LR will begin in January of 2018. The outcomes will enable Arkansas growers to improve their nutrient use efficiency and profit margins by applying the right rate of agricultural limestone.

Acknowledgments

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Table 1. Selected site information for the 20 soils used in a 120-day laboratory incubation study that evaluated the soil pH response to $CaCO_3$ rate for 20 soils collected from row-crop and pasture fields in Arkansas.

Site ID	County	Previous Crop	Sand	Silt	Clay	Texture	Soil Series
			--------------	(%)	-------------		
ARKL1	Arkansas	Corn	6	71	23	Silt loam	Stuttgart silt loam
ARKL2	Arkansas	Pasture	1	66	33	Silty clay loam	Kobel silty clay
CONL1	Conway	Pasture	16	59	25	Silt loam	Barling silt loam
CRAL1	Craighead	Pasture	12	61	27	Silty clay loam	Foley silt loam
CRIL1	Crittenden	Fallow	1	38	61	Clay	Alligator silty clay
CRIL2	Crittenden	Sorghum	3	52	45	Silty clay	Dundee silt loam
CRIL4	Crittenden	Corn	7	27	66	Clay	Earle clay
CROL1	Cross	Fallow	3	80	17	Silt loam	Collins silt loam
LAFL1	Lafayette	Soybean	14	33	53	Clay	Armistead clay
LAWL1	Lawrence	Hay	48	36	16	Loam	Boden gravelly sandy loam
LEEL2	Lee	Soybean	2	71	27	Silt loam	Zachary soils
LEELPHI	Lee	Wheat	12	74	14	Silt loam	Zachary soils
LIL1	Lincoln	Fallow	38	49	13	Loam	Rilla silt loam
MIL1	Mississippi	Cotton	72	18	10	Sandy loam	Hayti fine sandy loam
MIL4	Mississippi	Cotton	30	30	40	Clay loam	Grenada silt loam
MIL6	Mississippi	Cotton	1	39	60	Clay	Sharkey-Steele-Complex
PRL1	Prairie	Pasture	15	64	21	Silt loam	Dubbs silt loam
PRL3	Prairie	Hay	9	62	29	Silty clay loam	Immanuel silt loam
SFL4	St. Francis	Hay	31	10	59	Clay	Alligator & Sharkey clays
SFL1	St. Francis	Sorghum	4	71	25	Silt loam	Arkabutla silt loam

Table 2. Soil organic matter (SOM), Mehlich-3 extractable cations, estimated cation exchange capacity (ECEC), water pH (pH_w), 0.01 M $CaCl_2$ pH (pH_{CaCl_2}) for the 20 soils used in a 120-day laboratory incubation study that evaluated soil pH response to $CaCO_3$ rate for 20 soils collected from row-crop and pasture sites in Arkansas.

Site ID	SOM	K	Ca	Mg	Na	ECEC[a]	pH_w	pH_{CaCl_2}	Lime requirement[b] pH_w	Lime requirement[b] pH_{CaCl_2}
	(%)	-----------------------	(cmolc/kg soil)	----------------------------					- (lb of lime/acre)-	
ARKL1	3.60	0.44	3.35	1.03	0.13	4.95	5.48	5.33	5399	4456
ARKL2	3.40	0.61	2.77	1.83	0.07	5.27	4.85	4.31	4444	3721
CONL1	2.30	0.23	1.56	0.50	0.06	2.35	5.15	4.63	3590	2843
CRAL1	3.85	0.30	6.04	2.39	0.16	8.89	4.65	4.30	3478	3902
CRIL1	3.45	0.74	10.05	7.20	0.16	18.15	5.35	5.04	6755	5352
CRIL2	2.55	0.59	7.55	0.63	0.37	14.80	4.83	4.41	4706	3810
CRIL4	3.40	0.82	12.20	6.59	0.15	19.76	4.65	4.23	6202	5369
CROL1	1.60	0.56	2.06	0.76	0.06	3.44	5.78	4.92	1860	1633
LAFL1	3.15	0.91	10.84	7.35	0.11	19.21	5.35	5.13	3478	3636
LAWL1	3.40	0.21	1.27	0.81	0.04	2.32	4.10	3.90	3095	2838
LEEL2	1.40	0.53	4.48	2.62	0.07	7.70	4.40	4.33	1905	1667
LEELIPHI	1.85	0.33	3.25	0.93	0.05	4.56	5.93	5.39	2462	2424
LIL1	1.95	0.36	3.01	0.76	0.07	4.19	5.25	4.93	2667	2222
MIL1	1.90	0.24	1.15	0.35	0.03	1.76	5.18	4.59	3077	2069
MIL4	2.05	0.71	7.30	2.93	0.09	11.03	5.43	4.83	4590	5437
MIL6	3.40	0.87	15.21	5.23	0.15	21.45	5.35	5.13	4571	4324
PRL1	1.60	0.22	3.83	1.16	0.06	5.26	5.40	4.90	4097	3619
PRL3	3.30	0.19	1.77	0.72	0.05	2.72	4.50	4.06	4786	4067
SFL4	6.45	1.05	17.42	7.35	0.15	25.97	5.13	4.93	7921	6061
SFL1	1.90	0.27	3.10	1.56	0.015	4.98	4.93	4.30	4211	3378

[a] ECEC is the sum of basic cations.

[b] The amount of pure calcium carbonate required to raise the soil pH by one unit.

Economic Optimum Potassium Rate for Soybean Production in Arkansas

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Background Information and Research Problem

Accurate economic farm management decisions can only be made when the relationship between input and output are considered, given the current market conditions. Potassium (K) fertilizer is a key input to soybean production. This work seeks to identify economic opportunities associated with K fertilization in soybean production. By applying economic analysis to soil amendment alternatives, we can identify the economic incentives inherent in soil fertility decisions.

Applying K fertilizer can be thought of as an investment problem. Increased returns through higher yields come at the expense of upfront expenditure on K fertilizer. The payoff from investing in K is variable, as yield response to K depends on many factors, many of which are beyond the farmer's control. The uncertainty of yield responses greatly complicates the task to identify the profit-maximizing input level of K fertilizer. This places an even higher importance on performing K-fertilization trials that increase the explanatory power of the relationship between K fertilizer and yield. This is especially important in commodity markets where the price ratio is narrower, such that producers are forced to become as efficient as possible.

Replicated field trials measuring the change in soybean yield associated with different K-fertilizer rates were conducted from 2004 to 2016 at various locations throughout Arkansas resulting in 99 site-years of data. These data form the base from which this economic study is developed. The results of this analysis apply to soybeans grown under irrigation in Arkansas.

Procedures

When making investment decisions in the face of uncertainty, one acceptable approach is to conduct a mean-variance analysis for the available choices. The goal is to identify "the set of mean-variance choices from the investment opportunity set where for a given variance, no other investment opportunity offers a higher mean return" (Copeland and Weston, 1983). For this study, K-fertilization rate is the investment choice and standard deviation is utilized as the measurement of variance. Change in profit, measured by profit above making no K application, is calculated for two different soybean price assumptions as well as two different K-fertilizer price assumptions.

When establishing mean standard deviation objects of choice for this study, rates of applied K were grouped into ranges. The data set was divided by soil-test K levels, and the change in profit was calculated for those observations with very low, low, medium, optimum, and above optimum Mehlich-3 concentrations of K (Table 1). These groups follow the current University of Arkansas System Division of Agriculture Cooperative Extension Service (CES) recommendations for soybean production (Slaton et al., 2013). In addition, groupings of applied K levels were chosen to keep the number of observations per group at or above 15 where possible.

While the mean standard deviation approach provides useful insight, it is worthwhile to also consider a continuous relationship between K rate and associated soybean yield. A regression analysis utilized a quadratic mathematical functional form to generate estimates of both applied K and soil-test K's marginal effect on yield. Quadratic forms in fertility studies have previously been documented as evidenced by Watkins et al. (2010). The economic optimum relies on the relationship between these marginal productivity estimates of K fertilizer and the marginal value of that yield gain, based on the price ratio. Equation 1 provides the conceptual multiple regression model of the total physical product (TPP) curve:

$$Yield = \beta_0 + \beta_1 M3K^2 + \beta_2 KRate^2 + \beta_3 M3K + \beta_4 KRate + \beta_5 M3K + KRate + \varepsilon \qquad \text{Eq. 1}$$

where yield represents soybean bu/acre, *M3K* is the result of a soil-test K (ppm), *KRate* is the lb K_2O/acre applied as muriate of potash in each treatment, and ε is an error term. For this analysis, the marginal physical product curve is estimated directly, by taking the partial derivative of TPP with respect to applied K rate, as specified by Equation 2:

$$Yield\ Change = \beta_4 + \beta_5 M3K + \beta_2(2{*}KRate) + \varepsilon \qquad \text{Eq. 2}$$

where variables are as described above and yield change is bu/acre above the yield associated with zero applied K. The coefficients (*β*) estimated are then used in calculating the economic optimum by Equation 3:

$$KRate = \frac{\frac{KPrice}{OutputPrice} - \beta_4 - \beta_5{*}M3K}{2\beta_2} \qquad \text{Eq. 3}$$

where the input/output price ratio is calculated using the cost of K-fertilizer (*KPrice*) and soybean market prices (*OutputPrice*). It is hypothesized that a threshold exists in soil-test K where after a certain point, fertilizer K's effect on yield is no longer

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significant. Threshold tests are applied to Equation 2 to identify this threshold, and then two regressions were run, one above, and one below this threshold soil-test K value (Table 2).

Results and Discussion

The resulting mean changes in profit and the associated standard deviations for each range of K-fertilizer rates are summarized in Table 1. The first column of results, when soybean price is $10.00/bu, and the cost of K fertilizer is $0.25/unit, represents market prices in recent history. The results show that as more K is applied, the standard deviation of the change in profit increases. When soil-test K is low, medium, or optimum, risk averse producers should apply low levels of K, such as 40 lb K_2O/acre. This is due to the expectation that this fertilization rate will provide much of the benefit of increased profit, while also achieving the lowest level of standard deviation in profit change.

Regression results from direct estimation of the marginal physical product are summarized in Table 2. Threshold tests reveal a structural break at 92 ppm soil-test K. Model fit and parameter estimates are reported for those observations falling below and above the 92 ppm soil-test K, respectively. Firstly, model fit, as represented by the R^2 values of 0.335 and 0.224 could indicate room for improving the current understanding of the relationship between K-fertilizer rate and yield increase. Economic inference based on these estimates will vary less as explanatory power can be increased by further fertility research.

Below 92 ppm, soil-test K does not help explain yield increase. However, above 92 ppm, soil-test K is highly significant and is found to have a negative relationship with yield change, thus as soil-test K increases, the expected yield change due to K fertilization decreases. Specifically analyzing the K-fertilizer rate, for soils having a soil-test K below 92 ppm, a highly significant relationship is present where for every 1.0 lb K_2O/acre increase in the applied K_2O rate, soybean yield is expected to increase 0.0387 bushels/acre, on average. For soils with soil-test K above 92 ppm, a highly significant relationship is also present where for every 1.0 lb K_2O/acre increase in the applied K rate, the soybean yield response is reduced to just 0.0174 bu/acre. It is important to note that soil-test K is not only a slope shifter (as in the parameter differences above), but is also an intercept shifter, where 6.02 and 4.08 are the constants associated with the model below and above the structural break in soil-test K, respectively. These details become more important in the development of a decision aid.

Practical Applications

The results of this analysis will enhance K-fertilizer recommendations for soybeans in Arkansas by extending the use of soil-test K results. The final product will be recommendations for the economic optimal application rate of K, given local fertilizer and commodity prices. This will allow producers to make informed application decisions, and extract more value from the insight of the soil-test K results. In turn, agronomists will have an information set that provides economic-based fertilization recommendations that were previously unavailable. Researchers can use the results to design future K-fertilization studies, while Cooperative Extension Service and others will be able to use the information to educate the industry toward more sustainable fertilization practices.

The mean standard deviation analysis presented in Table 1 indicates that the variability of soybean response to K application limits the role prices play when choosing economically optimal K rates. Good economic decisions can be made, but it has less to do with the price ratio and more to do with the expected return and its associated variation. To fine-tune our K-fertilizer rate choices from an economic perspective, additional explanatory variables or other improvements in measuring yield response to K fertilization are needed.

A decision aid is being developed using the results, that would allow a producer or scientist to input their soil-test K results, commodity and fertilizer prices, and the tool's output would be the economic optimum K rate to apply. A table of these economic optimum K rates with the rows and columns representing a range of fertilizer and soybean prices will also be published as a general reference. These materials should be utilized when deciding on the amount of K fertilizer to apply to the field.

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Table 1. Mean change in profit (mean) and associated standard deviation (SD) for three price ratios and five soil-K scenarios.

Factors		Scenario 1		Scenario 2		Scenario 3	
Soybean price		$10.00/bu		$20.00/bu		$10.00/bu	
Potassium Cost		$0.25/lb K_2O		$0.25/lb K_2O		$0.50/lb K_2O	
Price ratio		40		80		20	
Fertilizer rate	**Observations**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
(lb K_2O/acre)	(n)	($/acre[a])					
Soil-test K ≤60 ppm							
40-80	16	**74.00**	**55.38**	163.31	111.70	**58.69**	**54.67**
120-160	16	**87.63**	**55.48**	**209.00**	**109.70**	53.88	57.03
Soil-test K 61-90 ppm							
30-45	16	**79.48**	**46.70**	**168.42**	**93.92**	**70.03**	**46.31**
60-90	31	72.71	56.40	163.48	114.38	54.65	54.90
120-135	21	77.58	71.10	185.35	142.27	47.40	71.03
150-160	16	59.94	74.30	159.56	148.67	20.25	74.36
Soil-test K 91-130 ppm							
40-45	31	**23.35**	**31.80**	**56.87**	**63.57**	**13.19**	**32.00**
60-90	34	22.10	37.70	63.84	75.87	2.47	37.57
120	27	**23.56**	**67.40**	77.11	134.87	(6.44)	67.44
160	25	**36.40**	**72.40**	**112.80**	**144.92**	(3.60)	72.46
Soil-test K 131-175 ppm							
40-80	20	**7.50**	**37.38**	**31.00**	**76.62**	(8.50)	35.87
120	19	**11.95**	**51.72**	**53.89**	**103.44**	(18.05)	51.72
160	17	(2.35)	60.61	35.29	121.22	(42.35)	60.61
Soil-test K ≥176 ppm							
40-80	10	(10.20)	31.40	(5.40)	62.69	(25.20)	31.77
120	8	(27.63)	13.20	(25.25)	26.53	(57.63)	13.27
160	11	(26.45)	41.40	(12.91)	82.79	(66.45)	41.40

[a] Bold font indicates an economically efficient set. Values in () indicate negative returns or loss.

Table 2. Marginal physical product response to potassium fertilization from Equation 2.[a]

Soil-test K < 92 ppm			
Observations	**R^2**	**AIC[b]**	**BIC[c]**
122	0.3350	6.491	214.258
Variable	**Coefficient[c]**	**Standard error**	***P*-value**
Soil-test K (β_5)	-0.0502	0.0389	0.199
Fertilizer K_2O Rate (β_2)	0.0387	0.0050	<0.0001
Intercept (β_4)	6.0213	2.8475	0.037
Soil-test K > 92 ppm			
Observations	**R^2**	**AIC[b]**	**BIC[c]**
202	0.2235	5.837	116.738
Variable	**Coefficient**	**Standard error**	***P*-value**
Soil-test K (β_5)	-0.0237	0.0052	<0.0001
Fertilizer K_2O Rate (β_2)	0.0174	0.0027	<0.0001
Intercept (β_4)	4.0815	0.9016	<0.0001

[a] Equation 2: $Yield\ Change = \beta_4 + \beta_5 M3K + \beta_2(2*KRate) + \varepsilon$
[b] AIC, Akaike information criterion.
[c] BIC, Bayesian information criterion.

Monitoring Potassium Losses in Runoff on Arkansas Discovery Farms: Preliminary Findings

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Background Information and Research Problem

Arkansas Discovery Farms are real working farms that allow us to document runoff of nutrients and sediments at the edge of field, using state-of-the-art automated water sampling devices, coupled with collection flumes that allow us to quantify runoff volume. Currently, we are monitoring nitrogen (N) and phosphorus (P) losses as well as total suspended solids (TSS). While potassium (K) losses from agricultural runoff are not considered water quality concerns like N and P, understanding how K is lost from agricultural fields is important to profitability and sustainability. There is little scientific information available that quantifies the amount of K loss in runoff (Sharpley, 1987; Sharpley et al., 1988). If there were substantial losses in runoff, then it would warrant finding ways to reduce the loss, thereby increasing fertilizer efficiency and profitability by decreasing K-fertilizer needs.

While K in soil is known to vary across fields, little is known about why there is spatial variability. Understanding why K varies (i.e., if it is related to texture or other soil properties) may increase our ability to improve variable-rate K applications and improve efficiency (Sharpley, 1989; Sharpley and Buol, 1987). In addition, little is known about the downward movement of K into the soil beneath the soil-sampling zone. For example, if it is moving below the sampling zone, is it available to plants (Sharpley and Smith, 1988). Armed with this knowledge, scientists could possibly decrease K-fertilizer needs and increase crop K-fertilizer recovery efficiency (Sharpley, 1990).

The goals of this project are to increase farm profitability by better understanding K dynamics in soil. Specific objectives are to: (a) quantify K losses in edge-of-field runoff for row-crop and livestock Discovery Farms; and (b) quantify the spatial distribution of K in soils across fields and with depth. As this project was initiated in May 2017, the K in runoff information presented in this report is preliminary and few conclusions and interpretations can be drawn from a partial year of sample collection and analysis.

Procedures

Objective 1

Discovery Farms Description

Currently, there are 12 Discovery Farms located across Arkansas (Fig. 1; https://aaes.uark.edu/discovery-farms/). This report summarizes field K loss via runoff water results from multiple fields monitored on 5 Discovery Farms. The Marley Farm is a poultry–beef grazing operation in the Beaver Lake–Upper White River Watershed. There are 10 poultry houses, with 1200 acres of pasture and about 1000 acres of woodland. We are monitoring runoff from 4 poultry houses that flow into a 3-acre pond and from 2 poultry houses where runoff flows through a pasture (cut for hay) into an ephemeral creek, connected to the White River. Monitoring stations will quantify nutrient and sediment loadings entering the pond and pasture before reaching the creek.

The Morrow Farm is a beef rotational grazing operation in the Illinois River Watershed in Northwest Arkansas. We are monitoring runoff from grazed pasture, and two locations on a stream where it enters and exits the farm. Here the focus is on the benefits of rotational grazing on soil health and the effect of re-establishing a riparian corridor along a stream on the farm to mitigate nutrient transport. The costs of Best Management Practice (BMP) implementation will be estimated and evaluated in terms of economic feasibility and efficiency (which practice or practices provide the most reduction at least cost).

The Moore Farm is a poultry operation with 8 houses, 4 of which were newly constructed. There are 200 acres of corn grown on the farm also. We worked with the farmer to design the new houses with a low nutrient footprint and install BMPs such as grass waterways and larger concrete pads at the house entrance. We are monitoring runoff from the front of the original (gravel entrance to the poultry house) and new houses (concrete pad at the front of the poultry houses). We are also monitoring runoff from an adjacent corn field, which has received poultry litter in the past.

The Maus farm is a 940-acre row-crop farm in the Mississippi River Basin Healthy Watersheds Initiative (MRBI) within the focus watershed of Point Remove–Lake Conway, in Pope County. There are about 200 acres of wheat, 240 acres of rice, 200 acres of corn, and 400 acres of soybean. We are monitoring runoff from 4 fields that have management ranging from cover crop, no cover crop, conservation tillage, and conventional tillage under a rotation of corn and soybean.

The Stevens Farm is a row-crop operation (about 1500 acres) concentrating on cotton and corn production and is located near Dumas in the Bayou Macon Watershed in Desha County. The Bayou Macon watershed (HUC = 08050002), located in Southeastern Arkansas and Northeastern Louisiana, appeared on the 2006 State of Arkansas' 303d list as being impaired for aquatic habitat by turbidity caused by sediment / siltation from intensive row-crop agriculture (ADEQ, 2016). The

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Bayou Macon Watershed was one of the watersheds approved by National Resource Conservation Service (NRCS) as a MRBI project area. Work on this farm will be considered a success if the conservation tillage practice decreases runoff, nutrient and sediment loss in runoff from cotton-corn rotations and stream ecological improvement in the Bayou Macon Watershed. An additional measure of success will be the adoption of conservation tillage by other farmers in the watershed project area.

Fertility management of the fields monitored for edge-of-field runoff for 2017 will be obtained from farmer interviews at the end of 2017. In prior years, only the Maus Farm received K-fertilizer every year. At the other farms, nutrients were generally applied as poultry litter to meet forage requirements of mixed cool- and warm-season grasses.

Runoff-Water Collection and Analysis

A total of 17 fields were monitored for runoff volume and quality. At the lower end of each field, automated, runoff water quality monitoring stations are in place to: 1) measure runoff flow volume; 2) collect water samples of runoff for water quality analysis; and 3) measure precipitation. The ISCO 6712 automated portable water sampler (Teledyne Isco, Lincoln, Neb.) is being utilized to interface and integrate all the components of the flow station. Runoff flow volume (discharge) is collected using trapezoidal- or H-flumes and, in the case of open channel discharge from drainage pipes, an ISCO area velocity meter is used that measures height of water and water velocity. These inputs are needed for Manning's Equation Discharge data, which is utilized to trigger flow-paced, automated collection of up to 100, 100-mL subsamples of runoff water, which are composited into a single 10-liter sample for analysis.

A subsample of the 10-L sample is collected and processed in the field for preservation and shipped in insulated shipping vessels to keep samples chilled to meet EPA guidelines for sample collection, handling, preparation, and analysis. Samples are filtered (<0.45 µm) and the concentration of water-soluble K determined by the Arkansas Water Resources Laboratory (certified by the Arkansas Department of Environmental Quality at https://arkansas-water-center.uark.edu/water-quality-lab.php).

Results and Discussion

Runoff event dates, volume, concentration of K, and K loss from sites at the Marley, Morrow, Moore, Maus, and Stevens Farms are presented in Tables 1, 2, 3, 4, and 5, respectively. The losses over the current, albeit short, monitoring period since the project began are summarized in Table 6. Average concentrations of water-soluble K ranged from 3.36 to 18.06 mg K/L, with the lowest concentrations measured in runoff from the Maus Farm (Table 6). At the Maus Farm, K concentrations varied little among fields (3.36 to 5.64 mg K/L), which were managed similarly.

Other items of interest include that, at the Marley Farm, the concentration and unit area loss of K in runoff from the 4 poultry houses (8.68 mg/L and 10.4 lb/acre, respectively) decreased after passing through the 300-m long grass waterway (7.35 mg/L and 7.2 lb/acre, respectively). At the Moore Farm, the average water-soluble K concentrations were lower in runoff from the new poultry houses designed with a lower environmental footprint (6.75 mg K/L) than from the original poultry houses (17.55 mg K/L). Given that runoff from the new houses was approximately half that from the original houses, the loss of K in runoff was appreciably lower from the new than original houses (3.6 and 23.4 lb K/acre, respectively; Table 4).

Given the short period of monitoring available to date, it is difficult to put the concentrations and total losses from these 17 farm/field situations in context with those measured elsewhere or in different years. However, Sharpley et al. (1988) did measure water-soluble K concentrations in runoff from native grass (dominantly little bluestem - *Andropogon scoparius* ichx) and wheat watersheds at El Reno, Okla., in which runoff had K concentrations ranging from <1 to 15 mg K/L. This range is similar to that observed at sites of the present study (Tables 1 to 6).

Practical Applications

Understanding the dynamics of K in soils with respect to runoff losses, downward movement below sampling zone and spatial variability of K concentrations across managed fields, can all affect K-fertilizer recommendations and result in better management strategies to decrease fertilizer yields and increase profitability. Environmental nutrient management is often focused only on N and P, yet K fertilizer is often recommended depending on the soil-test results. Even though K loss is not considered a water quality concern, we need to acknowledge that altering management to minimize N and P losses in runoff can have direct and indirect effects on soil K and positively or negatively influence the overall soil fertility framework.

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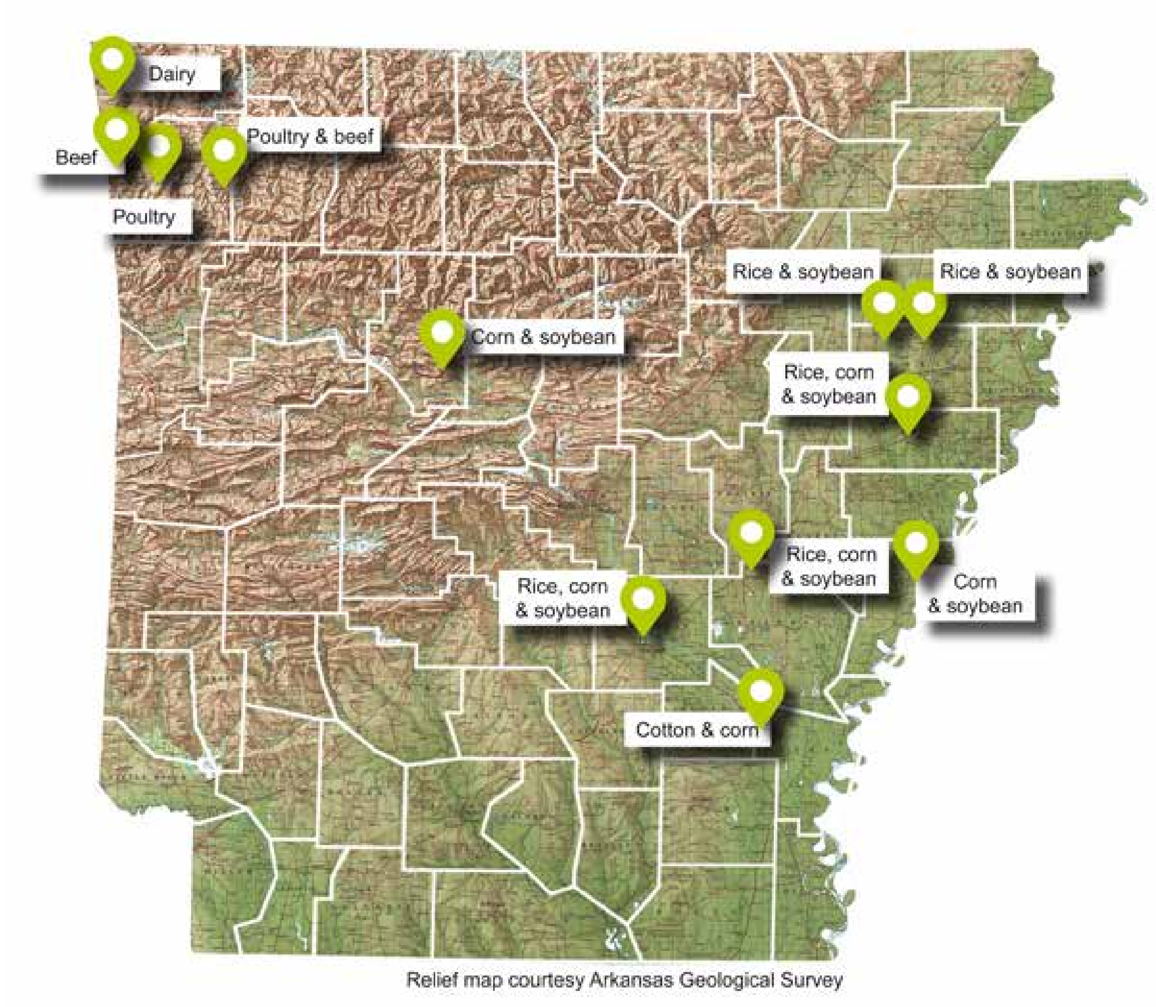

Fig. 1. Locations of Arkansas Discovery Farms.

Table 1. Runoff, potassium concentrations, and loss in runoff from the Marley Farm, Elkins, Ark.

			Potassium in runoff		
Date sampled	Total runoff	Unit area runoff	Conc.	Loss	Load
	(gal)	(gal/acre)	(mg/L)	(lb/acre)	(lb)
		Marley 1 – 17.4 acres - Runoff from four poultry houses			
5/22/2017	685600	39402	3.69	1.2	21.2
5/27/2017	205600	11816	6.64	0.7	11.5
6/5/2017	156800	9011	7.68	0.6	10.1
6/18/2017	62900	3615	12.39	0.4	6.5
7/4/2017	474600	27276	12.84	2.9	51.1
7/4/2017	238100	13684	5.52	0.6	11.0
8/14/2017	219500	12615	9.06	1.0	16.7
8/17/2017	262900	15109	6.78	0.9	15.0
		Marley 2 – 3.6 acres - Runoff from four poultry houses			
5/22/2017	339090	94192	3.42	2.7	9.7
5/27/2017	77100	21417	5.98	1.1	3.9
6/5/2017	38710	10753	10.00	0.9	3.2
7/4/2017	58810	16336	10.32	1.4	5.1
7/4/2017	58970	16381	5.94	0.8	2.9
8/15/2017	44050	12236	16.80	1.7	6.2
8/17/2017	91280	25356	8.31	1.8	6.4
		Marley 3 – 7.9 acres - Poultry houses after grass waterway			
5/22/2017	763100	96595	4.19	3.4	26.7
5/27/2017	117700	14899	7.3	0.9	7.2
6/5/2017	79900	10114	8.99	0.8	6.0
7/4/2017	76300	9658	9.92	0.8	6.3
7/4/2017	7026	889	6.33	0.1	0.4
8/17/2017	158700	20089	7.40	1.2	9.8

Table 2. Runoff, potassium concentrations, and loss in runoff from the Morrow Farm, Wedington, Ark.

			Potassium in runoff		
Date sampled	Total runoff	Unit area runoff	Conc.	Loss	Load
	(gal)	(gal/acre)	(mg/L)	(lb/acre)	(lb)
		Morrow 1 – 24 acres - Runoff from grazed pasture			
5/22/2017	132220	5509	8.13	0.4	9.0
5/27/2017	46482	1937	9.24	0.2	3.6
6/5/2017	68650	2860	15.72	0.37	9.0
6/19/2017	22610	942	19.28	0.2	3.6
		Morrow 2 – 87 acres - Ephemeral stream flow entering Morrow Farm			
5/22/2017	3045260	35003	5.33	1.6	135.4
5/27/2017	19932	229	8.22	0.02	1.4
6/5/2017	19920	229	9.20	0.02	1.5
8/14/2017	849940	9769	8.26	0.7	58.5
8/17/2017	1169850	13447	7.55	0.9	73.7
		Morrow 3 – 158 acres - Ephemeral stream flow leaving Morrow Farm			
5/22/2017	4813650	30466	6.50	1.6	260.9
5/27/2017	23160	147	46.67	0.06	9.0
6/5/2017	218491	1383	8.43	0.1	15.4
8/14/2017	127829	809	11.77	0.1	12.5
8/17/2017	165515	1048	8.72	0.1	12.0

Table 3. Runoff, potassium concentrations, and loss in runoff from the Moore Farm, Lincoln, Ark.

			Potassium in runoff		
Date sampled	**Total runoff**	**Unit area runoff**	**Conc.**	**Loss**	**Load**
	(gal)	**(gal/acre)**	**(mg/L)**	**(lb/acre)**	**(lb)**
Moore 1 – 30.7 acres – Runoff from corn field					
5/22/2017	797443	25975	18.38	4.0	122.4
6/5/2017	121351	3953	17.70	0.6	17.9
7/4/2017	273188	8899	30.96	2.3	70.6
8/6/2017	195172	6357	17.44	0.9	28.4
8/14/2017	607908	19802	12.81	2.1	65.1
8/17/2017	590368	19230	14.30	2.3	70.5
Moore 2 – 2.4 acres - Runoff from rear of original poultry houses					
5/22/2017	98487	41036	6.35	2.1	5.1
6/5/2017	16511	6880	8.43	0.5	1.1
7/4/2017	53465	22277	22.65	4.1	9.8
8/6/2017	64785	26994	18.23	4.0	9.6
8/14/2017	129750	54063	8.87	3.9	9.3
8/17/2017	94965	39569	7.52	2.4	5.8
Moore 3 – 2.5 acres - Runoff from front of original poultry houses					
5/22/2017	95595	38238	9.14	3.0	7.4
6/5/2017	255242	102097	11.35	9.8	24.4
7/4/2017	48803	19521	37.65	6.2	15.5
8/6/2017	37262	14905	20.08	2.5	6.3
8/14/2017	59705	23882	9.54	1.9	4.8
Moore 4 – 3.3 acres - Runoff from front of new poultry houses					
5/22/2017	176231	53403	5.16	2.4	7.8
6/5/2017	26483	8025	6.54	0.5	1.5
6/19/2017	16481	4994	9.73	0.4	1.4
8/6/2017	1993	604	5.87	0.03	0.1
8/14/2017	19024	5765	6.43	0.3	1.1

Table 4. Runoff, potassium concentrations, and loss in runoff from the Maus Farm, Atkins, Ark.

Date sampled	Total runoff	Unit area runoff	Potassium in runoff		
			Conc.	Loss	Load
	(gal)	(gal/acre)	(mg/L)	(lb/acre)	(lb)
Maus 1 – 18 acres– Runoff from corn field with cover crops					
5/28/2017	61041	3391	3.22	0.1	1.6
6/4/2017	701166	38954	2.01	0.6	11.7
7/16/2017	298825	16601	4.39	0.6	10.9
8/14/2017	456695	25372	2.90	0.6	11.1
9/1/2017	150978	8388	2.29	0.2	2.9
8/31/2017	10836	602	4.20	0.02	0.4
9/7/2017	68297	3794	3.61	0.1	2.1
9/15/2017	129915	7218	3.26	0.2	3.5
9/22/2017	132403	7356	3.54	0.2	3.9
10/2/2017	65876	3660	4.16	0.1	2.3
Maus 2 – 19 acres - Runoff from corn field with cover crops					
5/28/2017	409070	21530	4.77	0.9	16.3
6/4/2017	925461	48708	3.05	1.2	23.5
6/27/2017	69949	3682	4.48	0.1	2.6
7/3/2017	30680	1615	5.47	0.1	1.4
7/16/2017	77498	4079	5.40	0.2	3.5
8/14/2017	616148	32429	4.12	1.1	21.2
8/11/2017	302562	15924	5.31	0.7	13.4
9/1/2017	742179	39062	9.89	3.2	61.2
8/31/2017	52852	2782	7.89	0.2	3.5
9/7/2017	38028	2001	6.07	0.1	1.9
Maus 3 – 14 acres– Runoff from corn field with cover crops					
6/27/2017	24492	1749	4.54	0.1	0.9
7/16/2017	260927	18638	4.62	0.7	10.1
8/14/2017	779234	55660	3.48	1.6	22.6
8/11/2017	182614	13044	3.76	0.4	5.7
9/1/2017	196053	14004	3.51	0.4	5.7
8/30/2017	127784	9127	4.84	0.4	5.2
9/7/2017	51248	3661	3.39	0.1	1.5
9/15/2017	100957	7211	4.24	0.3	3.6
9/23/2017	244532	17467	4.34	0.6	8.9
10/2/2017	73209	5229	3.53	0.2	2.2
Maus 4 – 20 acres– Runoff from corn field with cover crops					
7/16/2017	138485	6924	5.31	0.1	2.8
8/14/2017	705096	35255	3.15	0.4	8.4
8/11/2017	73196	3660	3.17	0.04	0.9
9/1/2017	152468	7623	3.58	0.1	2.1
8/31/2017	202398	10120	5.06	0.2	3.9
9/7/2017	205927	10296	4.04	0.2	3.2
9/15/2017	285464	14273	4.20	0.2	4.5
10/2/2017	81190	4059	4.27	0.1	1.3

Table 5. Runoff, potassium concentrations, and loss in runoff from the Stevens Farm in 2017.

			Potassium in runoff		
Date sampled	Total runoff	Unit area runoff	Conc.	Loss	Load
	(gal)	(gal/acre)	(mg/L)	(lb/acre)	(lb)
Stevens 2 - 22 acres - Cotton with cereal rye cover crop					
5/20/2017	153449	580804	35.73	2.1	45.75
5/23/2017	487745	1846115	9.47	1.8	38.54
5/28/2017	233102	882291	12.87	1.1	25.03
5/29/2017	315204	1193047	8.83	1.1	23.22
6/3/2017	302351	1144399	8.48	1.0	21.39
6/22/2017	941549	3563763	7.33	2.6	57.59
7/5/2017	347434	1315038	6	0.8	17.39
7/7/2017	111394	421626	6.01	0.3	5.59
7/7/2017	364763	1380628	6.68	0.9	20.33
7/15/2017	190037	719290	6.41	0.5	10.16
7/19/2017	92828	351352	5.4	0.2	4.18
7/25/2017	207037	783635	4.9	0.4	8.47
7/26/2017	65785	248995	4.65	0.1	2.55
8/1/2017	272931	1033044	5.5	0.6	12.53
8/4/2017	196450	743563	4.76	0.4	7.80
8/7/2017	808981	3061993	6.51	2.0	43.95
8/13/2017	915559	3465391	5.23	1.8	39.96
8/28/2017	37941	143606	12.8	0.2	4.05
8/30/2017	1700490	6436355	6.31	4.1	89.54
9/18/2017	98824	374047	11.21	0.4	9.24
Stevens 3 - 37 acres - Cotton with cereal rye cover					
5/20/2017	62954	238280	16.43	0.2	8.63
5/24/2017	435640	1648897	21.91	2.2	79.65
5/28/2017	238684	903419	19.79	1.1	39.42
5/29/2017	371989	1407978	13.38	1.1	41.53
6/3/2017	514504	1947398	10.2	1.2	43.79
6/22/2017	1045050	3955514	9.82	2.3	85.63
7/5/2017	318961	1207267	7.1	0.5	18.90
7/16/2017	403499	1527244	6.03	0.6	20.30
7/24/2017	703786	2663830	4.13	0.7	24.25
8/2/2017	260249	985042	4.87	0.3	10.58
8/5/2017	185045	700395	4.05	0.2	6.25
8/7/2017	750254	2839711	5.55	0.9	34.75
8/13/2017	1202150	4550138	5.84	1.6	58.58
8/28/2017	2241230	8483056	5.95	3.0	111.28
Stevens 4 - 42 acres - Cotton without cover					
5/20/2017	302386	1144531	11.4	0.7	28.77
5/22/2017	737285	2790624	7.15	1.1	43.99
5/28/2017	421473	1595275	12.48	1.1	43.89
5/29/2017	427878	1619518	7.59	0.7	27.10
6/3/2017	546764	2069502	11.39	1.2	51.97
6/22/2017	892254	3377181	5.71	1.0	42.51
7/6/2017	973439	3684467	6.11	1.2	49.63
7/16/2017	859488	3253162	5.46	0.9	39.16
7/27/2017	222190	840989	5.21	0.2	9.66
8/7/2017	925246	3502056	7.37	1.4	56.90
8/13/2017	2185260	8271209	7.41	3.2	135.12
8/28/2017	88662	335585	8.45	0.2	6.25
8/30/2017	2482460	9396111	8.01	4.0	165.93
9/18/2017	116786	442035	21.63	0.5	21.08

Table 6. Runoff, potassium concentrations, and loss in runoff each site for events measured in 2017.

Farm	Field size	Treatment	Total runoff	Total unit area runoff	Potassium in runoff Conc.	Loss	Load
	(acres)		(total acre-inches)	(acre inches/acre)	(mg/L)	(lb/acre)	(lb)
Marley 1	17.4	Four poultry houses	84.9	4.9	8.07	8.2	159
Marley 2	3.6	Four poultry houses	26.1	7.2	8.68	10.4	42
Marley 3	7.9	Poultry houses after grass waterway	44.3	5.6	7.35	7.2	63
Morrow 1	24.0	Grazed pasture	9.9	0.4	13.09	1.1	28
Morrow 2	87.0	Ephemeral stream flow entering farm	188.0	2.2	7.71	3.1	303
Morrow 3	158.0	Ephemeral stream flow leaving farm	197.0	0.1	16.42	2.0	347
Moore 1	30.7	Corn field	95.2	3.1	18.60	12.2	420
Moore 2	2.4	Rear of original poultry houses	16.9	0.5	12.01	17.0	582
Moore 3	2.5	Front of original poultry houses	18.3	0.6	17.55	23.4	803
Moore 4	3.3	Front of new poultry houses	8.8	0.3	6.75	3.6	123
Maus 1	18.0	Corn with cover crop	76.5	4.2	3.36	2.8	57
Maus 2	19.0	Corn with cover crop	120.2	6.3	5.64	7.8	166
Maus 3	14.0	Corn with cover crop	74.1	5.4	4.03	4.7	74
Maus 4	20.0	Corn with cover crop	679.2	3.4	4.10	3.0	67
Stevens 2	22.0	Cotton with cereal rye cover crop	288.9	13.1	8.75	22.2	487
Stevens 3	37.0	Cotton with cereal rye cover crop	321.6	8.7	9.65	15.8	584
Stevens 4	42.0	Cotton without cover crop	411.8	7.9	8.96	13.9	722

Initial Soil Chemical Property and Health Ratings for Long-Term Fertilization Trials

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Background Information and Research Problem

Winter cover crops are being integrated into row-crop rotations in eastern Arkansas. The beneficial effects of cover crops on recycling mobile soil nutrients like nitrate (Shipley et al., 1992) are well documented, but the effect of cover crop growth on other soil chemical properties as reported by routine soil testing and the resulting fertilizer recommendations are less well known. In Arkansas, soil samples are collected from early fall following summer crop harvest into late winter and early spring. The time of soil sample collection often depends on the number of samples to be collected, soil moisture conditions, and previous crop. Slaton et al. (2016) showed that soil-test phosphorus (P) and potassium (K) changed minimally across fall and winter months when soil samples were collected following soybean (*Glycine max*), but soil-test K increased from rice (*Oryza sativa*) harvest until December at which time it plateaued. In general, soil-test P was relatively constant across time probably because harvested grain removes a large proportion of P taken up by crops and P in crop residue is slowly released as residue decomposes. These results suggest that soil-test K might change significantly across time following the harvest of high residue crops like corn (*Zea mays*) and rice as the K in crop residue leaches into the soil with rainfall. The presence of an actively growing cover crop, especially crops that accumulate substantial biomass, could change soil-test K dynamics across time and influence soil-test-based fertilizer recommendations. The goal of this research is to establish long-term plots cropped to corn, cotton (*Gossypium hirsutum*), and soybean that receive different annual P and K rates and are grown with or without a cereal rye (*Secale cereal*) cover crop to monitor short- and long-term changes in soil chemical properties and soil health. The first year research objective was to set up the research trial and collect background information on the site before initiating treatments in year 2.

Procedures

Trials were established in a 5.7-acre field at the University of Arkansas System Division of Agriculture's Rohwer Research Station (RRS) with soil mapped as Herbert silt loam (59%), McGehee silt loam (19%), and Sharkey and Desha clay (22%) and a 10-acre field at the Lon Mann Cotton Research Station (LMCRS) with soils mapped as Calloway (54%), Loring (28%), and Memphis (1%) silt loams and a Marvell fine sandy loam (16%). In early 2017, the fields were tilled and beds were pulled to prepare for corn planting. Twelve composite soil samples were collected from each field trial on 22 March (RRS) or 4 April (LMCRS). Each composite sample contained 20, 1.0-inch diameter soil cores collected from the 0 (top of bed) to 6 inch depth. The sample was thoroughly mixed and split into two subsamples. One subsample was analyzed for soil pH, Mehlich-3 extractable nutrients, soil textural analysis, and organic matter (loss on ignition, LOI) by the University of Arkansas System Division of Agriculture's Soil Testing Laboratory at the Arkansas Agricultural Research and Extension Center, Fayetteville, Ark., and the other subsample was submitted to Cornell University for analysis using the Basic Soil Health Analysis Package (BSHAP, Moebius-Clune et al., 2016). The BSHAP includes soil pH, soil organic matter (LOI), nutrient extraction by the Modified Morgan Method, wet aggregate stability, and soil respiration. The BSHAP analysis provides a health score for each parameter and an overall health score.

The fields at each site were flagged to contain two trials, one for P and one for K. The plots were 4 rows wide at each location and extended the length of the field, approximately 260 ft at LMCRS and 220 ft at RRS. Each experiment was a randomized complete block with a split-plot treatment structure where cover crop (with or without) was the main plot and fertilizer rate was the subplot. For the purposes of year 1, five treatments identified as A, B, C, D, and E were randomly assigned within each main plot block. Each field was planted to corn and uniformly managed to examine whether the research area and designated plots had inherent variability that resulted in visible differences in crop growth or yield. The corn at each site received recommended pest control and nitrogen fertilization but received no other fertilizer nutrients. Corn was planted on 22 March at the RRS (Armor 1100, 35,000 seed/acre) and 6 April at the LMCRS (Armor 1330, 34,000 seed/acre). At the LMCRS, corn received 46 lb nitrogen (N)/acre as urea on 13 April and 60 gal/acre of 28-0-0-5 (178 lb N/acre) was knifed into the soil on 17 May. Corn was harvested on 9 September and cereal rye was planted on 20 October (98 lb/acre). At the RRS, corn received 125 lb N/acre as 32% urea-ammonium nitrate on 25 April and 16 May, which was knifed into the edge of the bed. Corn was harvested on 26 August and cereal rye was planted on 11 October (65 lb/acre).

The two middle rows in a 125-ft (RRS) or 230-ft (LMCRS) section near the center of the field were harvested with a small plot combine at physiological maturity. Grain yields were ad-

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justed to 13% moisture and analysis of variance was performed interpreting differences among the main plot and subplot factors as significant when $Pr \leq 0.10$. Selected soil chemical properties within each trial area were analyzed by main plot ($n = 6$, 3 blocks and 2 cover crop treatments).

Results and Discussion

The initial soil chemical and physical properties and the effect of block and assigned cover crop treatment are presented in Tables 1 to 4. Within each of the four research areas, most of the soil properties were statistically similar between assigned cover crop areas with more frequent differences occurring among the blocks. The initial soil-test results guided placement of the P and K trials. The North field areas at LMCRS (Table 1) and RRS (Table 3) were assigned to contain the P-fertilizer trials. The initial soil-test P values were near the Optimum level (36 to 50 ppm for Mehich-3) at both sites. The K-fertilizer trials were assigned to the South field areas (Tables 2 and 4), which had either Low (61 to 90 ppm for Mehlich-3) or Optimal (131 to 175 ppm for Mehlich-3) levels of K availability according to the University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations.

The soils at both locations can be characterized as having silt loam texture, low organic matter content, near neutral soil pH, and very low zinc (Zn) availability. The soils have a long history of cropping (corn, cotton, and soybean), annual tillage, and irrigation for research. The BSHAP performed by Cornell University showed the soils to have low aggregate stability and microbial activity, which along with soil organic matter received Poor scores (0 to 20 on a scale of 100). In contrast, the soil chemical properties of pH and plant-available nutrients [P, K, magnesium (Mg), iron (Fe), manganese (Mn), and Zn] often received Excellent (60 to 80) to Optimal (80 to 100) scores. The overall BSHAP scores were not different between cover crop treatments and rated Excellent (60 to 80) for 11 of the 12 soils sampled from RRS and Medium (40 to 60) for all 12 samples from the LMCRS (Tables 1-4).

Block had a significant effect on corn yield in three of the four research areas, but the cover crop main effect and the interaction between assigned fertilizer treatment and cover crop had no significant effect on yield (Table 5). Corn yields differed among the preassigned fertilizer rates only in the K trial at the LMCRS. Treatments A and E, averaged across cover crop treatments, had the numerically greatest corn grain yields, which were both significantly greater than the yields produced by soil assigned treatments B and D. The assigned fertilizer treatments were not changed because treatments A and E represent soil that will receive no K fertilizer. The reason for some yield fluctuation among blocks and treatments was likely caused by non-uniform lodging of corn. Corn at the LMCRS was harvested after the remnants of Hurricane Harvey passed through eastern Arkansas, which included wind gusts in excess of 25 mph and 4 inches or more of rain that contributed to lodging.

Practical Applications

The 4 selected research sites provide excellent variations in soil K availability to examine the long-term effects of fertilization and cover crop growth on soil-test K. The near optimal soil-test P levels will provide interesting information on the depletion of available soil P and rate of soil-test decline across time. The low microbial activity and organic matter contents provide good starting points to examine how cover crops can be used to improve soil health as measured and interpreted by the Cornell BSHAP. Perhaps more interesting, the effect of fertilization or lack of fertilization with P and K fertilizers will allow soil productivity to be measured simultaneously. Plot specific soil samples will be collected to examine the initial soil chemical properties, P- and K-fertilizer treatments will be implemented in early 2018 and cotton will be planted as the first crop in the rotation sequence.

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Table 1. The influence of the cover crop main effect on selected soil properties measured by the Basic Soil Health Analysis Package (BSHAP) and routine soil analysis at the University of Arkansas System Division of Agriculture's Soil Testing Laboratory at the Arkansas Agricultural Research and Extension Center (AAREC), in spring 2017 before cover crop treatments were initiated in the North Research Area of Field B-1-N (Phosphorus Trial) at the Lon Mann Cotton Research Station.

Soil property	Cover crop	No cover	Cover *P*-value	Block *P*-value
Soil Testing Lab, AAREC				
SOM, %	1.6	1.6	1.000	0.100
Soil pH	7.4	7.4	0.856	0.945
Mehlich-3 P (ppm)	50	52	0.694	0.223
Mehlich-3 K (ppm)	109	110	0.892	0.077
Mehlich-3 Ca (ppm)	1457	1370	0.441	0.091
Mehlich-3 Mg (ppm)	309	311	0.852	0.063
Mehlich-3 S (ppm)	7	7	0.423	0.500
Mehlich-3 Fe (ppm)	364	362	0.510	0.093
Mehlich-3 Mn (ppm)	245	239	0.542	0.398
Mehlich-3 Cu (ppm)	3.2	2.6	0.535	0.211
Mehlich-3 Zn (ppm)	1.2	1.3	0.742	0.438
NO_3-N (ppm)	11	8	0.027	0.025
NH_4-N (ppm)	17	19	0.100	0.292
% Silt	76	75	0.184	0.087
% Clay	14	13	0.529	0.088
BSHAP, Cornell				
Aggregate stability, %	6.3	7.7	0.386	0.189
SOM, %	1.3	1.4	0.184	0.050
Respiration (mg CO_2 mg soil 4 d)	0.3	0.3	1.000	1.000
Soil pH	7.4	7.4	1.000	0.300
Modified Morgan P (ppm)	6.7	7.0	0.844	0.366
Modified Morgan K (ppm)	81	81	0.886	0.043
Modified Morgan Zn (ppm)	0.6	0.6	0.844	0.248
Overall soil quality score	57	52	0.471	0.596

Table 2. The influence of the cover crop main effect on selected soil properties measured by the Basic Soil Health Analysis Package (BSHAP) and routine soil analysis at the University of Arkansas System Division of Agriculture's Soil Testing Laboratory at the Arkansas Agricultural Research and Extension Center (AAREC), in spring 2017 before cover crop treatments were initiated in the South Research Area of Field B-1-N (Potassium Trial) at the Lon Mann Cotton Research Station.

Soil property	Cover crop	No cover	Cover *P*-value	Block *P*-value
Soil Testing Lab, AAREC				
SOM, %	1.2	1.4	0.321	0.618
Soil pH	7.5	7.6	0.840	0.679
Mehlich-3 P (ppm)	34	37	0.336	0.046
Mehlich-3 K (ppm)	74	86	0.307	0.564
Mehlich-3 Ca (ppm)	1012	1289	0.156	0.241
Mehlich-3 Mg (ppm)	289	353	0.313	0.227
Mehlich-3 S (ppm)	6	6	0.667	0.500
Mehlich-3 Fe (ppm)	336	365	0.063	0.378
Mehlich-3 Mn (ppm)	201	273	0.790	0.411
Mehlich-3 Cu (ppm)	1.2	1.4	0.130	0.500
Mehlich-3 Zn (ppm)	1.1	1.2	0.423	0.300
NO_3-N (ppm)	8	7	0.526	0.448
NH_4-N (ppm)	16	17	0.345	0.308
% Silt	70	68	0.862	0.780
% Clay	12	13	0.567	0.238
BSHAP, Cornell				
Aggregate stability, %	9.3	5.7	0.061	0.139
SOM, %	1.1	1.3	0.225	0.429
Respiration (mg CO_2 mg soil 4 d)	0.3	0.3	1.000	0.750
Soil pH	7.3	7.3	0.902	0.929
Modified Morgan P (ppm)	4.3	4.2	0.891	0.154
Modified Morgan K (ppm)	54	58	0.648	0.540
Modified Morgan Zn (ppm)	0.2	0.2	0.423	0.500
Overall soil quality score	47	50	0.490	0.746

Table 3. The influence of the cover crop main effect on selected soil properties measured by the Basic Soil Health Analysis Package (BSHAP) and routine soil analysis at the University of Arkansas System Division of Agriculture's Soil Testing Laboratory at the Arkansas Agricultural Research and Extension Center (AAREC), in spring 2017 before cover crop treatments were initiated in the North Research Area of Field 1-D (Phosphorus Trial) at the Rohwer Research Station.

Soil property	Cover crop	No cover	Cover *P*-value	Block *P*-value
Soil Testing Lab, AAREC				
SOM, %	1.2	1.2	0.529	0.250
Soil pH	7.1	7.0	0.422	0.100
Mehlich-3 P (ppm)	47	43	0.670	0.774
Mehlich-3 K (ppm)	149	145	0.733	0.753
Mehlich-3 Ca (ppm)	863	902	0.324	0.198
Mehlich-3 Mg (ppm)	113	127	0.464	0.536
Mehlich-3 S (ppm)	7	7	0.742	0.875
Mehlich-3 Fe (ppm)	361	350	0.473	0.893
Mehlich-3 Mn (ppm)	199	191	0.555	0.633
Mehlich-3 Cu (ppm)	3.0	3.1	0.625	0.261
Mehlich-3 Zn (ppm)	0.8	0.7	0.742	0.700
NO_3-N (ppm)	25	24	0.766	0.701
NH_4-N (ppm)	11	12	0.848	0.757
% Silt	66	68	0.240	0.742
% Clay	8	8	0.184	0.541
BSHAP, Cornell				
Aggregate stability, %	9.5	7.4	0.115	0.338
SOM, %	0.8	0.9	0.057	0.500
Respiration (mg CO_2 mg soil 4 d)	0.2	0.2	1.000	1.000
Soil pH	6.7	6.6	0.423	0.409
Modified Morgan P (ppm)	7.3	7.8	0.864	0.932
Modified Morgan K (ppm)	104	109	0.652	0.935
Modified Morgan Zn (ppm)	0.7	0.7	1.000	0.300
Overall soil quality score	60	60	---	---

Table 4. The influence of the cover crop main effect on selected soil properties measured by the Basic Soil Health Analysis Package (BSHAP) and routine soil analysis at the University of Arkansas System Division of Agriculture's Soil Testing Laboratory at the Arkansas Agricultural Research and Extension Center (AAREC), in spring 2017 before cover crop treatments were initiated in the South Research Area of Field 1-D (Potassium Trial) at the Rohwer Research Station.

Soil property	Cover crop	No cover	Cover *P*-value	Block *P*-value
Soil Testing Lab, AAREC				
SOM, %	1.4	1.2	0.338	0.800
Soil pH	7.0	7.0	0.423	0.050
Mehlich-3 P (ppm)	55	60	0.438	0.145
Mehlich-3 K (ppm)	150	145	0.416	0.367
Mehlich-3 Ca (ppm)	1020	961	0.257	0.279
Mehlich-3 Mg (ppm)	144	143	0.529	0.011
Mehlich-3 S (ppm)	7	7	0.423	0.125
Mehlich-3 Fe (ppm)	379	387	0.769	0.315
Mehlich-3 Mn (ppm)	243	236	0.827	0.207
Mehlich-3 Cu (ppm)	3.1	3.0	0.762	0.911
Mehlich-3 Zn (ppm)	0.7	0.8	0.529	0.875
NO_3-N (ppm)	28	25	0.687	0.596
NH_4-N (ppm)	10	10	0.734	0.520
% Silt	73	72	0.841	0.999
% Clay	8	7	0.187	0.096
BSHAP, Cornell				
Aggregate stability, %	6.2	6.7	0.578	0.740
SOM, %	1.0	0.9	<0.0001	1.000
Respiration (mg CO_2 mg soil 4 d)	0.3	0.3	1.000	0.750
Soil pH	6.6	6.5	0.456	0.432
Modified Morgan P (ppm)	11.1	9.7	0.469	0.359
Modified Morgan K (ppm)	116	119	0.289	0.085
Modified Morgan Zn (ppm)	0.7	0.8	0.529	0.875
Overall soil quality score	60	60	0.4226	0.500

Table 5. Analysis of variance *P*-values for grain yield as affected by block, assigned fertilizer rate (FR), and cover crop (CC) during the first year of four research areas to be used for long-term trials at the Lon Mann Cotton Research Station and Rohwer Research Station in 2017. Fertilizer and cover crop treatments were assigned, but not implemented during 2017.

	Cotton Research Station		Rohwer Research Station	
FR Treatment[a]	**K Trial**	**P trial**	**K Trial**	**P Trial**
	(bu/acre)			
A	127	139	243	235
B	112	134	238	240
C	117	135	236	238
D	111	131	227	250
E	121	133	233	235
$LSD_{0.10}$[b]	7	NS	NS	NS
Block	<0.0001	0.9409	0.0227	0.0059
FR	0.0050	0.6213	0.4596	0.1640
CC	0.8861	0.9073	0.4014	0.8040
FR × CC	0.5120	0.2734	0.5841	0.87287
C.V., %	5.8	6.2	4.9	4.5

[a] Treatment assignments were as follows: A, no P or K fertilizer; B, low rate of P or K fertilizer; C, intermediate rate of P or K fertilizer; D, high rate of P or K fertilizer; and E, no P or K fertilizer (duplicate treatment).

[b] LSD = least significant difference; C.V. = coefficient of variation.

Crop and Soil Test Responses to Annual Fertilization with Different Fertilizers

N.A. Slaton[1], R. DeLong[1], J. Hedge[2], Y. Liyew[2], and T. Jones[1]

Background Information and Research Problem

Soil tests are designed to assess the general fertility of soil and make recommendations about the specific nutrients and amounts of fertilizer nutrients needed to maximize nutrient availability for crop production. The number of fertilizer options and fertilization strategies available to farmers has expanded in recent years as fertilizer manufacturers compete for business and seek to develop fertilizers that are superior to standard fertilizers. The Mosaic Company (Plymouth, Minn.) has introduced MicroEssentials (MESZ, 12-40-0-10S-1Zn) and Aspire (0-0-58-0.5B) fertilizers into Arkansas as multi-nutrient fertilizer sources that are alternatives to blending fertilizer granules. One of the advertised advantages of MESZ fertilizer is that every granule contains nitrogen (N), phosphorus (P), sulfur (S), and zinc (Zn) and improves the distribution of these nutrients compared to blending small amounts of granular Zn sulfate with an ammoniated P and S source, elemental S, and K fertilizers. Similarly, Aspire granules include small amounts of boron (B), which eliminates the need to blend low rates of granular B with muriate of potash or apply liquid B post-emergence. The practicality of using these fertilizers is somewhat dependent upon the need for the B, S, and/or Zn that each fertilizer contains. Also, one must consider the frequency and magnitude of crop yield response to the S and micronutrients compared to no fertilization and standard fertilization programs (e.g., only macronutrients as recommended by soil test).

This report summarizes five years of crop yield response and soil-test nutrient responses after four years of fertilization from a project involving monoammonium phosphate (MAP), MESZ, muriate of potash, and Aspire. It is important to note that treatments used in the first two years of this project were changed in year three when the initial research objectives involving P and Zn were satisfied.

Procedures

The experiment was established in spring 2013 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station on a soil mapped as a Calloway silt loam. Composite soil samples were collected in early spring to a depth of 0 to 6 inches (2013 and 2014) or 0 to 4 inches (2015 to 2017) with each sample comprised of 6, 1-inch diameter soil cores from the middle of each sampled plot. Selected chemical property means of soil receiving only N fertilizer are listed in Table 1.

Individual plots are 30-ft long and consist of 5, 30-inch wide beds arranged in 4 blocks that are stacked on top of each other. Each block is 70 beds wide with each of the 14 treatments randomly located within each block. The plots are furrow irrigated with well water from the Alluvial aquifer. Plot integrity has been maintained by limiting tillage to knocking down the top of the beds with a tiller or do-all implement. Beds are reformed annually following the application of fertilizer treatments and any other fertilizers (e.g., N) that might be applied preplant.

The 14 fertilizer treatments are listed in Table 2. The trial was initially set up as a 3 (P and Zn source) × 4 (P rate) factorial with two standard treatments including a no fertilizer control and a N-fertilizer only treatment. Corn (*Zea mays*) was grown in 2013 and 2014. In 2013 and 2014, muriate of potash was broadcast uniformly (90 lb K_2O/acre) to treatments 3 to 14 and ammonium sulfate was applied to treatments 7 to 10 to balance the S added with each MESZ rate in treatments 11 to 14. The 2-year corn trial ended after harvest in 2014, and treatments 3 to 14 were modified by omitting K from treatments 3 to 6; adding 90 lb K_2O/acre/year applied as muriate of potash and omitting $ZnSO_4$ from treatments 7 to 10; and adding 90 lb K_2O/acre/year as Aspire to treatments 11 to 14. The overall design of the trial can now be described as a randomized complete block, 3 (P and K source) × 4 (P rate) factorial with two N-fertilizer only controls. After corn was grown in 2013 (Mycogen 2V707 planted 23 May) and 2014 (DeKalb 66-87 planted 12 April), the land was rotated to soybean (*Glycine max*) in 2015 (Armor 49-R56 planted 8 June), grain sorghum (*Sorghum bicolor*) in 2016 (Pioneer 40R80 planted 6 April) and soybean in 2017 (Armor 48-D24 planted 9 May).

In late winter or early spring 2017, soil samples were collected from treatments 2, 4, 8, 11, 12, 13, and 14. Treatments 4, 8, and 12 allow comparison of soil properties among treatments that have always received 60 lb P_2O_5 as MAP (4 and 8) or MESZ (12), but different amounts of Zn, S, B, and K. Comparison of treatments 11 to 14 allow examination of the effect of annual applications of increasing rates of P, S, Zn, and B.

Analysis of variance (ANOVA) was performed on crop yield data by year using the 3 × 4 factorial treatment structure compared to the N-fertilizer only treatment (no. 2). The ANOVA for soil-test information was performed for soil samples collected in 2017 as a randomized complete block design. Differences among treatments were identified as significant when the

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treatment P-value was <0.10. The ANOVA was performed with the GLM procedure of SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.) with block as a random effect and fertilizer treatment as a fixed effect.

Results and Discussion

The P rate main effect and the fertilizer source by P rate interaction had no significant effect on crop yield in any of the five years (Table 3). The main effect of fertilizer source, averaged across P addition rate, significantly affected the yield of corn in 2013 and 2014, grain sorghum in 2016, and soybean in 2017. Soybean grown in 2015, following two years of corn did not respond to fertilizer source or rate. In 2013, corn fertilized with P, regardless of the source and Zn rate, produced greater yields than corn receiving no P and Zn. The addition of P and Zn as MESZ or MAP + $ZnSO_4$ produced the greatest corn yields in 2014 indicating that the response was largely due to Zn. After the fertilizer treatments were changed in spring 2015 to include K and B components, the soybean yields in 2015 were not affected by fertilizer treatments. Grain sorghum yields in 2016 were relatively low, but showed differences among fertilizer sources with a trend for higher numerical yields produced by grain sorghum fertilized with MESZ. In 2017, visual differences in soybean growth were apparent with subtle to moderate K deficiency symptoms appearing on soybean that received no K (N Only and MAP). Soybean receiving no K produced yields that were 7 to 11 bu/acre lower than soybean receiving muriate of potash or Aspire. Soybean fertilized with MESZ and Aspire, also produced greater yields than soybean fertilized with MAP and muriate of potash indicating possible benefits from S, Zn, or B. Although we cannot know for sure, the greater yield may have been from B, as soybean yields have been increased by B fertilization at this station (data not shown). In selected treatments sampled at the R2 development stage, mean trifoliolate leaflet B concentrations ranged from 21 to 27 ppm in soybean receiving no K or muriate of potash and 45 to 46 ppm for soybean receiving MESZ and Aspire.

Soil-test P, K, and Zn concentrations were interpreted as Low (16 to 25 ppm P), Medium (91 to 130 ppm K), and Very Low (<1.6 ppm Zn) for corn production when this experiment was initiated (Table 1). Soil samples collected in early 2017 represent the cumulative effect of P, S and Zn applied in 2013 and 2014 plus P, K, Zn, S, and B applied in 2015 and 2016 (Table 2) less the amounts of these same nutrients removed in harvested grain (Table 3). Thus, the amounts of these nutrients applied from 2013 through 2016 are summed in Table 4. Soil-test values of all five nutrients (P, K, S, Zn, and B) were significantly affected by the fertilizer treatments with the qualitative response following what would be expected. In general, soil-test P increased from P addition with the same increase occurring for all MAP and MESZ applied at 60 lb P_2O_5/acre (sum total of 240 lb P_2O_5/acre; treatments 4, 8, and 12). Soil-test P, Zn, and S increased as MESZ rate increased. Based on the no P control and the four MESZ rates, the soil-test value of each nutrient increased linearly with rates of 1 ppm P per 27 lb P_2O_5/acre, 1 ppm Zn per 4.33 lb Zn/acre, and 1 ppm S per 50 lb S/acre. Soil that was fertilized with Aspire or muriate of potash during the last two years, generally had greater soil-test K than soil receiving no K. Although soil-test B tended to increase from the addition of Aspire, it should be noted that the soil-test B values are not accurate indicators of soil B availability and that values fluctuate temporally. For example, the range of differences among treatments shown in Table 4 is 0.15 ppm, which is about the same as the range (0.2 ppm) observed among years in Table 1.

Practical Applications

Annual use of multi-nutrient granular fertilizers such as MESZ and Aspire can increase soil-test values of P, K, S, Zn, and B. It is important to note that this research did not compare increases or variance in soil-test measurements of multi-nutrient granular fertilizers against the application of multiple blended fertilizers, and conclusions and soil-test nutrients regarding this comparison cannot be made. The grain yield data suggest that corn, grain sorghum and soybean yields did not respond to P fertilization but did respond to other nutrients included in the scope of the treatments. As such, the data does support that the addition of S, K, Zn, B, or some combination of these nutrients is sometimes beneficial to crop yields on soils that have initial Very Low to Low availability of these nutrients.

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Table 1. Selected soil chemical properties in soil that received no phosphorus or potassium fertilizers for five cropping years.

Year	Soil pH	P	K	Ca	Mg	S	Fe	Mn	Zn	B
		Mehlich-3 extractable nutrients								
		[ppm (± standard deviation)]								
2013	7.1	17 (±2.3)	128 (±9.1)	1487	289	8	193	322	0.8	0.1
2014	6.9	11 (±2.9)	91 (±11.2)	1305	247	7	161	274	1.2	0.2
2015	7.2	8 (±1.5)	75 (±9.6)	1428	270	7	161	337	0.8	0.2
2016	7.1	9 (±0.7)	67 (±2.3)	1446	275	7	163	303	0.6	0.0
2017	7.2	10 (±1.5)	80 (±11.6)	1444	283	8	262	682	1.1	0.2

Table 2. Fertilizer products and nutrient rates comprising 14 fertilizer treatments during the last five years.

	P Rates and Source[a]		2013-2014[b]		2015-2017[c]	
Treatment	P Rate	P source	Zn Rate	K rate	K Source	K rate
(no.)	(lb P_2O_5/acre)		(lb Zn/acre)	(lb K_2O/acre)		(lb K_2O/acre)
1	0	Control	0	0	None	0
2	0	N only	0	0	None	0
3	30	MAP	0	90	MOP	0
4	60	MAP	0	90	MOP	0
5	90	MAP	0	90	MOP	0
6	120	MAP	0	90	MOP	0
7	30	MAP	0.75	90	MOP	90
8	60	MAP	1.50	90	MOP	90
9	90	MAP	2.25	90	MOP	90
10	120	MAP	3.00	90	MOP	90
11	30	MESZ	0.75	90	ASP	90
12	60	MESZ	1.50	90	ASP	90
13	90	MESZ	2.25	90	ASP	90
14	120	MESZ	3.00	90	ASP	90

[a] The same P sources and rates have been used for the duration of the experiment. MAP, monoammonium phosphate (11-52-0); and MESZ, Microessentials (12-40-010S-1Zn).

[b] During the first two years of the experiment, treatments 7 to 10 received Zn as granular $ZnSO_4$ with an analysis of 36% Zn and 17.5% and matched the Zn rate supplied as MESZ in treatments 11 to 14. Application of $ZnSO_4$ to treatments 7 to 10 was discontinued after 2014. Muriate of potash (MOP) was applied to treatments 3 to 14 at a uniform rate during 2013 and 2014. Ammonium sulfate was applied to treatments 7 to 10 to balance the S added to with each MESZ rate in treatments 11 to 14.

[c] During 2015 to 2017, K fertilization was discontinued in treatments 3 to 6, and the K source was changed to Aspire (ASP) for treatments 11 to 14.

Table 3. The effect of fertilizer (phosphorus, potassium, and zinc) source, averaged across annual P application rates, on crop yields for five years.

Fertilizer source[a]	2013 (Corn)	2014 (Corn)	Fertilizer source[a]	2015 (Soybean)	2016 (Grain sorghum)	2017 (Soybean)
	(bu/acre)			(bu/acre)		
N only	205	176	N only	60	100	63
MAP	219	178	MAP	60	97	63
MAP + Zn	219	195	MAP + MOP	61	101	71
MESZ	229	196	MESZ + Aspire	61	107	74
$LSD_{0.10}$	12	11	LSD0.10	NS	8	<3
Source (FS)	0.1003	0.0016	Source (FS)	0.9332	0.0450	<0.0001
P rate (PR)	0.3997	0.1749	P rate (PR)	0.6926	0.7629	0.9679
PR × PS	0.4445	0.1214	PR × PS	0.5572	0.1663	0.3087

[a] Fertilizer Abbreviations: MAP, monoammonium phosphate (11-52-0); Zn, Zn sulfate (36% Zn and 17.5% S); MESZ, MicroEssentials (12-40-0-10S-1Zn); MOP, muriate of potash (0-0-60); Aspire, (0-0-58-0.5B).

Table 4. The effect of fertilizer treatment on selected Mehlich-3 extractable nutrients after four years of cropping and fertilization from soil samples collected in spring 2017 (See Table 2 for annual treatment list).

Treatment	4 Year sum total nutrient rate					Mehlich-3 extractable nutrients				
No	P_2O_5	K_2O	S	Zn	B	P	K	S	Zn	B
	------------- (lb fertilizer-nutrient/acre applied) ----------					----------------------------- (ppm) ----------------------------				
2	0	180	0	0	0	10	80	7.8	1.1	0.18
4	240	180	0	0	0	19	82	8.3	1.8	0.18
8	240	360	1.5	3.0	0	19	108	8.5	1.8	0.20
11	120	360	30	3.0	1.5	16	102	8.0	1.8	0.30
12	240	360	60	6.0	1.5	22	112	9.5	3.8	0.30
13	360	360	90	9.0	1.5	25	108	9.0	3.2	0.33
14	480	360	120	12.0	1.5	28	93	10.3	3.9	0.33
$LSD_{0.10}$						4.5	14	1.4	1.2	0.05
P-value						<0.0001	0.0015	0.0739	0.0031	<0.0001
C.V., %						18.3	11.2	13.0	38.4	16.1

Cotton Response to Phosphorus and Potassium Fertilizer at Multiple Locations in Arkansas

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Background Information and Research Problem

Phosphorus (P) and potassium (K) are extremely important nutrients for growth and development of the cotton (*Gossypium hirsutum*) plant. Phosphorus is required for energy in the plant while K is required for regulating the stomatal opening and closing, maintaining leaf turgor pressure, and leaf photosynthesis (Oosterhuis et al., 2014). Phosphorus deficiency causes delayed maturity, stunted leaves, reduced stem diameter, and reduced boll load. Potassium deficiency seriously decreases cotton yield potential and fiber quality. Therefore, optimum P and K fertility is necessary for optimum yield, quality, and profit. The objectives of the current study are i) to evaluate the influence of P and K fertilizer on cotton yields with respect to soil-test P and K levels, ii) develop calibration for fertilizer recommendations based on soil-test concentrations, and iii) determine the influence of K-fertilizer application timing on cotton yield.

In 2017, cotton was planted on 440,000 acres in Arkansas. Advances in plant breeding, pest control, irrigation, and other production practices are continuously increasing cotton yield potential. The state-average cotton yield in Arkansas increased from 598 lb/acre in 1976 to 1075 lb/acre in 2016 (USDA-NASS, 2017) largely because of the introduction of fast-fruiting cultivars, and improvements in pest management and irrigation. Modern cotton cultivars produce higher yields and develop their boll load over a shorter period compared with obsolete cotton cultivars (Campbell and Jones, 2005). Thus, modern cotton cultivars response to K-fertilizer application rates should be periodically evaluated to ensure that K deficiency is not limiting crop yield potential.

Current recommendations for P and K fertilizer are based on soil tests for these nutrients using the Mehlich-3 extraction. The current soil-test thresholds for cotton were last updated in 2006. However, limited data is available to support the calibration of these soil-test recommendations. The objective of this experiment was to evaluate the effect of P or K application rate on seed cotton yield under current production practices common to Arkansas. Results from these and similar studies will be used to evaluate existing P- and K-fertilizer recommendations for irrigated cotton production in Arkansas.

Procedures

Phosphorus Experiments

Phosphorus rate calibration trials were conducted at five locations in 2017. Field studies were implemented at the Judd Hill Foundation farm (JHFF) located in Poinsett County, at the University of Arkansas System Division of Agriculture's Rohwer Research Station near Rohwer (RRS), two trials at the University of Arkansas Lon Mann Cotton Research Station near Marianna (LMCRS), and one location in a commercial production field in Mississippi County (MissCo). The soil series and selected agronomic information for each site are listed in Table 1. Because of adverse weather during harvest, two locations (MissCo and JHFF) have not yet been harvested.

Prior to P application, a composite soil sample was taken from the 0- to 6-inch depth of each replication. Each composite soil sample consisted of 6 to 8 cores with an equal number of cores collected from the top of the bed and bed shoulder. Soil samples were oven-dried, crushed, extracted with Mehlich-3 solution, and the concentrations of elements in the extracts were measured by inductively coupled plasma atomic emission spectroscopy. Soil pH was measured in a 1:2 (volume:volume) soil-water mixture. Mean soil chemical properties are listed in Table 2.

Phosphorus was applied at rates of 0, 40, 80, 120, and 160 lb P_2O_5/acre as triple superphosphate. The experimental design was a randomized complete block with each treatment replicated 5 times. Phosphorus treatments were applied onto the soil surface in a single application within 2 days of planting. Blanket applications of muriate of potash were made to supply 120 lb K_2O /acre. All experiments were fertilized with a total of 150 lb nitrogen (N)/acre as urea in a single application depending on the location. Cotton was grown on beds and furrow irrigated as needed either by research station staff or the cooperating producer. Each plot was 25-ft long and 10- to 12.6-ft wide allowing for 4 rows of cotton spaced 30 to 38 inches apart. Cotton management closely followed University of Arkansas System Division of Agriculture Cooperative Extension Service recommendations. The middle two rows of each plot were harvested with a cotton picker equipped with electronic scales and moisture sensor to calculate plot yields. The results are reported as seed cotton yields.

Potassium Experiments

Potassium rate calibration trials were conducted at 5 locations in 2017. Field studies were implemented at the Judd Hill Foundation farm (JHFF) located in Poinsett County, at the University of Arkansas Rohwer Research Station near Rohwer (RRS), at the Manila Municipal Airport Farm (MMAF), at the University of Arkansas Lon Mann Cotton Research Station near Marianna (LMCRS), and one location in a commercial production field in Mississippi County (MissCo). The soil series and

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selected agronomic information for each site are listed in Table 1. Composite soil samples were collected from each replicate of each trial as described for the P trials (Tables 3). Because of adverse weather during harvest, two locations (MissCo and JHFF) have not yet been harvested. Potassium was applied as muriate of potash at rates of 0, 50, 100, 150, and 200 lb K_2O/acre. The experimental design was a randomized complete block with each treatment replicated 5 times. All K treatments were applied onto the plot surface from 1 day before planting to 18 days after planting (Table 1). Triple superphosphate was broadcast to supply 40 to 80 lb P_2O_5/acre. Plot size and management was conducted using standard cotton management guidelines provided by the Cooperative Extension Service similar to the P trials.

An additional study was conducted at two locations during 2017 (LMCRS and MMAF) to investigate the impact of midseason K applications on cotton yield (Table 4). The study was arranged as a two-factor factorial with preplant K rate and midseason K rate as the two factors. The preplant K rates were 0, 50, 100, 150, and 200 lb K_2O/acre applied as muriate of potash. The midseason K rates, applied at first bloom, were either 0 or 60 lb K_2O/acre applied as muriate of potash. The study was arranged in a randomized complete block design with five replications.

Analysis of variance was performed for each individual P or K trial using the GLM procedure of SAS (SAS Inisitute, Inc., Cary, N.C.). When appropriate, significant differences among means were separated by the least significant difference (LSD) test with significance interpreted at the 0.10 level.

Results and Discussion

Phosphorus Experiments

Yield response to P fertilizer was measured at only one location in 2017 (Table 5). Of the five locations, two locations (LMCRS1 and LMCRS2) had Mehlich-3 extractable P values that were below optimum (Very Low, <16 ppm) and would have received a recommendation for P fertilization. At LMCRS2, application of 40 to 160 lb P_2O_5/acre significantly increased yields compared to the no P control with maximal yields produced by 40 to 120 lb P_2O_5/acre. The LMCRS1 site did not respond to P fertilizer. These results are consistent with previous studies suggesting that soil-test P is not an accurate predictor of crop response to P fertilization. Historically, cotton producers have utilized sufficient levels of P fertilizer to maintain relatively high soil-test P levels as reports of P deficiency in cotton are rare in Arkansas

Potassium Experiments

Potassium fertilizer application failed to improve seed cotton yield at two of the three harvested K rate trial locations (Table 6). A significant yield response to K was observed at LMCRS1, which had the lowest soil-test K of all K rate trial sites (Table 3). According to current soil-test thresholds, this site would have received a recommended rate of 95 lb K_2O/acre. However in this rate study, 150 lb K_2O/acre was required to optimize yields.

When K-fertilizer rate and timing were evaluated, neither preplant nor midseason K-fertilizer rate influenced cotton yield at MMAF (Tables 7 and 8). At LMCRS2, the main effects of K-fertilizer rate and timing increased yields, but no interaction between K-fertilizer rate and application time was observed. Potassium fertilizer applied at planting generally increased seed cotton yields at LMCRS2 compared to the unfertilized treatment (Table 7). Also, the midseason application of 60 lb K_2O/acre increased yields at LMCRS2, irrespective of the preplant K-fertilizer rate (Table 8). There are some reports from cotton growers and crop consultants in Arkansas that supplemental in-season K applications are often needed in cotton even after recommended rates were applied prior to planting. This timing study is a single step in helping to resolve this controversy, but additional studies are necessary to ensure current recommendations provide optimum yields. While these studies do not provide definitive evidence of optimum fertilizer rates for cotton, they do provide a beginning point for developing a comprehensive database necessary to provide support for recommendations in the future.

Practical Applications

The 2017 results show that P fertilization increased cotton yield at one of two sites having Very Low soil-test P. Potassium fertilization significantly increased cotton yield at one site with Low soil-test K, but failed to increase yield at other sites with Medium or Optimum soil-test K levels. Initial studies indicate that midseason K application may be needed to maximize yields even when preplant K is applied. The data from these studies will be added to a database on cotton response to P or K fertilization to evaluate the utility of existing soil-test thresholds and recommended fertilizer-P and K rates needed to produce optimum cotton yield. Studies will be implemented to evaluate the long-term effect of P- and K-fertilizer rates on cotton yield and soil-test P and K levels.

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Table 1. Site identification code, soil series, cotton cultivar, and planting and harvest dates for cotton fertilization trials conducted in Desha (RRS[a]), Lee (LMCRS), Mississippi (MMAF, MissCo), and Poinsett (JHFF) counties during 2017.

Location	Soil series	Cultivar	Planting date	Harvest date
RRS	Hebert silt loam	Delta Pine 1646 BFA	25-April	12-October
LMCRS1	Loring silt loam	Stoneville 4949	19-May	19-October
LMCRS2	Memphis silt loam	Stoneville 4949	19-May	18-October
MMAF	Crevasse sand	Stoneville 4946	15-May	13-November
MissCo	Routon-Dundee-Crevasse-Complex	Delta Pine 1518	25-May	--[b]
JHFF	Dundee silt loam	ST4949 GLT	11-May	--

[a] RRS = Rohwer Research Station, near Rohwer; LMCRS = Lon Mann Cotton Research Station, Marianna; MMAF = Manila Municipal Airport Farm in Mississippi County; and JHFF = Judd Hill Foundation farm in Poinsett County.
[b] Harvest data not yet available.

Table 2. Selected chemical property means of soil samples collected from the 0- to 6-inch depth before P-fertilizer application for five P-fertilization trials established in Desha (RRS[a]), Lee (LMCRS1, LMCRS2), Mississippi (MissCo), and Poinsett (JHFF) counties during 2017.

		Mehlich-3-extractable nutrients						
Site ID	Soil pH[b]	P	SD P[c]	K	Ca	Mg	Cu	Zn
		(ppm)						
RRS	5.6	58	±5	155	1072	201	1.4	3.3
LMCRS1	5.9	13	±2	56	834	212	1.2	1.2
LMCRS2	6.5	14	±2	87	990	284	1.9	1.1
MissCo	6.6	36	±4	103	1700	192	2.5	11.5
JHFF	6.7	64	±12	105	1264	185	2.2	3.6

[a] RRS = Rohwer Research Station, near Rohwer; LMCRS = Lon Mann Cotton Research Station, Marianna; MMAF = Manila Municipal Airport Farm in Mississippi County; and JHFF = Judd Hill Foundation farm in Poinsett County.
[b] Soil pH was measured in a 1:2 (weight: volume) soil-water mixture.
[c] SD, Standard deviation of Mehlich-3 extractable soil-test P means.

Table 3. Selected chemical property means of soil samples taken from the 0-to 6 inch depth before K-fertilizer application for five trials conducted in Desha (RRS[a]), Lee (LMCRS1), Mississippi (MMAF, MissCo), and Poinsett (JHFF) counties during 2017.

		Mehlich-3-extractable nutrients						
Site ID	Soil pH[b]	P	K	SD K[c]	Ca	Mg	Cu	Zn
		(ppm)						
RRS	5.6	58	156	±14	982	163	1.3	3.0
LMCRS1	6.5	27	84	±8	1210	291	2.0	1.2
MMAF	7.1	39	130	±21	1758	340	2.9	3.6
MissCo	6.5	36	103	±14	1924	207	2.6	11.9
JHFF	6.7	53	112	±20	1201	188	2.1	3.0

[a] RRS = Rohwer Research Station, near Rohwer; LMCRS = Lon Mann Cotton Research Station, Marianna; MMAF = Manila Municipal Airport Farm in Mississippi County; and JHFF = Judd Hill Foundation farm in Poinsett County.
[b] Soil pH was measured in a 1:2 (weight: volume) soil-water mixture.
[c] SD, Standard deviation of Mehlich-3 extractable soil-test K in the 0- to 6-inch depth.

Table 4. Selected chemical property means of soil samples taken from the 0-to 6-inch depth before K-fertilizer application for two K rate and application time trials conducted in Lee (LMCRS2[a]) and Mississippi (MMAF) counties during 2017.

		Mehlich-3-extractable nutrients						
Site ID	Soil pH[b]	P	K	SD K[c]	Ca	Mg	Cu	Zn
		(ppm)						
LMCRS2	6.5	15	76	±11	1046	246	1.6	1.1
MMAF	7.1	46	128	±23	1842	323	2.6	3.9

[a] LMCRS = Lon Mann Cotton Research Station, Marianna; and MMAF = Manila Municipal Airport Farm in Mississippi Country; and JHFF = Judd Hill Foundation farm in Poinsett County.
[b] Soil pH was measured in a 1:2 (weight: volume) soil-water mixture.
[c] SD, Standard deviation of Mehlich-3 extractable soil-test K in the 0- to 6-inch depth.

Table 5. Effect of P-fertilization rate on seed cotton yield for trials conducted in Desha (RRS[a]) and Lee (LMCRS1 and LMCRS2) counties during 2017.

	Seed cotton yield		
P_2O_5 Rate	RRS	LMCRS1	LMCRS2
(lb P_2O_5/acre)	(lb/acre)		
0	3666	2307	1902
40	3728	2413	2447
80	3794	2274	2419
120	3641	2262	2337
160	3852	2231	2185
C.V., %[b]	7.9	9.2	8.3
P value	0.8365	0.8427	0.0074
$LSD_{0.10}$[c]	NS[d]	NS	230

[a] RRS = Rohwer Research Station, near Rohwer; and LMCRS = Lon Mann Cotton Research Station, Marianna.
[b] CV, Coefficient of variation.
[c] LSD, Least significant difference at *P* = 0.10.
[d] NS, not significant (*P* > 0.10).

Table 6. Effect of K-fertilization rate on seed cotton yield for trials conducted in Desha (RRS[a]), Lee (LMCRS1), and Mississippi (MMAF) counties during 2017.

	Seed cotton yield		
K_2O Rate	RRS	LMCRS1	MMAF
(lb K_2O/acre)	(lb/acre)		
0	3574	1423	3069
50	3651	1808	2844
100	3390	2048	2817
150	3353	2142	2848
200	3674	2224	2951
C.V., %[b]	8.8	7.6	7.6
P value	0.6474	<.0001	0.4953
$LSD_{0.10}$[c]	NS[d]	168	NS

[a] RRS = Rohwer Research Station, near Rohwer; LMCRS = Lon Mann Cotton Research Station, Marianna; and MMAF = Manila Municipal Airport Farm in Mississippi Country
[b] CV, Coefficient of variation.
[c] LSD, Least significant difference at *P* = 0.10.
[d] NS, not significant (*P* > 0.10).

Table 7. Effect of K-fertilization rate, averaged across midseason K rates, on seed cotton yield in Lee County (LMCRS2[a]) and Mississippi County (MMAF) during 2017.

	Seed cotton yield	
Preplant K_2O Rate	LMCRS2	MMAF
(lb K_2O/acre)	(lb/acre)	
0	2189	2549
50	2299	2572
100	2440	2700
150	2261	2560
200	2170	2752
C.V., %[b]	7.9	23.3
P value	0.089	0.504
$LSD_{0.10}$[c]	247	NS[d]

[a] LMCRS = Lon Mann Cotton Research Station, Marianna; and MMAF = Manila Municipal Airport Farm in Mississippi Country
[b] CV, Coefficient of variation.
[c] LSD, Least significant difference at *P* = 0.10.
[d] NS, not significant (*P* > 0.10).

Table 8. Effect of midseason K-fertilization rate, averaged across preplant K rate, on seed cotton yield at Lee County (LMCRS2[a]) and Mississippi County (MMAF) during 2017.

	Seed cotton yield	
Mideseason K_2O Rate	LMCRS2	MMAF
(lb K_2O/acre)	(lb/acre)	
0	2194	2549
60	2348	2572
C.V., %[b]	7.9	23.3
P value	0.092	0.386
$LSD_{0.10}$[c]	153	NS[d]

[a] LMCRS = Lon Mann Cotton Research Station, Marianna; and MMAF = Manila Municipal Airport Farm in Mississippi Country
[b] CV, Coefficient of variation.
[c] LSD, Least significant difference at *P* = 0.10.
[d] NS, not significant (*P* > 0.10).

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